Geographic Information System (GIS) for ecology: a bibliometric network analysis

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Abstract: Introduced in 1960s to store, analyse, and manipulate data collected for the Canada Land Inventory by mapping information about soils, agriculture, recreation, wildlife, waterfowl, forestry and land use, since their origins Geographic Information Systems (GISs) have had a fundamental role in the study of the environment. As computers systems for capturing, storing, checking, and displaying data related to positions on Earth's surface, GISs have quickly become an effective and powerful tool for addressing ecological issues, analysing the relationship between living things and their habitats, assessing the environmental impact of man-made transformations of a territory. This article aims to show and discuss the results of a study concerning quantitative distribution of GIS for ecology in literature from Scopus database using bibliometric analysis. Bibliometric analysis is a scientific computer assisted review methodology to explore the major research interests in scientific literature, so to identify core research authors, as well as their relationship, by covering articles, conference papers, book chapters and reviews related to a given topic or field. The high number of scientific manuscripts published on the subject (5,204) in the analysed period (1979-2021), remarked the soundness of this topic. While China shows the greatest number of published documents, USA is the country with the most cited documents. Specifically, "remote sensing", "spatial analysis" and "land use" are the keywords most frequently linked to GIS and ecology, so to underline respectively three aspects: the relevance of environment monitoring by satellite, airplane or drone, the utility of relating ecological questions to the geo-localization, the necessity of produce thematic maps for describing the economic and cultural activities (e.g., agricultural, residential, industrial, and recreational uses) that are practiced at a given place. Since the study shows that trend of publications focusing on the application of GIS for ecology is increasing, further growing is expected in the next future, also considering the ductility that these computer systems provide in different fields.

Keywords: ecology, GIS, bibliometric analysis, environmental monitoring, land use, remote sensing

1. Introduction

Due to its very nature as the study of organisms and how they interact with the environment around them (Odum & Barrett, 1971), ecology has practical applications in different fields, such as conservation biology (Wiens et al., 2010), wetland management (Denny, 2012), agriculture (Wezel et al., 2009), forestry (Mitchell et al., 2009), agroforestry (Batish et al., 2007), fisheries (Jennings et al., 2009), urban planning (Niemelä, 1999), community health (Richmond et al., 2005), economics (Costanza et al., 1997), basic and applied science (Choi, 2007), and human social interaction (Cronk, 1991).

Generally ecological research studies have a spatial component, which can vary from the geolocalization of certain species to animal migration routes, from the distribution of specific habitat types (Mollalo et al., 2018) to climate change impact monitoring (Boateng, 2012). Consequently, many ecological research projects would benefit from using a Geographic Information System (GIS) to explore spatial relationships within and between data (Gough & Rushton, 2000) (Vogiatzakis, 2003). Spatial relationships in ecology are very important, since the ecologists are often interested to analyse data with the objective of quantify spatial patterns (Liebhold & Gurevitch, 2002). Their relationships show the geometric or geographic properties of the data permitting to identify their distribution by means of spatial analysis. Spatial analysis is defined as the process of studying entities to extract data characteristics such as locations and attributes (Paramasivam & Venkatramanan, 2019).

By using spatial analysis tools, it is finally possible to create thematic maps. A thematic map is a type of geographical map that provides information on one or more aspects of the territory represented, using appropriate symbols and colours in order to allow an immediate and georeferenced overview of what you want to describe. A thematic map can highlight the ecological, chemical, physical, anthropic, economic, archaeological, environmental and geoscientific aspects (Petchenik, 1979). Thematic maps are generally obtained through data pre-processing, and this can be done through classification. The classification in ecology is defined as a process that allows to define and distinguish different ecological zones, or as the variation of one or more ecological features (Keith et al., 2020). Traditional approaches focus on different features such as soils, vegetation, climatic conditions, living species, habitats, water resources and sometimes even anthropogenic factors (Bailey, 1976).

Including hardware and software components, GIS allows to acquire, store, manipulate, analyse, manage, and present spatial or geographical data. In other terms, it has the typical

GIS characteristics, letting users to create interactive queries, analyse spatial information, modify data in maps, and present the results of all these operations (Clarke 1986). The use of GIS in natural resource management has expanded rapidly (Duncan & Lach, 2006), and is becoming an essential tool in many areas of ecological research (Böhm, 2016). Spatial data are in vector or raster format. The former includes points, lines and polygons associated with attributes. Rasters are continuous matrices of grid cells, with each cell containing a single value summarising the landscape feature it represents. The spatial resolution of a raster is reflected in its grid cell size. Both raster and vector data relevant to ecology and conservationhave become widely available (Millington et al., 2013).

GIS can also be used to link data together as needed for statistical analysis, as it provides a way to easily create tables and populate them with information from other datasets. This makes preparing data for statistical analysis much easier. Additionally, while GIS is primarily used to visualize and/or analyse data, it can provide important information when deciding where and how to collect data.

The integration of GIS and environment modelling finds a valuable field of application in the discipline of landscape ecology that is involved in the study of the patterns and interactions between ecosystems within a region of interest. These interactions, influenced by the distribution of species in relation to other species or to the physical environment, gained importance with the adoption of GISs (Johnston, 1998). In fact, these systems are largely used for a wide range of applications for answering questions on the ecology and distribution of individual species and communities (Scott et al. 2002).

GIS in ecology may involve studies both in the terrestrial and marine-coastal environments. For land use purposes, GIS allows the use of remote sensing data (Alqurashi & Kumar, 2013), which permit monitoring of specific features and processes in a particular area, e.g. estimating scales and rates of degradation of green cover, flora and fauna (Chuvieco, 1993). Furthermore, GIS allows the integration of different spatial data, for example data on soils, climate, vegetation and others and also to visualize the available information in the form of maps, graphs or diagrams, 3D models (Bibby & Shepherd, 2000). On the other hand, in recent years GISs have increased their presence as tools to better understand and manage coastal and marine environments (Vandecastoele et al., 2014). As a consequence, the term "Coastal and Marine Geographic Information System" (CMGIS) has been introduced to indicate that the GIS application was finalized to integrate heterogeneous data concerning coastal, sea, and ocean environments (Alcaras et al., 2019). The applications cover several aspects, e.g., coastal environment analysis and management (Kitsiou et al., 2002), coastline monitoring (Alcaras et al., 2022), bathymetric modelling (Figliomeni & Parente, 2022), mapping benthic habitats (Urbànski & Szymelfenig 2003), etc.

GISs can also be grouped into other two macro-categories: static and mobile. The so-called "Desktop GISs" belong to the first category, and are therefore traditional GISs, in which a user sits at a workstation to perform spatial analysis (Egenhofer & Kuhn, 1998). This group includes the GIS archives (geo-database), which represent a collection of information on the territorial distribution of one or more features, such as crop productivity (Tan & Shibasaki, 2003) or fish assemblages (Joy & Death, 2004). The geospatial data can be distributed on internet and intranet networks, exploiting the analysis deriving from GIS software and, through the classic web-based application functions, publish geographic information on the World Wide Web, in this case they are referred as WebGIS (Agrawal & Gupta, 2017). The development of web applications has led to the birth of Mobile GIS, that can be used on phone or tablets enabling navigation applications like Google Maps (Fu & Sun, 2011). Mobile GISs support acquiring data in field, a useful operation for many applications, such as forest fire management (Jo et al., 2004) or vegetation distribution assessment (Alcaras et al., 2021).

