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Bibliometric Analysis of Soil and Landscape Stability, Sensitivity and Resistivity

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Abstract: In times of global change, it is of fundamental importance to understand the sensitivity, stability and resistivity of a landscape or ecosystem to human disturbance. Landscapes and ecosystems have internal thresholds, giving them the ability to resist such disturbance. When these thresholds are quantified, the development of countermeasures can help prevent irreversible changes and support adaptations to the negative effects of global change. The main objective of this analysis is to address the lack of recent studies defining terms like sensitivity, resistivity and stability in reference to landscapes and ecosystems through a Bibliometric analysis based on Scopus and Web of Science peer-reviewed articles. The present research also aims to quantify landscape statuses in terms of their sensitivity, stability and resistivity. The term "landscape stability" is mainly related to quantitatively measurable properties indicating a certain degree of stability. In contrast, the term "landscape sensitivity" is often related to resilience; however, this definition has not substantially changed over time. Even though a large number of quantification methods related to soil and landscape stability and sensitivity were found, these methods are rather ad hoc. This study stresses the importance of interdisciplinary studies and work groups.

Keywords: landscape resilience; landscape analysis; quantification methods; terminology definition; literature review

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1. Introduction

As stated by the Organization for Economic Cooperation and Development [1] and in the Global Environmental Outlook [2], providing a decent life and well-being for nearly 10 billion people by 2050, without further compromising the ecological limits of our planet, is one of the most serious challenges and responsibilities humankind has ever faced ([3]; Organisation for Economic Co-operation and Development [1]). Over the last few decades, anthropogenic activities have caused several changes, including climate change and land use changes (e.g., deforestation, agriculture). Human activities have also had other impacts on ecosystems, transforming the Earth's natural system, exceeding its resource capacity and disrupting its self-regulatory mechanisms, often with irreversible consequences for the global population, as noted by the Intergovernmental Panel on Climate Change [4]. Human interventions have reached a point where the ecological foundations of natural systems that support other species and provide invaluable ecosystem services are in great danger [5].

To tackle the problems listed above, it is imperative to understand the sensitivity, stability and resistance of both landscapes and ecosystems to human disturbance. Ecosystems are highly complex [6,7], as they cover different spatio-temporal scales, from microbial to continental, or from short life cycles to geologic timescales. Consequently, to correctly compare ecosystems, spatio-temporal scales must be defined. In light of global, regional and local policies to fight, prevent or cope with the negative effects of global change, it is often easier to make use of the landscape scale. To have an objective criterion for the comparison of ecosystems, choosing a specific scale becomes crucial, e.g., to apply specific measures to cope with the negative effects of specific anthropogenic interferences, such as climate and land use changes or to appropriately distribute subsidies for agriculture. The ecological status of a landscape needs to be characterized in order to answer questions like the following:

- Is a landscape sensitive or resilient to climatic and/or socio-economic changes, and how can stability, sensitivity or resistivity be quantified?
- At what degree of sensitivity can a landscape be considered stable or unstable?
- At what land use intensity are threshold conditions reached, i.e., where a landscape switches from stable to unstable conditions?

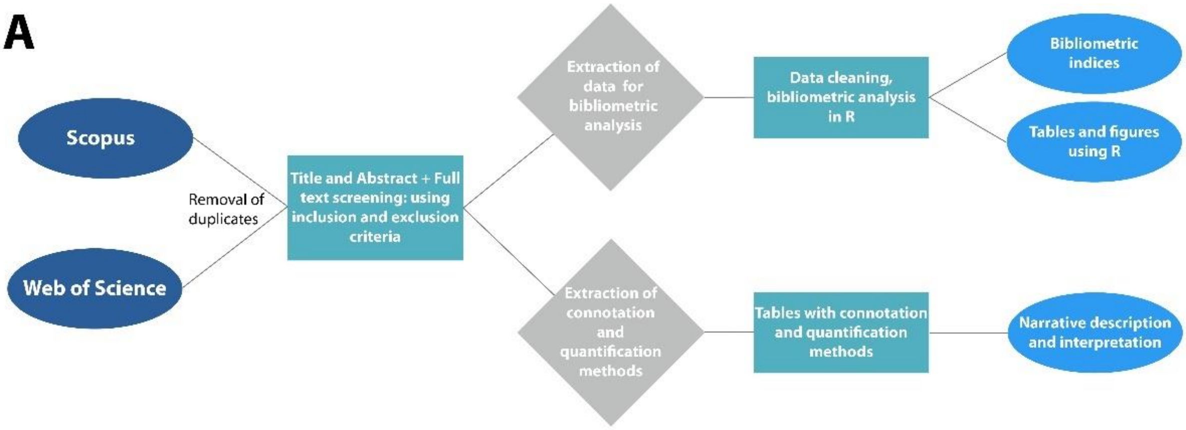
The answers to these questions are quite complex, since landscapes are assessed from different points of view, and different disciplines are involved. Even though many studies have been published in recent decades investigating the effects of global change on landscape sensitivity and stability [8–11], a systematic review of the connotation of the terms is still missing. The main objective of this analysis is to contribute and promote a general understanding of the terminology used. Different approaches are reviewed that aim to quantify landscape statuses in terms of their sensitivity, stability and resistivity. A detailed bibliometric analysis was conducted that incorporated different disciplines, such as general environmental sciences, geology, geomorphology, soil science, and ecology, as well as agronomy and other related environmental sectors that deal with the aforementioned terminology on landscape scales. Bibliometric analyses are becoming increasingly popular in the geosciences and environmental academic fields [12]; they evaluate the distribution models of publications using mathematical and statistical techniques [13], making it possible to perform comprehensive science mapping analyses. Their general purpose is to systematically collect the available literature in order to deepen our understanding of scientific research and its developments (e.g., trends in specific topics, number of papers, journals, authors, countries and research consortia). As highlighted in recent syntheses on, for example, landslides [14] and erosion modelling [12], bibliometric analyses are revealing increasing cooperation in research networking [15] and are providing a deeper understanding of research topics [16]. The methods and parameters adopted by various authors to quantify the sensitivity, stability and resistivity of landscapes will be identified.

The goal of our applied process is to: (i) screen and identify current knowledge about sensitivity, stability and resistivity on a landscape scale, (ii) delineate different connotations used in various scientific sectors and determine the most frequently used ones, (iii) identify the articles and fields of research that have had the greatest impact on the topic, (iv) identify the most widely used methods and/or parameters to qualitatively assess or quantify sensitivity, stability and resistivity on a landscape scale, (v) monitor the changes in the terminology over time, and (vi) identify the different landscape contexts studied.

2. Materials and Methods

This study is based on a systematic literature collection that was carried out in March 2021 and updated at the end of December 2021. It aims to identify all peer-reviewed publications from several earth science fields such as soil science, geomorphology, geology, agricultural sciences, ecology and other related environmental sectors that deal with the terms sensitivity, stability and resilience on a landscape scale.

The search was without timespan restriction and, hence, comprised publications from 1958 to the present day (December 2021). The workflow is illustrated in Figure 1A.



B

Question element	Inclusion Criteria	Exclusion criteria	Screening stage
Subject	Any article dealing with soils or landscapes.	Any article not related to soil or landscape.	Both
Outcomes	Presence of a definition of stability, sensitivity, or resistivity. Presence of a quantification methods of stability, sensitivity or resistivity of soil or landscape.	Absence of definition or quantification method. Presence of a quantification methods that is not replicable.	Both
Language	Any article written in English.	Any article not written in English, including those having only English titles and abstracts.	Both
Typology of publication	Peer-reviewed research articles and reviews.	Non-peer-reviewed articles, conference proceedings, books and thesis.	Both

Figure 1. (**A**) General Workflow. (**B**) Inclusion and exclusion criteria used during the screening process.

2.1. Data Sources

The research was carried out on the two most widely used bibliographic online databases: (i) “Scopus” (Elsevier), and (ii) “Web of Science Core Collection” on the Web of Science (WoS) platform (Clarivate). The latter also covers SCI-EXPANDED, SSCI, A&HCI, CPCI-S, CPCI-SSH, BKCI-S, BKCI-SSH, ESCI and CCREXPANDED. While Web of Science covers a period from 1945 to the present and Scopus starts only from 1970, the latter has a larger number of journals in its database [17]. Both databases include English publications as well as papers in other languages, but only if an English abstract is present. Scopus and Web of Science are equipped with a citation analysis system, but generally, the numbers of citations are higher in Scopus [18]. Both searches were conducted covering the entire time spans of the two databases. This procedure allowed us to cover most publications available to the scientific community and, notably, to identify the most relevant ones. Other databases, such as Google scholar, were purposely excluded due to their lack of proper meta data. Finally, another intention was to consider only articles that had been published in renowned peer-reviewed journals, and thus, to follow the quality standards of good scientific practice. Grey literature (books, unpublished masters and doctoral theses) were deliberately excluded, as they cannot be considered as generally accepted by the scientific community.

2.2. Search for Articles

The search was performed only for scientific articles written in English. This ensured that the publications had significant relevance to the international scientific community and have been globally disseminated and recognized. To carry out the search, the Boolean operator OR was used, allowing us to combine several terms within a single search string.

Since the keyword terms were made up of several words, quotation marks were used to combine multiple words within the same term to specifically identify publications in which these terms were used completely and written in the correct order.

For this study, the following keywords in association with the Boolean operator term "OR" were identified: "Landscape Stability" OR "Landscape Sensitivity" OR "Landscape Resistivity" OR "Geomorphological Stability" OR "Geomorphological Sensitivity" OR "Geomorphological Resistivity" OR "Geomorphic Stability" OR "Geomorphic Sensitivity" OR "Geomorphic Resistivity" OR "Soil Stability" OR "Soil Sensitivity" OR "Soil Resistivity".

Since the two bibliographic databases do not allow users to enter the same search parameters in terms of the categories, we defined categories separately for each database. In Scopus, the search was limited to article titles, abstracts and keywords, and was subsequently refined to the scientific sectors of "Earth and Planetary Sciences", "Environmental Sciences" and "Agricultural and Biological Sciences". Finally, articles were filtered by including only those belonging to journals pertaining to the research fields of the review.

In contrast to Scopus, in Web of Science, the search was done using field tags "TS", which limit the search by topic. Additionally, in this case, we refined the search to the most relevant categories, i.e., "Geosciences multidisciplinary", "Environmental sciences", "Soil science", "Geography physical", "Agricultural engineering", "Ecology", "Water resources", "Plant sciences", "Agriculture dairy animal science", "Engineering geological", "Agricultural economics policy", "Agronomy", "Multidisciplinary sciences", "Engineering environmental", "Forestry", "Geology", "Biodiversity conservation", "Agriculture multidisciplinary", "Environmental studies", "Geography", "Remote sensing" and "Biology".

For both searches, only research articles and reviews were included, thereby excluding all other types of publications, such as conference proceedings, books, abstracts, etc. The results of the two searches were imported to the Mendeley library free reference manager. First, the software automatically removes duplicates. After that, all articles are exported in table format, allowing us to proceed to the screening process.

2.3. Article Screening and Study Eligibility Criteria

For the screening process, relevant information, such as authors' names, journal name, title, DOI, year of publication and type of article, were added to a spreadsheet.

All articles identified in the search procedure and entered into the table were screened following a two-stage process (Figure 1B). In the first stage, only article titles and abstracts were screened. Any publication identified as not relevant for the purposes of this analysis was excluded from the second stage, where the entire publication was read. Finally, all articles that passed the second stage of screening, according to the eligibility criteria, were subsequently subject to bibliometric analysis.

A first selection was conducted in which titles and abstracts were read in order to exclude all articles related to a scientific sector other than those defined above.

The exclusion criteria used during the screening process were as follows:

1. absence of a definition of the search terms (stability, sensitivity, resistivity), or
2. absence of quantification methods of the search terms, and
3. articles belonging to a different field of research,
4. articles where only the title and abstract are reported in English, but the rest of the text is in another language. Generally, it was not possible to exclude these articles earlier using the filter options in Scopus and Web of Science.

2.4. Data Collection

From all publications that passed the different steps of the screening process, various data were extracted, including bibliographic information (authors' names and countries, publication title, affiliation, keywords, journal, year, references, citations, abstract, DOI), as were connotations of stability, sensitivity, and resistivity as well as the methods and parameters of their quantification. For each article, the field or fields of research were identified.

These data were recorded in two types of documents:

1. For the bibliometric analysis, a bibtext file (readable by the R package bibliometrix [19]) was prepared with all the articles that passed the screening process. The bibtext file was automatically extracted from Scopus with all the relevant information for the bibliometric analysis. To avoid formatting conflicts, the data extracted from Web of Science were entered manually in the same bibtext file. Due to the fact that articles were sometimes present in both databases with different citation statistics, we decided to use the Scopus, since it generally presents higher numbers of citations than Web of Science.
2. For further analysis and interpretation, another table was set up including the outcomes of the analysis in terms of the specific definitions of stability, sensitivity and resistivity, as well as the respective quantification methods.

2.5. Bibliometric Analysis

Data extracted in the bibtext format were loaded into the R software environment for statistical computing and graphics (version 4.0.2, R Foundation for Statistical Computing, Vienna, Austria [20]), and subsequently, a bibliometric analysis was carried out using the bibliometrix package [19]. Before starting the analyses, a thorough check of the database for errors was performed.