Ecological phenomena can be studied at different natural scales, but they usually show characteristic variability over a range of spatial and temporal scales (Wiens, 1989).

The definition of scale in ecological and cartographic has a different meaning. In cartography, the scale represents a relationship between the distance represented on the map and the real one, and therefore a large cartographic scale covers a relatively small area. The term scale, in ecology, has a meaning similar to that of amplitude, therefore the expression large scale is usually interpreted as large areas and little detail (Schneider, 2001). The study of the spatial structure (pattern) and the spatial domain (scale) of phenomena is a central topic in ecology (Levin, 1992). GIS applications can therefore be classified on the basis of the spatial scale of the phenomenon investigated, distinguishing between phenomena on a global and local scale. An example of global scale study is given by Fensholt & Proud (2012), where long term vegetation trends are considered. Local studies can be on different spatial scale, such as national scale (Ferretti et al., 2018), regional scale (Navarro Cerrillo et al., 2020) or urban scale (Singh, 2019).

Among several GIS applications in ecology, some of the most interesting regard climate change. In fact, modelling within a GIS has been largely employed to investigate the potential effects of rapid anthropogenic climate change on both species and community distribution.

Using climate response surfaces, Huntley et al. (1995) modelled the potential future allocations of eight plants species in Europe. Brzeziecki et al. (1995) examined the spatial distribution of forest communities in Switzerland under potential climate change; the approach used an empirical vegetation-site model to provide information about future scenarios.

Sea level rise appears to be one of the main consequences of climate change. There are different studies with the implementation of GIS to analyse the entity of this phenomenon. Li et al. (2009) developed GIS methods to assess and visualize the impacts of potential inundation using the best available global datasets based on a hypothetical sea level increase of one to six meters. Neumann et al. (2010) introduced a new way to model the response to sea-level rise and its economic impacts on coastal properties using a spatially comprehensive GIS-based modelling approach. Lichter et al. (2012) presented a systematic framework for assessing the costs of sea-level rise and extreme flooding at the local level; it is built on coupling readily available GIS capabilities with quantitative estimates of the effects of natural hazards.

GIS, global navigation satellite system (GNSS), remote sensing, and spatial statistics are tools to analyse and integrate the spatial component in different ecological studies. Kitron (1998) explains several methodologies of these, and the landscape ecology-epidemiology approach is described. There are also reviewed the applications of these methodologies to vector-borne diseases. Walker & Walker (1991) have used a GIS to investigate questions related to energy development and climate change for the North Slope in Alaska. Simoonga et al. (2009) summarize the applications made to date with remote sensing and GIS for the epidemiology and ecology of schistosomiasis in Africa. Luoto (2000) studied the habitat composition and structure and the topography of five different agricultural areas by GIS techniques because in this case habitat diversity was directly linked to topographical roughness. Bishop et al. (2002) have used GIS techniques and pitfall sampling to characterize carrion beetle preferences for soil texture and land use in Kearney County, Nebraska. The GIS was used to select sites where sampling was conducted using pitfall traps baited with rat carcasses.

So, the aim of this study is to examine a quantitative distribution of the GIS for the ecology literature from the Scopus database using bibliometric analysis, highlighting which authors, countries and journals have the greatest impact and are most active in scientific research, also highlighting which keywords are most used and connected.

2. Data and methods

Bibliometry is a field of information and library science. Bibliometric analysis methods are used to conduct quantitative and statistical analysis of literature and have been applied in different topics to identify authorships, publications, journals and areas in which research are developed (Thanuskodi, 2010). Science mapping is a methodology that combines quantitative analysis, classification, and visualisation to identify the composition and inter-relationships between bibliographic objects (Andersen & Swami, 2021). It permits the visualization of bibliometric networks, where a network is a web composed by nodes and links (Noyons et al., 1999). In particular, nodes can identify different items, such as publications, journals, researchers and keywords while links are the relations between pairs of nodes. Bibliometric network analysis can be used to identify the most influential publications and authors in a particular field, to track the evolution of research topics over time, and to identify patterns of collaboration between researchers and institutions. It can also be used to identify gaps in research and to generate new research questions.

An important feature of bibliometric analysis is the ability to group items into clusters, which are labelled using progressive numbers. In fact, by mapping the links between publications, bibliometric network analysis can be used to identify clusters of related research, to analyse the flow of ideas between different fields, and to identify key players in the scientific community. A cluster is a group of nodes (or items) that are more densely connected to each other than to the rest of the network (Tamala et al., 2022). Clustering is an important aspect of network analysis because it allows us to identify groups of related items and to explore the structure of the network. Clusters can be identified using various clustering algorithms, which typically measure the strength of the connections between nodes in the network and group nodes that are more strongly connected together (Waltman et al., 2010).

Once clusters have been identified, they can be analysed and visualized to gain insights into the structure and content of the network (Madani, 2015).

The most commonly studied types of relations between items are reported below.

- Citations: can be divided into direct citations, that are not commonly used; co-citations, i.e. two publications are co-cited if there is a third publication that cites both publications; and bibliographic coupling, the opposite of co-citations, i.e. two publications are bibliographically coupled if there is a third publication that is cited by both publications (Van Eck N. J., & Waltman L., 2020).

- Co-occurrence of two keywords is the number of publications in which both keywords occur together in the title, abstract, or keywords list. Occurrence refers to the number of times a particular keyword appears in a set of documents. In this type of analysis, a set of documents is typically analysed to identify patterns of association between keywords.The analysis involves counting the number of times each keyword appears in thedocuments (from title, abstract or keyword list) (Tamala et al., 2022) (Oladinrin et al., 2022).
- Co-authorship, where researchers, research institutions, or countries are linked to each other based on the number of publications they have authored jointly (Oladinrin et al., 2022) (Van Eck N. J., & Waltman L., 2020).

Depending on the type of investigated relationship, links between nodes can be defined in different ways as reported below.

- In the analysis of the citation of a document, links refer to the connections or relationships between documents that are created by citations. When one document cites another, a link or connection is established between the two documents (Yu, 2020).
- In co-occurrence analysis of keywords, a link refers to a connection or relationship between two keywords that frequently appear together in a set of documents. A link would be established between these two keywords each time they appear together in the same article (Tamala et al., 2022).
- In co-authorship analysis, a link refers to a connection between two researchers, research institutions, or countries that jointly have authored an article (Oladinrin et al., 2022).

Each link has a strength, represented by a numerical value, the higher this value, the stronger the link. The elements are described thanks to certain attributes, those of particular importance are the weight and score attributes, which are also represented by numerical values. Of course, the weight of an article should represent its importance. There are two standard weight attributes, called the link attribute and the total link strength attribute, which respectively indicate the number of links of an article with other articles, and the total strength of the links of an article with other articles.

The total link strength can be defined in different ways in dependence of the investigation that is carried out as described below.