The papers that passed the screening process were analyzed to identify the most relevant ones, as well as the relevant authors, i.e., those that produced the highest number of articles. Therefore, the author dominance ranking, as proposed by Kumar and Kumar [21], was applied. Moreover, each author’s productivity over time, as well as the respective trend line, was analyzed. The general scientific productivity observed in terms of the frequency of publications of a specific author in a given field of study was compared with the theoretical frequency based on Lotka’s coefficient [22]. With the Lotka function of the bibliometrix package, the beta coefficient of the bibliographic database was determined in order to statistically compare the similarity between the observed and the theoretical distribution. Lotka’s law describes the frequency of publications by a given author in a particular field of study using the inverse square law, where there is a fixed relationship between the number of authors who publish a certain number of articles and the number of authors who have published only a single article. We hypothesized that the theoretical beta coefficient of Lotka’s law would be equal to 2 [22]. Through the biblioNetwork function in bibliometrix, an in-depth citation analysis was conducted based on a co-citation network [23,24]. Two articles are co-cited when both are cited in a third article. This type of analysis traces the intellectual structures of science [25]; it quantitatively identifies the relationships among scientific ideas [26] and subject similarities [27]. If two articles are highly co-cited, this is evidence that these articles are significant and related to each other [24]. The results are illustrated using the networkPlot function, where nodes are research papers and links are co-citations.

NetworkPlot can also analyze scientific collaboration networks [28,29], which we investigated in detail and reported as a map, where the nodes are authors and the links reflect co-authorships.

Finally, keyword co-occurrences were analyzed to study the knowledge components and structure of a field of research through the detection of clusters of the most common keywords in the literature [30,31].

2.6. Connotation and Quantification Methods

The various connotations of the search terms were collected in a table in chronological order so that the evolution of their definitions over time could be assessed.

Regarding the quantification methods and parameters, a table describing the different approaches applied to the different fields of research was generated. The evolution of the quantification methodologies over time is also reported by arranging the relevant data in chronological order.

3. Results

3.1. Literature Search and Screening

A literature search was carried out in December 2021; 1082 articles were obtained, i.e., 433 articles from Web of Sciences and 619 from Scopus. As no time restrictions were set, this included papers from 1958 to 2022. After removing duplicates, the total number of publications was 859.

After a double-stage screening process, only 147 articles were considered useful for the research, coming from 64 difference sources (Journals) and dating from 1976 to 2022 (Table 1). The overlap between the two abstract and citation databases was 20.47%. The average number of citations per document was 36.15, as identified by Scopus and Web of Sciences.

Table 1. Key information about the obtained data after the double-stage screening process.

Main Information about Data	Results
Timespan	1976–2022
Sources (Journals)	64
Documents	147
Average years from publication	10.7
Average citations per documents	36.15
Average citations per year per doc	2.65
References	8169
Overlap	20.47
Article	143
Review	4

The identified publications mostly consisted of research articles (97.3%, *n* = 143), followed by reviews (2.7%, *n* = 4). Considering the whole period, the Annual Growth Rate of publications was found to be 2.19%.

Figure 2 shows the number of articles published for each year from 1976 to 2022. Publication activity started at a rather low value, with only slight annual increase, including years without and relevant publications, up to 1998. However, in the following years, activity increased exponentially. The highest number of relevant publications was registered for 2019, with 18 articles published.

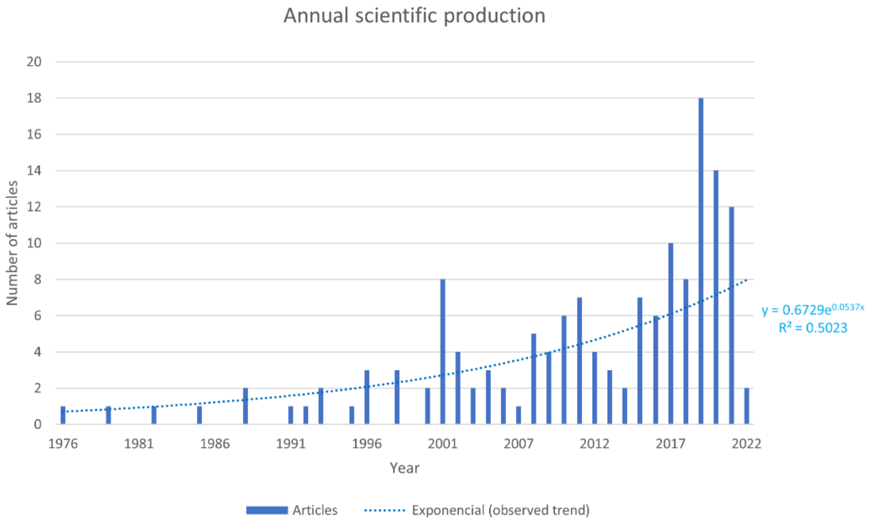


Figure 2. Annual production of articles during the period 1976–2022.

Authors' countries were assessed using the postal addresses reported in the articles. As shown in Table 2, the top 10 most productive countries contributed 96 articles, corresponding to 65.3% of the total outcome. The United States of America was the most productive country, with 27 published articles. Four articles were written in collaboration with other countries. The USA was followed by the United Kingdom, with 16 published articles, five of which were written in collaboration with other countries. China was in third position, with 14 published articles, 3 of which were in collaboration with other countries.

Table 2. Number of publications and citations of the 10 most productive countries in the period 1976–2022. SCP: Number of publications by country; MCP: Number of articles for the country, written in collaboration with other countries; TC: Total number of citations.

Country	Time Interval	Articles	SCP	MCP	TC	TC/Articles
USA	2022–1988	27	23	4	1661	61.52
United Kingdom	2022–1976	16	11	5	1132	70.75
China	2022–2002	14	11	3	75	5.36
Australia	2020–2985	10	8	2	162	16.20
Germany	2021–2010	8	5	3	138	17.25
Iran	2022–2006	8	4	4	179	22.38
France	2019–2004	4	3	1	108	27.00
Canada	2014–1996	3	2	1	102	34.00
India	2021–2012	3	3	0	25	8.33
Italy	2021–2016	3	1	2	57	19.00

The most cited articles came from the United States, with 1661 citations and an average citation rate of 62 for each of the 27 articles, followed by United Kingdom, with 1132 citations and an average citation rate of 71 for the 16 articles. In third position, New Zealand showed 292 citations for only 2 articles and an average citation rate of 146.

The average number of article citations was consistent with the number of articles published per countries, except for China (5.36), which had the lowest average article citation value among the top 10 of the most productive countries.

As shown in Figure 3, in addition to the number of articles produced by individual authors, we determined the relevance of the corresponding articles by counting the average number of citations (within the database used for the bibliometric analysis), accounting for the period in which the authors worked on a given topic. Jayne Belnap and Matthew A. Bowker can be considered the most productive authors, with 5 articles published each. Both authors focused on soil ecology. Jayne Belnap has received 243 citations (TC), corresponding to an average of 49. In contrast, Matthew A. Bowker has received 277 citations (TC) with an average article citation of 55. All other contributing authors produced up to 3 articles each and focused on different fields of research, ranging from fluvial geomorphology to the assessment of soil properties and soil quality through soil indicators and other studies in the field of ecology.

Altogether, the top 10 authors produced 31 articles, or 21.1% of all articles that passed the screening process.

In order to assess the quality of publications as well as the general productivity, we used as indicators including the total number of global citations, i.e., total number of citations identified in the Scopus and Web of Sciences databases, and local citations, i.e., the total number of citations that an article received from other publications within our database of 147 articles.

Table 3 shows the ranking of the most relevant papers in terms of citations. Top on the list is 'Brunsden and Thornes, 1979' [32] with 472 citations. This paper was the first to attempt to define the term landscape sensitivity for research in the field of geomorphology. It was followed by 'Six et al., 2000' [33] with 327 citations; those authors focused on soil aggregate distribution and soil stability as quality indicators. In third position was 'Orwin et al., 2004' [34], with 272 citations; those authors proposed new indices with which to quantify the stability (i.e., resistance and resilience) of soil biota to exogenous disturbances.

Regarding local citations, 'Brunsden and Thornes, 1979' were in first position, with 21 citations in other articles included in our database, followed by 'Harvey, 2001' [35], with 9 citations. The latter paper was included in a Special Issue of Catena from 2001 on landscape sensitivity, focusing on the sensitivity of fluvial systems. 'Brunsden, 2001' [36], in third place, provided an assessment of landscape sensitivity in geomorphology.

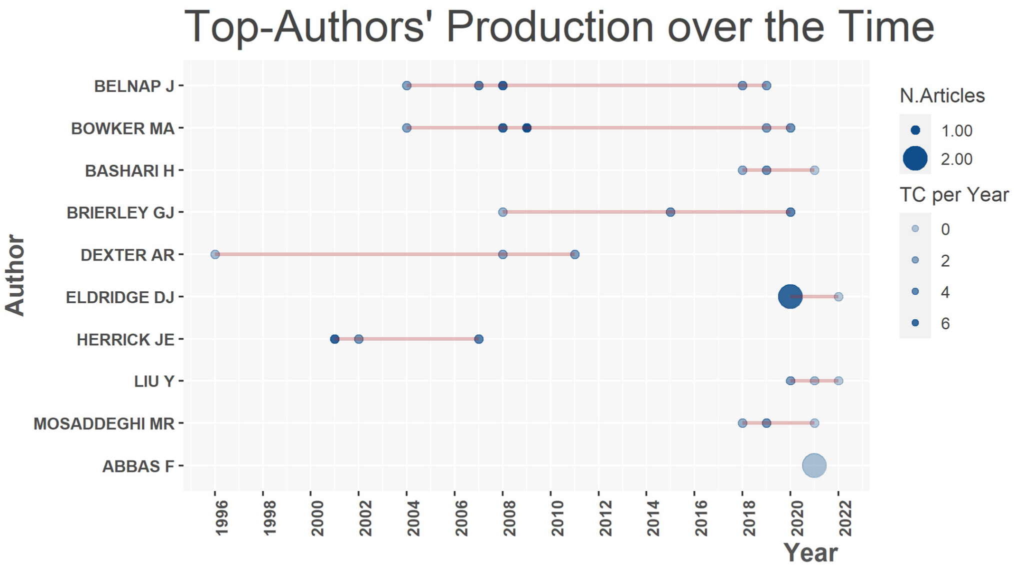


Figure 3. Production of top authors over time. TC: Average citations per year.

Table 3. Total and local citation analysis of the 10 most relevant documents in the present dataset. TC: Total number of citations, LC: Local number of citations.

	Document	DOI	TC	TC/YEAR	LC
[32]	Brunsden and Thornes, 1979	10.2307/622210	472	10.7273	21
[33]	Six et al., 2000	10.2136/sssaj2000.6431042x	327	14.2174	3
[34]	Orwin and Wardle, 2004	10.1016/j.soilbio.2004.04.036	272	14.3158	2
[35]	Harvey, 2001	10.1016/S0341-8162(00)00139-9	261	11.8636	9
[36]	Lal, 1993	10.1016/0167-1987(93)90059-X	189	6.3	0
[37]	North, 1976	10.1111/j.1365-2389.1976.tb02014.x	185	3.9362	3
[38]	Brunsden, 2001	10.1016/S0341-8162(00)00134-X	181	8.2273	7
[39]	Knox, 2001	10.1016/S0341-8162(00)00138-7	166	7.5455	5
[40]	Thomas, 2001	10.1016/S0341-8162(00)00138-7	166	7.5455	5
[41]	Bullard and McTainsh, 2003	10.1016/S0341-8162(00)00133-8	164	7.4545	4

The Lotka function can be used to determine the coefficients of scientific productivity [22]. As illustrated in Figure 4, the theoretical distribution was very similar to the distribution derived for our bibliographic dataset. The observed frequency of authors who published only one article was 91%, i.e., close to the theoretical frequency of 81%. From more than one article, the frequency of authors drastically decreased, i.e., to 6.9 for two papers, 1.2% for three papers and 0.3% for more than three papers. Although for observed productivity, the curves switched to higher theoretical and lower observed values, the two curves showed similar trends.

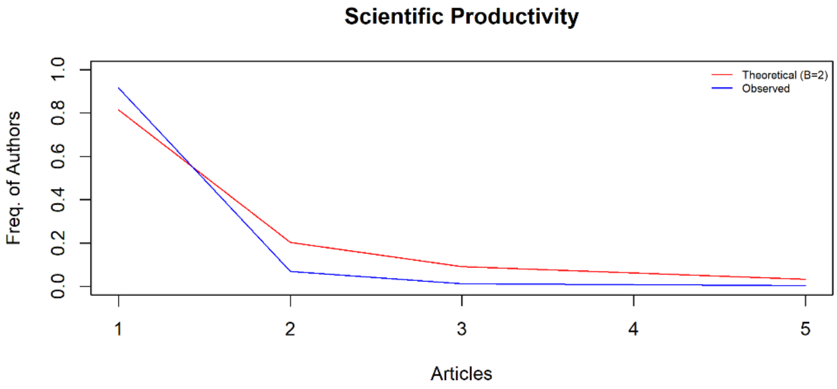


Figure 4. Lotka's law of scientific productivity.