- In the analysis of the citation, the total link strength refers to the strength or weight of the links between publications in the citation network. It is a measure of the frequency and importance of the citations between different publications. In the case of journal citation analysis, the total link strength can be calculated by summing the number of citations made by all publications to a particular journal, or the number of citations made by a particular journal to all other journals in the network (Yu, 2020).

- In the analysis of the co-occurrence of two keywords, the frequency of co-occurrence of two or more keywords in a set of documents is analysed to identify patterns of association between those keywords. Total link strength is a metric that reflects the strength of the association between two keywords based on the frequency of their co-occurrence in the set of documents being analysed. It is calculated by summing the number of times the two keywords appear together in the set of documents (Tamala et al., 2022).
- In the analysis of the co-authorship of authors, total link strength refers to the overall strength of the collaboration links between elements (researchers, research institutions, or countries). The strength of the link between two elements can be quantified by various measures, such as the number of co-authored papers, the number of citations received by their co-authored papers, or the co-authorship network centrality of the authors. Total link strength is calculated by summing up the strengths of all the links between a particular author and their co-authors (Oladinrin et al., 2022).

The data used in this research were collected from the Scopus database. The search string used is “GIS” AND “Ecology”. The results were exported as “.csv” files including Citation information, Bibliographical information, Abstract & keywords and references.

There are several tools and software programs available for bibliometric network analysis, including VOSviewer, CiteSpace, and Gephi. In this work the bibliometric network analysis was executed using VOSviewer software (version 1.6.16) (Van Eck & Waltman, 2020). It supplies tools for constructing and visualizing bibliometric networks. The principal functions are: Creating maps based on network data; Visualizing and exploring maps.

3. Results and discussion

The research on the string “GIS” and “Ecology” identified 5,204 products included in SCOPUS database and downloaded on 11/07/2022. The analysis carried on these products was based on the co-authorship, co-occurrence and citation to provide the network of:

- Co-occurrence of the author keywords;

- Co-authorship among authors and countries;
- Citation related to documents and journals.

Figure 1 shows the temporal trend of the publications relating to the string “GIS” AND “Ecology”. Therefore, it is possible to see the number of publications per year.

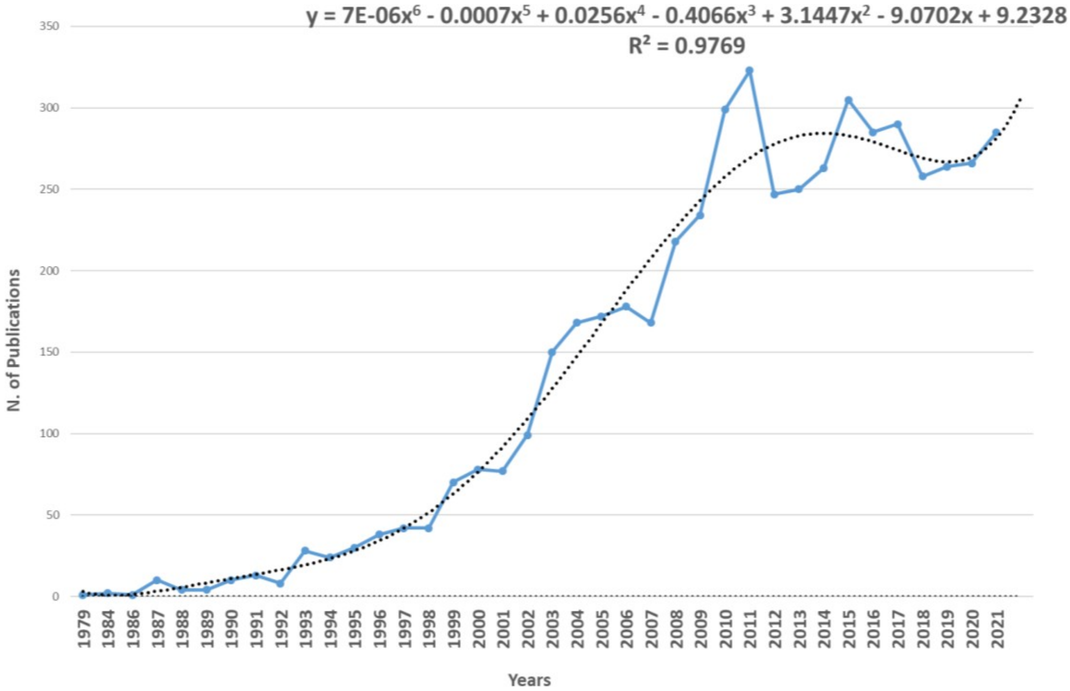

Figure 1 – Temporal trend of publications related to “GIS” AND “Ecology”.

The temporal analysis was conducted over an interval ranging from 1979 to 2021 and showsa positive trend. However, analysing the graph in detail, there are short phases of decrease in scientific production followed by a recovery of the trend. The production peak is reached in 2011 with 323 publications.

The analysis of the co-occurrence of keywords produced 28,983 results. By selecting the minimum number of keywords using VOSViewer (threshold=3), 1,000 items are obtained, which are grouped into 6 clusters. The Network of co-occurrence are shown in Figure 2.

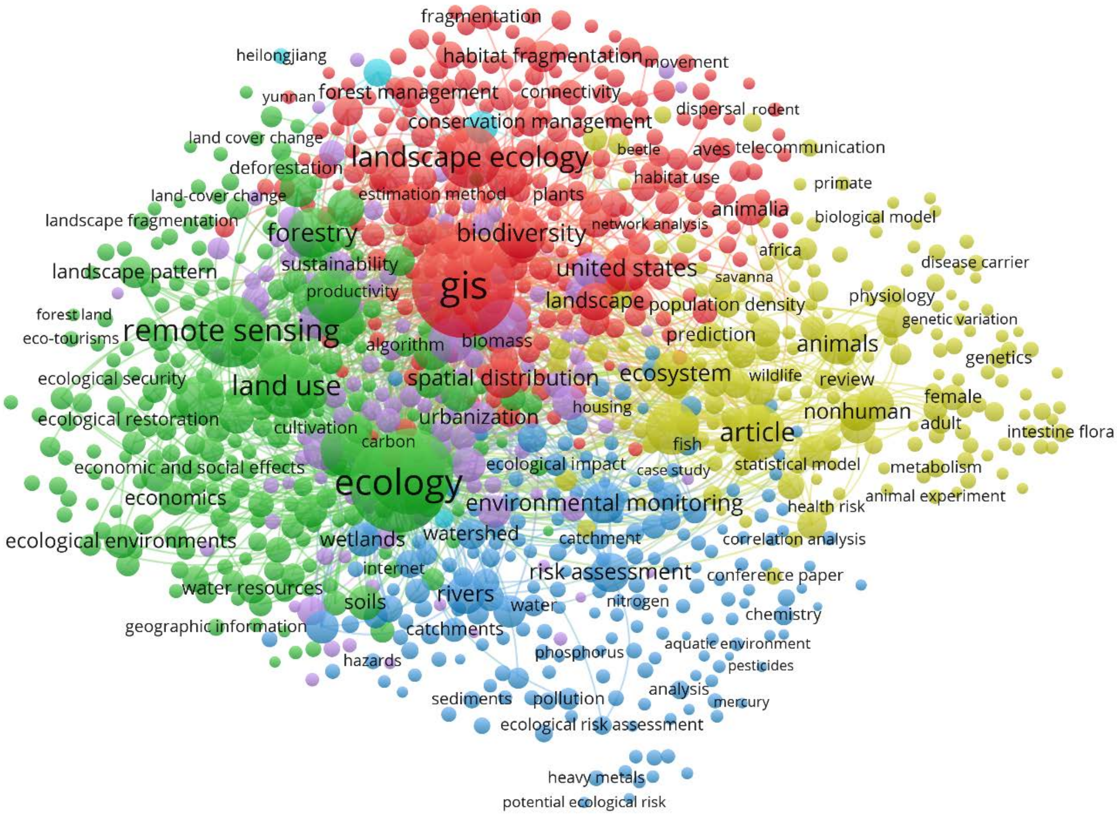

Figure 2 – The network of co-occurrence of keywords obtained by VOSViewer.