A journal analysis was carried out by measuring the productivity and impact of the articles present in the respective journals. In Table 4, the numbers of publications and total citations of the five most relevant journals are shown.

Table 4. The five most relevant journals, according to the number of local citations. TC: Total number of citations; PY Start: year of the first publication of this journal included into database.

Journal	Articles	TC	PY Start
Catena	16	1079	2001
Science of the Total Environment	8	109	2014
Geomorphology	7	167	2006
Soil and Tillage Research	7	320	1991
Soil Science Society of America Journal	6	420	1982

This analysis identified five journals which represent 29% of all articles, i.e., 44 articles published. Of those five journals, 'Catena' was the most productive, with 16 articles. These articles also received the most citations, with an average of 67 per paper. The first article included in the database was published in 2001, concurrently with the publication of the special issue on landscape sensitivity. The second most productive journal was 'Science of the total Environment' with 6 articles, but with fewer total citations than the other four journals, i.e., an average citation rate per article of 14. In third place was 'Geomorphology', with 7 articles and an average number of citations per paper of 24. The numbers of citations were consistent with the number of publications, except for Science of the Total Environment.

Regarding the growth rate of journal articles, the first journal to publish a paper on landscape stability, sensitivity or resistivity was 'Soil Science Society of America', in 1982. This was followed by 'Soil and tillage research' in 1991. With the publication of the "landscape sensitivity" special issue in 2001, 'Catena' was the most productive journal up to 2014. From 2014 to today, the most productive journal has been 'Science of the Total Environment'.

An in-depth citation analysis was carried out to identify connections within the bibliographic dataset. As documented in Figure 5, three clusters, colored red, blue and green, can be seen. The blue cluster shows the publication of 'Brunsden and Thornes, 1979' who have the highest number of co-citations. This is a cluster in which the main topic is geomorphology and landscape sensitivity; different topics were sometimes treated, but research was always related to the macro area of geomorphology. The green cluster, in which the dominant topic was fluvial geomorphology and sediment connectivity, comprised 14 papers. The blue and green clusters are heavily interlinked with each other. In contrast, the minor but independent red cluster had soil structure and soil stability as its main topic, and comprised only four papers.

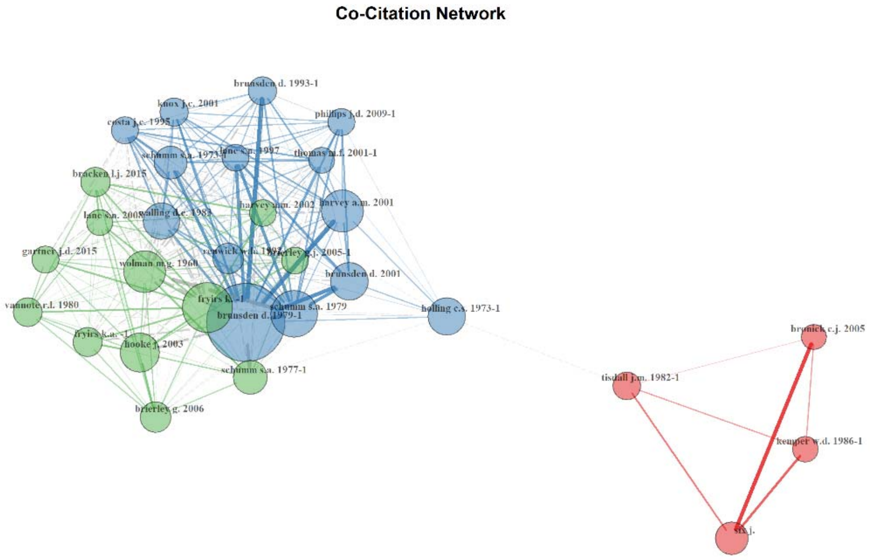


Figure 5. Co-Citation Network.

An author collaboration network is defined as a network where the nodes are authors and the links between them represent co-authorships. The size of the nodes indicates the number of articles authored by a given scholar.

As illustrated in Figure 6, 12 clusters were present. The individual clusters included a limited number of authors, indicating that collaboration is limited to a few authors for the topics covered in this bibliometric analysis. The larger clusters covered topics including soil stability, soil biology, soil structure and ecology. Minor clusters covered topics like aggregate stability, fluvial geomorphology, soil stability, soil properties and soil degradation.

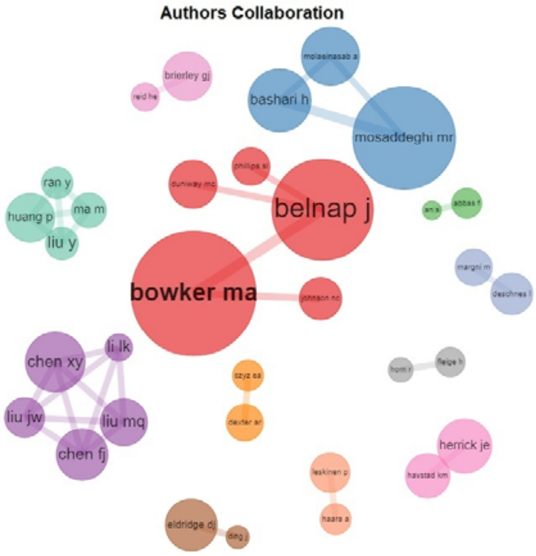


Figure 6. Author collaboration network.

Based on our analysis of keyword co-occurrences, Figure 7 shows that there were three clusters. One cluster (blue) was related to soil, in which the most important keywords were soils, soil stability, soil property, soil structure and soil stabilization. Another (green), which was closely related to sensitivity, had the following keywords: soils, sensitivity analysis, ecosystem and climate change. A third cluster (green) was dedicated to erosion and was associated with keywords including soil erosion, erosion, soil stability, soil aggregates, soil structure, land use and sediment transport.