In the Table 1 are shown the first 20 results of the co-occurrence analysis of keywords, ordered by Total Link Strength.

Table 1 – First 20 results of the co-occurrence analysis of keywords, ordered by total link strength.

Keywords	Total Link Strength	Occurrence
GIS	42,858	3,772
Ecology	30,941	2,611
Remote sensing	14,302	1,225
Ecosystem	14,160	867
Land use	12,152	865
Landscape ecology	9,585	859
China	9,042	639
Forestry	7,208	492
Biodiversity	6,857	473
Animal	6,714	414
Environmental monitoring	6,597	302
Environmental protection	6,561	376
United States	6,026	418
Spatial analysis	6,010	478
Sustainable development	5,408	438
Vegetation	5,405	360
Conservation of natural resources	5,263	223

Human	4,957	263
River	4,804	289
Risk assessment	4,590	265

Keywords ranking higher by total link strength reflect the topics most related to the search string used in our case. As reported in Table 1, it is possible to see how the keyword “GIS” is widely used for the ecology. It can also be noted that keywords such as remote sensing, spatial analysis and land use are among the most used keywords, and that reinforce the concept of using GIS to analyse ecological problems.

The analysis of the citations of a document produced 5,335 results. By selecting the minimum number of citations of a document using VOSViewer (threshold=2), 833 items are obtained, which are grouped into 49 clusters. The network of citation related to documents is shown in Figure 3.

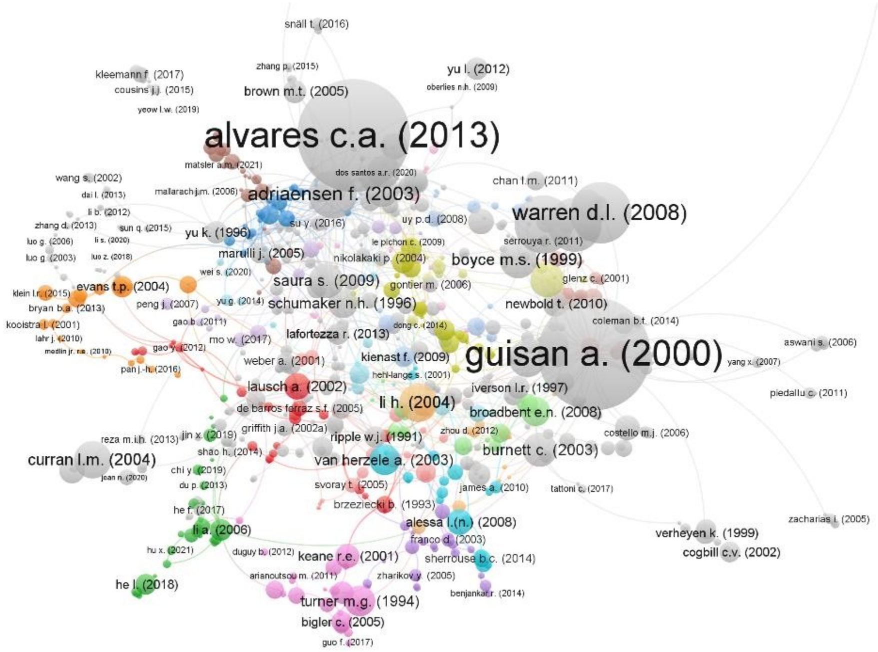

Figure 3 – The network of citation related to documents obtained by VOSViewer.

Table 2 shows the 20 most cited documents identified by the first authors. In this case, the documents are ordered by the number of citations.

Table 2 – First 20 most cited documents on the topic.

Documents	Citation	Links
Guisan A. (2000)	5,131	65
Alvares C.A. (2013)	5,124	2
Warren D.L. (2008)	1,525	3
Kearney M. (2009)	1,357	6
Soberón J. (2007)	1,179	3
Adriaensen F. (2003)	946	66

Li H. (2004)	591	20
Boyce M.S. (1999)	577	11
Iverson L.R. (1998)	573	4
Curran L.M. (2004)	572	3
Saura S. (2009)	496	19
Hirzel A.H. (2008)	479	12
Burnett C. (2003)	467	11
Spear S.F. (2010)	440	10
Bunn A.G. (2000)	412	12
Kumar L. (1997)	401	3
Van Herzele A. (2003)	395	2
Brooker S. (2006)	395	2
Turner M.G. (1994)	391	6
Schumaker N.H. (1996)	376	11

The paper "Predictive habitat distribution models in ecology" written by Guisan A., Zimmermann N. E. in 2000 and published in "Ecological Modelling, Volume 135, Issues 2–3" is the most cited documents about the topic. On the other hand, the paper with the greatest number of links (66) is "The application of 'least-cost' modelling as a functional landscape model", written by Adriaensen, F., Chardon, J. P., De Blust, G., Swinnen, E., Villalba, S., Gulinck, H., & Matthysen, E. in 2003, and published in "Landscape and urban planning, Volume 64, Issues 4.

The analysis of the co-authorship of authors produced 13,719 results. By selecting the maximum number of authors (threshold=10) and the minimum number of documents of an author (threshold=3) using VOSViewer, 574 items are obtained, which are grouped into 24 clusters.

The analysis of the co-authorship of the authors was conducted a second time, examining in this case the ID of the authors, as the first one is false due to several cases of homonymy.

Executing the analysis on the IDs of the authors in question, it was found that the same name appeared several times but with different IDs. Carrying out the analysis on the IDs of all the authors, with the same thresholds as the first search, the results shown in Table 3 were obtained. Out of 17,150 authors, 397 belong to the applied thresholds. Of these, only 265 results have links to each other, which can be grouped into 213 clusters. Also in this case, the number of citations orders them.

Table 3 – First of 20 items of the co-authorship analysis of authors ordered by number of citations.