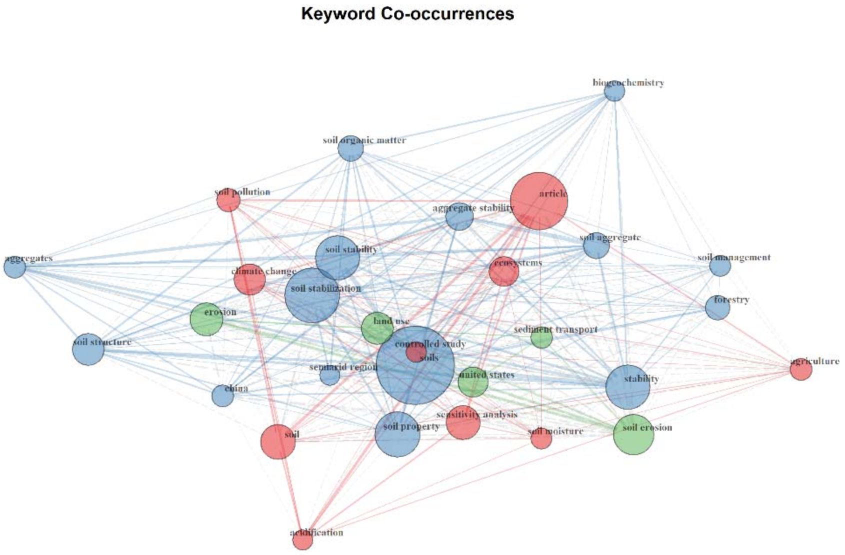


Figure 7. Keyword co-occurrences.

3.2. Identification of Connotation

Following the study eligibility criteria, all articles including a connotation regarding soil, landscape and geomorphological stability, sensitivity and resistivity—which is considered to be related to sensitivity—were identified.

All connotations identified during the screening process are reported in the following tables. Regarding sensitivity, 34 different connotations were identified, starting with Brunsden and Thrones, 1979 [32], who proposed the initial connotation of the term “landscape sensitivity” in a geomorphological sense: “The sensitivity of a landscape to change is expressed as the likelihood that a given change in the controls of a system will produce a sensible, recognizable and persistent response. The issue involves two aspects: the propensity for change and the capacity of the system to absorb the change”. This can be considered a basic definition of the term “landscape sensitivity”.

We observed two peaks in publication activity: one in 1993, corresponding to the appearance of a collection of publications entitled ‘Landscape Sensitivity’, edited by D.S.G Thomas and R.J. Allison, and the other in 2001, corresponding to the release of the ‘Landscape Sensitivity’ special issue, published in Catena.

The various connotations listed in Table 5 cover different fields of research, such as ecology, geomorphology, fluvial geomorphology, soil erosion, soil pollution, hydrology, land use change and soil structure.

Table 5. Connotations of “soil and landscape sensitivity”, reverse chronologically ordered.

Article		Connotations of Soil and Landscape Sensitivity
[42]	(Song et al., 2021)	Soil resistance refers to the capacity of soil to retain stability upon exposure to stress. Soil resilience means the ability of soil to resist degradation and recover to its pre-perturbation status within an appropriate time scale.
[43]	(Manolaki et al., 2020)	The term landscape sensitivity can imply both resistance to change and resilience, i.e., the ability to recover from a change. Landscape sensitivity was defined as the ratio of the change in a system to the change in a landscape component; the larger the ratio, the greater the sensitivity.
[44]	(Mirzaee et al., 2020)	Resistance of soil particles to erosive forces such as rainfall and runoff is defined as soil sensitivity to erosion.

Table 5. *Cont.*

	Article	Connotations of Soil and Landscape Sensitivity
[45]	(Song et al., 2020)	Soil resistance (the capacity of soil to maintain its stability upon exposure to of stress) and soil resilience (the ability of soil to resist degradation and return to its pre-perturbation status).
[46]	(Llena et al., 2019)	The geomorphic sensitivity of the landscape: the response of the system to environmental change or disturbance and its recovery.
[47]	(Brogan et al., 2019)	Sensitivity is defined as "the propensity of a system to respond to a minor external change". Sensitivity also can vary across landscapes and over time, depending on other, previous perturbations.
[48]	(Wohl, 2018)	Earlier descriptions of resilience include landscape sensitivity and transient and persistent landforms. Transience and persistence, which are commonly defined in terms of the duration of a specific landform relative to the frequency of the process creating that landform, also take into account the temporal dimensions of the associated context (i.e., the recurrence interval of disturbances).
[49]	(Lizaga et al., 2018)	Geomorphic or landscape sensitivity refers to how geomorphic systems respond to environmental change, that is, the ability of a system faced with external interference to withstand the change.
[50]	(Rathburn et al., 2018)	Landscape sensitivity is another way to assess landscape resilience and resistance (i.e., the ability to resist changes in form and process caused by external factors). Sensitivity can thus be considered a function of the spatial and temporal distributions of the resisting properties (e.g., rock strength, resistance to weathering and erosion) and the disturbance forces (e.g., sediment load, high shear stress).
[51]	(James, 2018)	Landscape sensitivity, in turn, reflects a large variety of factors such as geology, soil, vegetation cover, antecedent conditions and topography. Legacy sediment is both a response to and a driver of landscape sensitivity and change.
[52]	(Anthony Stallins and Corenblit, 2018)	Like resilience theory, landscape sensitivity encompasses the propensities of a geomorphic system to recover from disturbance, as well as the tendency to change in state.
[53]	(Haara et al., 2017)	Landscape sensitivity describes the tolerance of landscape to change, which affects visibility, recreation and ecological sustainability. Landscape sensitivity varies both spatially and temporally.
[54]	(Fryirs, 2017)	Sensitivity is a system response characteristic that describes the severity of a response to a disturbance relative to the magnitude of the disturbance force.
[55]	(Phillips and Van Dyke, 2016)	Resilience is the ability of a system to return to its previous state after a perturbation. The landscape sensitivity concept in geomorphology incorporates resilience as well as resistance.
[56]	(Store et al., 2015)	The term "landscape sensitivity" has been used to indicate geomorphic sensitivity, which means how geomorphic systems respond to environmental changes such as erosion, increasing temperature, winds and storms and human activity. It can imply both resilience to change and the ability to recover from change. It can be defined as the likelihood that implementing certain forestry practices or other activities will evoke criticism and concern from the public.
[57]	(Roy et al., 2014)	Soil sensitivity represents receptor changes (if any) in soil properties over a certain area due to deposition in a single fraction.
[58]	(Zhang et al., 2013)	Soil erosion sensitivity is defined as the possibility of soil erosion occurrence and the identification of areas which are susceptible to erosion due to natural factors.
[59]	(Falconer et al., 2013)	Landscape sensitivity is measured to assess the degree to which a landscape can accommodate the type of change being predicted.
[60]	(Jain et al., 2012)	The sensitivity of a system is defined by the system specifications that describe its propensity for change and its ability to absorb any disturbing forces. The sensitivity dictates the landform response to external change.