Author ID	**Authors**	**Citations**	**Documents**	**Total Link Strength**
7202133982	Warren D.L.	1,700	3	0
57193801356	Adriaensen F.	1,267	3	3
7006037654	Matthysen E.	1,267	3	3
7006804226	Iverson L.	1,103	6	5

6602927497	Zoetendal E.G.	949	5	2
7401882003	Prasad A.	818	3	3
6602923300	Hirzel A.H.	782	3	0
7102884981	Collier C.T.	737	3	1
35568173200	Fortin M.-J.	672	3	2
7005926568	Brooker S.	663	3	2
35495729400	De Vos W.M.	647	3	1
7006518879	Skidmore A.K.	530	8	3
6701879014	Kienast F.	457	5	0
6701837656	Nikula A.	440	5	2
56187482800	Helle P.	418	4	2
7005706196	Keane R.E.	416	4	0
7004039799	Hermy M.	393	5	0
23006071200	Pei H.	377	4	5
10738998900	Crossman N.D.	369	6	5
57207275546	Fu B.	359	6	5

The analysis of the co-authorship of countries produced 186 results. Selecting the maximum number of countries (threshold=20) and the minimum number of documents of a country (threshold=3), 92 items were obtained and grouped into 13 clusters. In Table 4 the first 20 items of the co-authorship analysis of countries are reported. In this case, they are ordered by the number of total link strength.

Table 4 – First 20 items of the co-authorship analysis of countries ordered by number of total link strength

Countries	Citation	Documents	Total Link Strength
United states	57,165	1,276	534
United Kingdom	10,389	278	287
China	16,662	1,655	259
Germany	8,047	247	213
Italy	5,446	198	140
Australia	7,726	190	138
Canada	7,524	187	133
Netherlands	4,700	106	129
Spain	5,655	123	126
France	2,764	113	100
Sweden	1,650	51	77
Switzerland	7,957	61	68
Belgium	4,013	60	66
South africa	2,250	53	66
Denmark	1609	38	65
Norway	2,396	36	65
Brazil	7,016	101	61
Japan	1,403	88	60
Finland	2,032	55	59
Portugal	797	41	59

The results shown in Table 4 highlight the leading role of United States in claiming to be the country most connected to the others. The United States is also the country with the most documents cited, while China is the country with the most documents published. Figure 4 shows the network of co-authorship among countries.

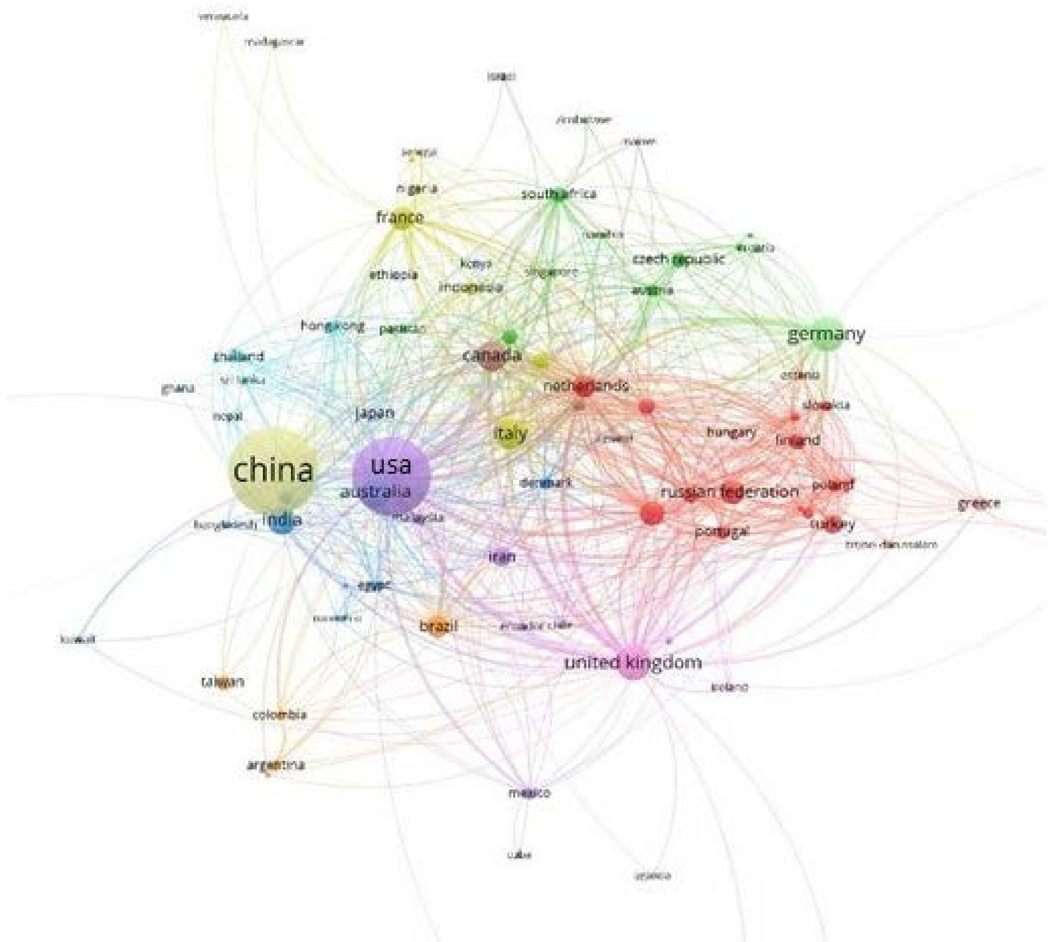

Figure 4 – The network of co-authorship among countries obtained by VOSViewer.

The analysis of the citation of source (journal) produced 1,684 results. By selecting the minimum number of documents of a source (threshold=3) and the minimum number of citations of a source (threshold=2) using VosViewer, only 259 items are obtained, which are grouped into 34 clusters. In the Table 5, the first 20 sources (Journals) are reported. In this case, they are ordered by number of produced documents.

Table 5 – The first 20 journals ordered by the number of published documents.

Source	Documents	Citations	Total Link Strength
Proceedings of SPIE - The International Society for Optical Engineering	123	134	19
Ecological Indicators	104	3,951	149
Environmental Monitoring and Assessment	96	2,360	78

Nongye Gongcheng Xuebao/ Transactions of The Chinese Society of Agricultural Engineering	92	807	33
Landscape and Urban Planning	89	6,214	253
Iop Conference Series: Earth and Environmental Science	88	100	14
Chinese Journal of Applied Ecology	82	843	71
Landscape Ecology	80	4,767	166
Shengtai Xuebao/ Acta Ecologica Sinica	80	791	74
International Archives of The Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives	75	255	18
Ecological Modelling	71	8,846	186
Environmental Management	71	2,335	84
International Geoscience and Remote Sensing Symposium (IGARSS)	65	77	4
Forest Ecology and Management	59	2,523	43
Science of The Total Environment	58	1,702	46
Journal of Environmental Management	45	2,310	87
Shengtai Xuebao	43	246	37
Sustainability (Switzerland)	42	348	57
Communications in Computer and Information Science	40	28	4
Advanced Materials Research	38	32	6

The results presented in table 5 show how the "Proceedings of SPIE - The International society for optical engineering" produced the higher number of documents while "Ecological modelling" is the most cited journal. In Figure 5, the network of citation related to journals is shown.

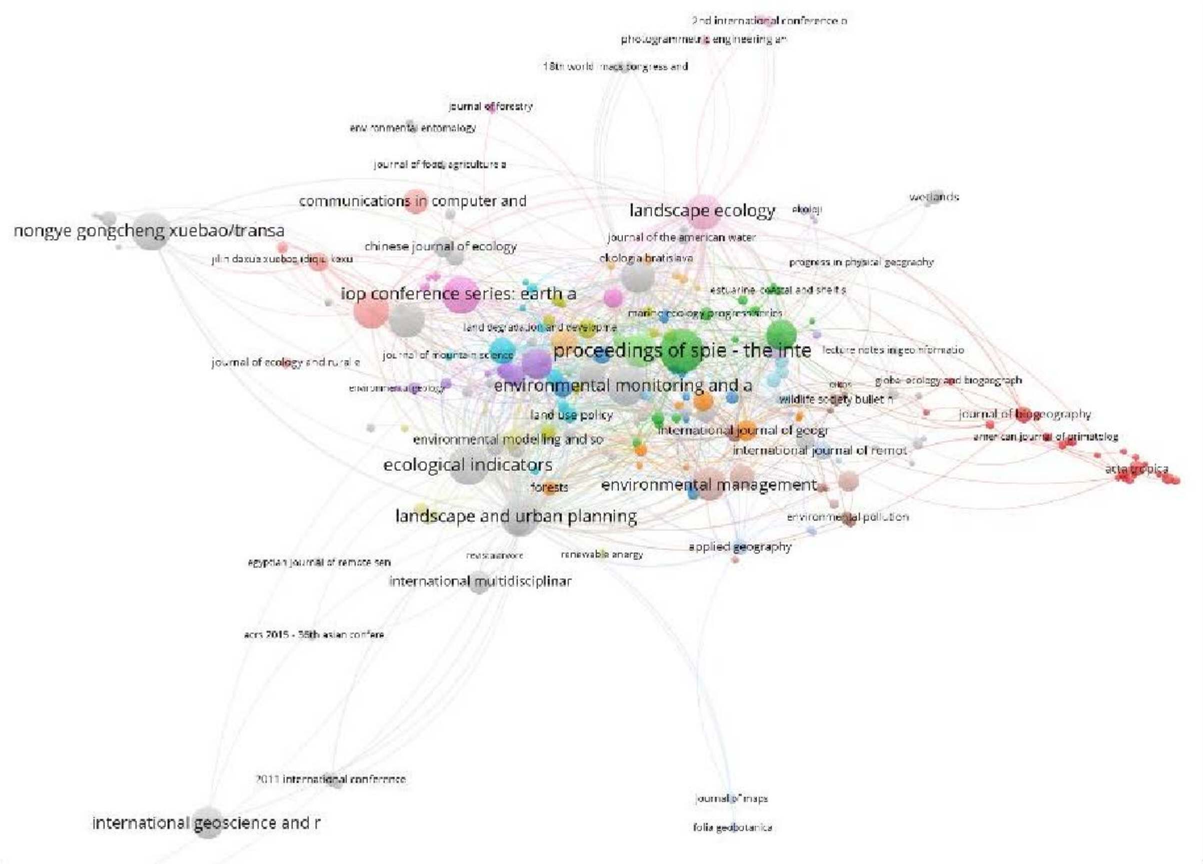

Figure 5 – The network of citations related to journals obtained by VOSViewer.

4. Conclusions

In this study, the global scientific literature on the issue of GIS for ecology is explored. The total number of products, i.e. articles, conference papers, book chapters and reviews, published on the subject (5,204) in the analysed period (1979-2021), remarked the soundness of this topic. Specifically, “remote sensing”, “spatial analysis” and “land use” are the keywords most frequently linked to GIS and ecology. On the contrary, the analysis of the co-occurrence of keywords showed a very weak connection on the issue of ecological economics.

The leading role in scientific production concerning GIS for ecology is occupied by USA and China, since the first is the country with the most cited documents as well as the highest total link strength value, and the latter produced the greater number of published documents.

Our study shows that the trend of publications focusing on the application of GIS for ecology is increasing, so further growing is expected in the next future, also considering the ductility that these computer systems provide in different fields.

The high number of articles, the type of keywords and the variety of the scientific journals hosting the analysed works underline the fundamental role that GIS assumes for different aspects of ecology, managing to also cover transversal interests in several application fields and to have a multidisciplinary effectiveness. In fact, the various tools available in a GIS software allow to geo-reference databases, overlay heterogeneous layers, perform spatial analyses, produce thematic maps and information that can be used in subsequent studies. In this way, GIS becomes a powerful tool to support ecological studies permitting to highlight links between environmental components, identify critical areas, develop provisional models, evaluate impacts and describe future scenarios.

About technical aspects concerning bibliometric analysis as resulting in our study, it is important to note that there is an issue regarding the homonymy of authors. In fact, as happened in the applications we carried out, several documents could be assigned to the sameauthor despite being produced by different persons with the same name. To avoid this issue,it is useful to utilize the ID, thus attributing the effective authorship and showing the real number of documents that each author produced.

In conclusion, our study confirms that the use of bibliometric network analysis is an important and useful tool for comprehensively reviewing the literature, concerning in this case GIS for ecology, since it allows to highlight the spatial and temporal dimensions of the scientific production through links between and among authors, documents, keywords, and countries inevolutionary scenarios.

References

Agrawal S., & Gupta, R. D., 2017, Web GIS and its architecture: a review. Arabian Journal of Geosciences, 10(23), 1-13. https://doi.org/10.1007/s12517-017-3296-2

Alcaras, E., Amoroso, P. P., Figliomeni, F. G., Parente, C., & Prezioso, G. 2022, AccuracyEvaluation of Coastline Extraction Methods in Remote Sensing: a Smart Procedure for SENTINEL-2Images. The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, *48*, 13-19. https://doi.org/10.5194/isprs-archives-XLVIII-4-W3-2022-13-2022

Alcaras E., Amoroso P. P., Parente C., & Prezioso G., 2021, Remotely Sensed Image FastClassification And Smart Thematic Map Production. ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences. https://doi.org/10.5194/isprs-archives-XLVI-4-W5-2021- 43-2021

Alcaras, E., Parente, C., & Vallario, A. 2019, Integration of Nautical Charts and Satellite Images in Marine GIS of the Gulf of Naples. In Nautical and Maritime Culture, from the Past to the Future (pp. 1-10). IOS Press. https://doi.org/10.3233/PMST190002

Alqurashi, A., & Kumar, L. 2013., Investigating the use of remote sensing and GIS techniques to detect land use and land cover change: A review. Advances in Remote Sensing. https://doi.org/10.4236/ars.2013.22022

Andersen, N., & Swami, V. 2021., Science mapping research on body image: a bibliometricreview of publications in body image, 2004–2020. Body image, 38, 106-119. https://doi.org/10.1016/j.bodyim.2021.03.015

Bailey R. G.,1976, Ecoregions of the United States (map). Ogden, UT: US Department of Agriculture, US Forest Service, Intermountain Region.