Table 5. *Cont.*

Article		Connotations of Soil and Landscape Sensitivity
[61]	(Phillips, 2009)	The landscape sensitivity concept encompasses the probability that a given change in the boundary conditions or forcings of a geomorphic system will 'produce a recognizable and persistent response'.
[62]	(Gregory et al., 2008)	Regarding rivers, disturbance responses reflect the sensitivity to change or capacity for adjustment of any given reach.
[63]	(Kheir et al., 2006)	Landscape sensitivity is assumed to be inversely proportional to vegetal cover but directly proportional to slope and drainage density.
[41]	(Bullard and McTainsh, 2003)	Landscape sensitivity is the capacity of systems to absorb, resist or respond to changes in controlling factors such as moisture availability, sediment availability or transport capacity. The sensitivity of a given landscape is largely determined by its internal connectivity, i.e., the density and strength of the links between different parts of a geomorphic system.
[64]	(Tao et al., 2002)	Sensitivity, in this context, refers to the degree to which a system will respond to acid deposition. Thus, the term emphasizes the risk of an increase in the rate of change of the soil chemistry (the acidification rate).
[65]	(Usher, 2001)	Landscape sensitivity is expressed as the ratio of the change in a system to the change in a landscape component; the larger the ratio, the greater the sensitivity.
[66]	(Miles et al., 2001)	Landscape sensitivity indicates the likelihood of change, i.e., of instability versus stability.
[35]	(Harvey, 2001)	Sensitivity can be expressed by the ratio between the mean relaxation time of the system and the mean recurrence time between effective events. It distinguishes between robust landscapes, where the effects of disturbances are minimized, and sensitive landscapes, where the effects of disturbances may persist, i.e., landscapes which are transient in nature.
[40]	(Thomas, 2001)	The concept of landscape sensitivity, therefore, implies conditional instability within a system, with the possibility of the occurrence of rapid and irreversible change due to perturbations in the controlling environmental processes.
[36]	(Brunsden, 2001)	The landscape sensitivity concept describes the likelihood that a given change in a system or in the forces applied to that system will produce a recognizable and persistent response. Sensitivity refers to the propensity of a system to respond to minor external changes. Beyond a certain threshold, a significant adjustment occurs in the system. The system is considered to be sensitive if it is near such a threshold and will respond to an external influence.
[67]	(Thomas and Allison, 1993)	The question of sensitivity thus focuses on the potential and likely magnitude of change within a physical system and the ability of that system to resist change A cause/effect relationship can be identified where external processes control, influence and dictate change.
[68]	(Evans, 1993)	The sensitivity of a given landscape to erosion depends upon the threshold at which erosional forces are triggered by weather or earthquake shocks, in association with gravity, overcoming the resistance of rock, soil and vegetation.
[69]	(Downs and Gregory, 1993)	Sensitivity can be mathematically described as the ratio of two differentials that express the response or induced output change resulting from stimulus or applied input change.
[70]	(Schumm, 1991)	Sensitivity refers to the propensity of a system to respond to a minor external change. Changes occur at a threshold, which, when exceeded, results in a significant adjustment. If the system is sensitive, i.e., near the threshold, it will respond to the external influence.
[32]	(Brunsden and Thornes, 1979)	The sensitivity of a given landscape is expressed as the likelihood that a change in the controls of the system will produce a recognizable and persistent response. The concept involves two aspects: the propensity for change and the capacity of the system to absorb such a change.

Regarding the connotation of soil and landscape stability, 19 definitions were identified (Table 6). The oldest definition of soil stability was provided by North (1976) [38]: "The stability of a soil is indicated by its ability to resist potentially disruptive forces".

Table 6. Connotations of soil and landscape stability, ordered reverse chronologically.

Article		Connotations of Soil and Landscape Stability
[71]	(Picariello et al., 2021)	Soil stability encompasses both resistance, i.e., the ability to withstand a perturbation or stress, and resilience, i.e., the ability to recover to pre-perturbation levels.
[72]	(Eldridge et al., 2020)	The ability of surface soil aggregates to break down in water; stable soil fragments will stay intact upon wetting.
[73]	(Vojtekova and Vojtek, 2019)	The term landscape stability refers to the spatial and functional stability in various land-use categories over time. Basically, landscape stability represents the share of stable areas between the first and last years of study. In contrast, landscape structure instability refers to situations when a small change in the environment is enough to divert the system from its oscillating mode around a central state.
[74]	(Zhang and Zhang, 2019)	Landscape stability describes a balanced state in the landscape structure and pattern of a fixed size. A landscape pattern describes the response when that landscape is controlled and shaped by climate or human disturbances.
[75]	(Menezes et al., 2019)	Periods of landscape stability in which the pedogenesis exceeded the sedimentation rates, resulting in the formation of soil profiles
[76]	(Liu et al., 2019)	Landscape stability describes a landscape that has been stable (i.e., when perturbed, it tends to return to an undisturbed state) and which will not undergo significant structural changes in the short term. The term also implies that the natural processes that contribute to the functions and sustainability of that landscape will not be disrupted
[77]	(Prokopová et al., 2019)	Ecological (landscape) stability is defined as the ability of a given ecosystem to return to its initial equilibrium state after a disturbance. Additionally, this notion describes the intrinsic ability to maintain ecological functions despite disturbance. The notion is based on three complementary attributes: resilience, adaptability and transformability.
[78]	(Xuan et al., 2016)	Landscape stability is an index that is effective at revealing past changes. Landscape stability assessments measure the risk faced by a certain area after a disturbance and analyze the relationship between that disturbance and stability, as well as other relationships between the structure of ecological areas and their stability.
[79]	(Guo et al., 2015)	Soil stability indicates the extent of the anti-erosion properties of various soil types,
[80]	(DeJong et al., 2010)	the ratio of initial penetration resistance and the remolded resistance.
[81]	(Mikheeva, 2010)	Stability describes the ability of soil to retain its properties, regime parameters, phase ratio and structural organization within a set of limits determined by natural variations under different external perturbations (including anthropogenic ones).
[82]	(Chaudhary et al., 2009)	Soil stability is the ability of soils to resist erosive forces.
[83]	(Derbel et al., 2009)	The stability index provides information about the ability of soil to withstand erosion and to recover after disturbance.
[34]	(Orwin and Wardle, 2004)	Stability (resistance and resilience to disturbance) is a key factor influencing the properties and processes of a soil system.
[36]	(Brunsden, 2001)	Landscape stability is assessed according to the temporal and spatial distributions of resisting and disturbing forces and is therefore diverse and complex.
[37]	(Lal, 1993)	Soil stability refers to the susceptibility of soil to change under natural or anthropogenic perturbations.
[84]	(Friedman and Zube, 1992)	The purposes of this article is to present means by which to assess (i) the spatial and temporal changes in land use and land cover at the landscape and vegetation community scales, and (ii) landscape stability. Landscape stability is defined as no change in the extent of each of the relevant components.
[32]	(Brunsden and Thornes, 1979)	Landscape stability is a function of the temporal and spatial distributions of resisting and disturbing forces and may be described by the landscape change safety factor, here considered to be the ratio of the magnitude of barriers to change to the magnitude of the disturbing forces.
[38]	(North, 1976)	The stability of a soil is indicated by its ability to resist potentially disruptive forces.