Bartz Petchenik B., 1979, From place to space: the psychological achievement of thematicmapping. The American Cartographer, 6(1), 5-12. https://doi.org/10.1559/152304079784022763

Batish D. R., Kohli R. K., Jose S., & Singh H. P., 2007, Ecological basis of agroforestry. CRC press. https://doi.org/10.1201/9781420043365

Bibby, P., & Shepherd, J. 2000., GIS, land use, and representation. Environment and planning B: Planning and Design, 27(4), 583-598. https://doi.org/10.1068/b2647

Bishop A. A., Hoback W. W., Albrecht M., & Skinner K. M., 2002, A comparison of an ecological model and GIS spatial analysis to describe niche partitioning amongst carrion beetles in Nebraska. Transactions in GIS, 6(4), 457-470. https://doi.org/10.1111/1467-9671.00122

Boateng, I., 2012., GIS assessment of coastal vulnerability to climate change and coastal adaption planning in Vietnam. Journal of Coastal Conservation, 16(1), 25-36. https://doi.org/10.1007/s11852-011-0165-0

Böhm M., & Popescu V. D., 2016, Landscape ecology, biogeography, and GIS methods. Reptile Ecology and Conservation: A Handbook of Techniques, 298.

Brzeziecki, B., Kienast, F., & Wildi, O., 1995., Modelling potential impacts of climate change on the spatial distribution of zonal forest communities in Switzerland. Journal of Vegetation Science, 6(2), 257-268. https://doi.org/10.2307/3236221

Choi Y. D., 2007, Restoration ecology to the future: a call for new paradigm. Restoration Ecology, 15(2), 351-353. https://doi.org/10.1111/j.1526-100X.2007.00224.x

Chuvieco, E., 1993., Integration of linear programming and GIS for land-use modelling. International Journal of Geographical Information Science, 7(1), 71-83. https://doi.org/10.1080/02693799308901940

Clarke K.C., 1986, Advances in geographic information systems, computers, environmentand urban systems, Vol. 10, pp. 175–184. https://doi.org/10.1016/0198-9715(86)90006-2

Costanza R., Cumberland J. H., Daly, H., Goodland, R., & Norgaard, R. B., 1997, An introduction to ecological economics. CRC Press. https://doi.org/10.1201/9781003040842

Cronk L., 1991, Human behavioral ecology. Annual Review of Anthropology, 25-53. https://doi.org/10.1146/annurev.an.20.100191.000325

Denny P., 2012, The ecology and management of African wetland vegetation: A botanicalaccount of African swamps and shallow waterbodies (Vol. 6). Springer Science and Business Media. https://doi.org/10.1007/978-94-009-5504-2

Duncan A. L., & Lach D. H., 2006, Privileged knowledge and social change: effects on different participants of using geographic information systems technology in natural resource management. Environmental management, 38(2), 267-285. https://doi.org/10.1016/0198-9715(86)90006-2

Egenhofer M. J., & Kuhn W., 1998, Beyond desktop GIS. GIS PlaNET, Lisbon, Portugal.

Fensholt R., & Proud S. R., 2012, Evaluation of earth observation based global long term vegetation trends—Comparing GIMMS and MODIS global NDVI time series. Remote sensing of Environment, 119, 131-147. https://doi.org/10.1016/j.rse.2011.12.015

Ferretti F., Sboarina C., Tattoni C., Vitti A., Zatelli P., Geri F., Pompei E., Ciolli M., 2018,The 1936 Italian Kingdom Forest Map reviewed: A dataset for landscape and ecological research. Ann.Silvic. Res, 42, 3-19. http://dx.doi.org/10.12899/asr-1411

Figliomeni, F. G., & Parente, C. 2022, Bathymetry from satellite images: a proposal for adapting the band ratio approach to IKONOS data. Applied Geomatics, 1-17. https://doi.org/10.1007/s12518-022-00465-9

Fu P., & Sun J., 2011, Web GIS: principles and applications (pp. 89-114). Redlands: Esri Press.

Gough M. C., & Rushton S. P., 2000, The application of GIS-modelling to mustelid landscape ecology. Mammal review, 30(3-4), 197-216. https://doi.org/10.1046/j.1365-2907.2000.00067.x

Huntley, B., Berry, P. M., Cramer, W., & McDonald, A. P., 1995., Special paper: modellingpresent and potential future ranges of some European higher plants using climate response surfaces. Journal of biogeography, 967-1001. https://doi.org/10.2307/2845830

Jenning S., Kaiser M., & Reynolds J. D., 2009, Marine fisheries ecology. John Wiley and Sons. https://doi.org/10.1577/1548-8659(2003)132%3C0619:BR%3E2.0.CO;2

Jo M. H., Lee M. B., Lee S. Y., Kim J. B., Kwon B. K., & Heo Y. J., 2004, Developing Mobile GIS Spatial Data Compression Method for Forest Fire Extinguishment Information Management. Journal of the Korean Association of Geographic Information Studies, 7(2), 78-86.

Johnston C.A., 1998, Geographical Information Systems in Ecology. Oxford, Blackwell Science.

Joy M. K., & Death R. G., 2004, Predictive modelling and spatial mapping of freshwater fish and decapod assemblages using GIS and neural networks. Freshwater Biology, 49(8), 1036-1052. https://doi.org/10.1111/j.1365-2427.2004.01248.xKeith, D. A., Ferrer-Paris, J. R., Nicholson, E., & Kingsford, R. T., 2020., IUCN Global Ecosystem Typology 2.0. International Union for Conservation of Nature. https://doi.org/10.2305/IUCN.CH.2020.13.en

Kitron U., 1998, Landscape ecology and epidemiology of vector-borne diseases: tools for spatial analysis. Journal of medical entomology 35.4: 435-445. https://doi.org/10.1093/jmedent/35.4.435

Kitsiou, D., Coccossis, H., & Karydis, M., 2002., Multi-dimensional evaluation andranking of coastal areas using GIS and multiple criteria choice methods. Science of the total environment, 284(1-3), 1-17. https://doi.org/10.1016/S0048-9697(01)00851-8

Levin S. A. 1992, The problem of pattern and scale in ecology: the Robert H. MacArthur award lecture. Ecology, 73(6), 1943-1967. https://doi.org/10.2307/1941447

Li X., Rowley R. J., Kostelnick J. C., Braaten D., Meisel J., & Hulbutta K., 2009, GIS analysis of global impacts from sea level rise. Photogrammetric Engineering & Remote Sensing, 75(7), 807-818. https://doi.org/10.14358/PERS.75.7.807

Lichter M., & Felsenstein D., 2012, Assessing the costs of sea-level rise and extreme flooding at the local level: A GIS-based approach. Ocean and Coastal Management 59: 47-62. https://doi.org/10.1016/j.ocecoaman.2011.12.020

Liebhold A. M., & Gurevitch J., 2002, Integrating the Statistical Analysis of Spatial Data in Ecology. Ecography, 25(5), 553–557. http://www.jstor.org/stable/3683660

Luoto M., 2000, Spatial analysis of landscape ecological characteristics of five agriculturalareas in Finland by GIS. Fennia, 178(1), 15-54.

Madani, F. 2015, 'Technology Mining'bibliometrics analysis: applying network analysis and cluster analysis. Scientometrics, 105(1), 323-335. https://doi.org/10.1007/s11192-015-1685-4

Millington A. C., Walsh S. J., & Osborne, P. E., 2013, GIS and remote sensing applications in biogeography and ecology (Vol. 626). Springer Science and Business Media. https://doi.org/10.1007/978-1-4615-1523-4

Mitchell R. J., Hiers J. K., O'Brien J., and Starr, G., 2009, Ecological forestry in the Southeast: understanding the ecology of fuels. Journal of Forestry, 107(8), 391-397. https://doi.org/10.1093/jof/107.8.391

Mollalo A., Sadeghian A., Israel G. D., Rashidi P., Sofizadeh A., & Glass G. E., 2018, Machine learning approaches in GIS-based ecological modeling of the sand fly Phlebotomus papatasi,a vector of zoonotic cutaneous leishmaniasis in Golestan province, Iran. Acta tropica, 188, 187-194. https://doi.org/10.1016/j.actatropica.2018.09.004

Navarro Cerrillo R. M., Palacios Rodríguez G., Clavero Rumbao I., Lara M. Á., Bonet F. J., & Mesas-Carrascosa F. J., 2020, Modeling major rural land-use changes using the GIS-based cellular automata metronamica model: The case of Andalusia (Southern Spain). ISPRS International Journal of Geo-Information, 9(7), 458. https://doi.org/10.3390/ijgi9070458

Neumann J. E., Hudgens D. E., Herter J., & Martinich J., 2010, Assessing sea-level rise impacts: a GIS-based framework and application to coastal New Jersey. Coastal management 38.4: 433-455. https://doi.org/10.1080/08920753.2010.496105

Niemelä J., 1999, Ecology and urban planning. Biodiversity and Conservation, 8(1), 119- 131. https://doi.org/10.1023/A:1008817325994

Noyons E. C., Moed H. F., & Luwel M., 1999, Combining mapping and citation analysis for evaluative bibliometric purposes: A bibliometric study. Journal of the American society for Information Science, 50(2), 115-131. https://doi.org/10.1002/(SICI)1097-4571(1999)50:2<115::AID-ASI3>3.0.CO;2-J

Odum E. P., & Barrett G. W., 1971, Fundamentals of ecology (Vol. 3, p. 5). Philadelphia: Saunders.

Oladinrin, O. T., Arif, M., Rana, M. Q., & Gyoh, L., 2022., Interrelations between construction ethics and innovation: a bibliometric analysis using VOSviewer. Construction Innovation. https://doi.org/10.1080/15623599.2020.1819584

Paramasivam C. R., & Venkatramanan S., 2019. An introduction to various spatial analysistechniques. GIS and geostatistical techniques for groundwater science, 23-30. https://doi.org/10.1016/B978-0-12-815413-7.00003-1

Richmond C., Elliott S. J., Matthews R., & Elliott B., 2005, The political ecology of health:perceptions of environment, economy, health and well-being among 'Namgis First Nation. Health andplace, 11(4), 349-365. https://doi.org/10.1016/j.healthplace.2004.04.003

Schneider D. C., 2001, The Rise of the Concept of Scale in Ecology: The concept of scaleis evolving from verbal expression to quantitative expression, BioScience, Volume 51, Issue 7, July 2001, Pages 545–553, https://doi.org/10.1641/0006-3568(2001)051[0545:TROTCO]2.0.CO;2

Scott M.J., Heglund P.J., Morrison M.L., Haufler J.B., Raphael M.G., Wall W.A., SamsonF.B., 2002, Predicting species occurrences: issues of accuracy and scale. Island Press, Washington.

Simoonga C., Utzinger J., Brooker S., Vounatsou P., Appleton C.C., Stensgaard A.S., Olsen A., Kristensen T.K., 2009, Remote sensing, geographical information system and spatial analysis for schistosomiasis epidemiology and ecology in Africa. Parasitology 136.13 (2009): 1683-1693. https://doi.org/10.1017/S0031182009006222

Singh A, 2019, Remote sensing and GIS applications for municipal waste management. Journal of environmental management, 243, 22-29. https://doi.org/10.1016/j.jenvman.2019.05.017

Tamala, J. K., Maramag, E. I., Simeon, K. A., & Ignacio, J. J. 2022., A bibliometric analysisof sustainable oil and gas production research using VOSviewer. Cleaner Engineering and Technology, 7, 100437. https://doi.org/10.1016/j.clet.2022.100437

Tan, G., & Shibasaki R., 2003, Global estimation of crop productivity and the impacts of global warming by GIS and EPIC integration. Ecological Modelling, 168(3), 357-370. https://doi.org/10.1016/S0304-3800(03)00146-7

Thanuskodi S., 2010, Journal of Social Sciences: A bibliometric study. Journal of Social Sciences, 24(2), 77-80. https://doi.org/10.1080/09718923.2010.11892847

Urbański, J. A., & Szymelfenig, M., 2003., GIS-based mapping of benthic habitats. Estuarine, coastal and shelf science, 56(1), 99-109. https://doi.org/10.1016/S0272- 7714(02)00125-7

Van Eck N. J., & Waltman L., 2020, VOSviewer Manual: Manual for VOSviewer version 1.6. 16. Leiden: Centre for Science and Technology Studies (CWTS) of Leiden University.

Vandecasteele, A., Devillers, R., & Napoli, A., 2014., From movement data to objectsbehavior using semantic trajectory and semantic events. Marine Geodesy, 37(2), 126-144. https://doi.org/10.1080/01490419.2014.902885

Vogiatzakis I. N., 2003, GIS-based modelling and ecology: a review of tools and methods. Department of Geography, University of Reading.

Walker, D. A., & Walker, M. D. 1991, History and pattern of disturbance in Alaskan arcticterrestrial ecosystems: a hierarchical approach to analysing landscape change. Journal of Applied Ecology, 244-276. https://doi.org/10.2307/2404128

Waltman, L., Van Eck, N. J., & Noyons, E. C., 2010., A unified approach to mapping andclustering of bibliometric networks. Journal of informetrics, 4(4), 629-635. https://doi.org/10.1016/j.joi.2010.07.002

Wezel A., Bellon S., Doré T., Francis C., Vallod D., & David C., 2009, Agroecology as a science, a movement and a practice. A review. Agronomy for sustainable development, 29(4), 503- 515. https://doi.org/10.1051/agro/2009004

Wiens J. A., 1989, Spatial scaling in ecology. Functional ecology, 3(4), 385-397. https://doi.org/10.2307/2389612

Wiens J. J., Ackerly D. D., Allen A. P., Anacker B. L., Buckley L. B., Cornell H. V., Damschen E.I., Davies T.J., Grytnes J.A., Harrison S.P., Hawkins B.A., Holt R.D., McCain C.M., & Stephens, P.R., 2010, Niche conservatism as an emerging principle in ecology and conservation biology. Ecology letters, 13(10), 1310-1324. https://doi.org/10.1111/j.1461-0248.2010.01515.x

Yu, Y., Li, Y., Zhang, Z., Gu, Z., Zhong, H., Zha, Q., ... & Chen, E., 2020., A bibliometricanalysis using VOSviewer of publications on COVID-19. Annals of translational medicine, 8(13). https://doi.org/10.21037%2Fatm-20-4235