These connotations cover different fields of research, of which the most significant are ecology, followed by soil biology, soil properties, land use change, paleoenvironmental studies, geotechnics and the effects of land use on landscapes.

Table 7 reports the parameters that are used to quantify soil and landscape stability/sensitivity in reverse chronological order. In total, we identified 104 papers reporting quantification methods. The most important thematic field is the study of soil properties and soil structure, with 40 instances, followed by ecology (19 instances) and soil erosion (11 instances). Other key research fields are soil biology, agriculture, geomorphology and remote sensing.

For quantitative assessments of soil and landscape sensitivity, different methods are applied, depending on the field of research. One of the most commonly used parameters is aggregate stability (e.g., [85–87]), which is measured using the following variables: mean weight diameter (MWD) [88], geometric mean diameter (GMD) [89], water stable aggregates [90], macro aggregates stability [90], the resistance of a soil sample to slaking [91] and aggregate distribution before and after disruption [33].

Remote sensing applications are often used to evaluate land use changes, for example, by applying a Landscape Function Analysis (LFA), which is employed to estimate soil resistance to erosion.

Sensitivity to soil erosion is mainly evaluated using qualitative and quantitative methods. Other methods include landscape character assessment s(LCAs) [92,93] and analyses of soil sensitivity to acid deposition [94].

Table 7. Parameters of quantification of stability and sensitivity.

Article		Parameters of Quantification of Soil and Landscape Stability/Sensitivity	Research Field
[89]	(Ran et al., 2022)	mean weight diameter (MWD), geometric mean diameter (GMD),	soil properties
[85]	(Abbas et al., 2021b)	aggregate stability	soil properties
[95]	(Sawicka et al., 2021)	base saturation (BS), aluminum saturation (Alsat),	soil properties
[88]	(Liu et al., 2021)	mean weight diameter (MWD)	soil structure
[96]	(Ghosh et al., 2021)	mean weight diameter (MWD), geometric mean diameter (MWD), normalized soil stability index (NSSI)	soil erosion
[97]	(Mamedov et al., 2021)	modal suction (MS), soil VDP (area under a specific water capacity curve and above the soil shrinkage line)	soil structure
[98]	(Abbas et al., 2021a)	relative stability of soil aggregates (RSA)	soil structure
[99]	(Jiaguo et al., 2021)	slope class, aspect class, land use class	soil pollution
[86]	(Teixeira et al., 2021)	soil aggregate stability	soil structure
[100]	(Molaeinasab et al., 2021)	soil cover percentage, litter cover percentage, origin and degree of decomposition, cryptogam cover percentage, crust brokenness, soil erosion type and severity, deposited material, soil surface nature, slake test	soil properties
[42]	(Song et al., 2021)	soil resilience, soil resistance	soil structure
[101]	(Minhas et al., 2021)	structural index (ratio of volume of drainable pores to modal suction 'peak of water capacity curve')	soil hydrology
[44]	(Mirzaee et al., 2020)	baseline inter-rill soil sensitivity to erosion, slope factor, rainfall intensity, runoff rate, inter-rill sediment, detachment capacity, baseline rill soil sensitivity to erosion, flow shear stress, rill detachment threshold parameter or soil baseline critical shear stress	soil erosion
[43]	(Manolaki et al., 2020)	ecological sensitivity, cultural sensitivity (integrity and value), visual sensitivity	ecology
[102]	(Crawford et al., 2020)	mean weight diameter (MWD) of soil aggregates	soil biology
[103]	(Okolo et al., 2020)	mean weight diameter, % of soil organic matter, %silt, %clay	soil structure
[103]	(Okolo et al., 2020)	normalized channel steepness index (ksn)	remote sensing
[104]	(Brahim et al., 2020)	rainfall and runoff erosivity factor, slope length and steepness factor, soil erodibility factor, vegetation cover, management and cultural practices factor, conservation practice factor.	soil erosion
[105]	(Ran et al., 2020)	mean weight diameter (MWD), geometric mean diameter (GMD), fractal dimension (D)	soil restoration

Table 7. *Cont.*

Article		Parameters of Quantification of Soil and Landscape Stability/Sensitivity	Research Field
[106]	(Oliva et al., 2019)	aerial cover for rain interception, litter cover, origin and degree of incorporation, cryptogram cover, deposited materials, soil crust type and degree to which it was disturbed, surface crust resistance and slake test, time that soil aggregates retain integrity in water	ecology
[107]	(Dor et al., 2019)	aggregate durability index (ADI) based on changes in soil particle-size distribution	soil properties
[108]	(Durante et al., 2019)	Ca exch, Mg exch, K exch, Ptot and Ntot	ecology
[109]	(Karadag and Senik, 2019)	erosion sensitivity, landslide sensitivity, water infiltration sensitivity, habitat sensitivity	ecology
[110]	(Farazmand et al., 2019)	geology, soil texture, climate, runoff, topography, vegetation, land use, current erosion, gully erosion	ecology
[46]	(Llena et al., 2019)	index of sediment connectivity	geomorphology
[111]	(Sepehr et al., 2019)	mean weight diameter of aggregates (MWD), soil aggregate stability (SAS), clay dispersion index (CDI)	soil biology
[112]	(Riggert et al., 2019)	precompression stress and bulk density	soil degradation
[113]	(Chung et al., 2019)	soil aggregate stability	soil biology
[87]	(Young et al., 2019)	soil aggregate stability	soil structure
[114]	(Daniell et al., 2019)	soil cover percentage, litter cover percentage, origin and degree of decomposition, cryptogam cover percentage, crust brokenness, soil erosion type and severity, deposited material, soil surface nature, slake test	soil pollution
[93]	(Safaei et al., 2019)	soil organic carbon, % silt, % clay	soil structure
[115]	(Klopp et al., 2019)	soil swelling	soil structure
[116]	(Niewiadomska et al., 2018)	soil resistance under natural conditions over time (t0), resistance of soil subjected to pressure over time	ecology
[117]	(Molaeinasab et al., 2018)	soil cover percentage, litter cover percentage, origin and degree of decomposition, cryptogam cover percentage, crust brokenness, soil erosion type and severity, deposited material, soil surface nature, slake test	soil quality
[49]	(Lizaga et al., 2018)	Upslope and downslope component, average weighting factor of the upslope contributing area, average slope gradient of the upslope contributing area, upslope contributing area	land use change
[118]	(Merante et al., 2017)	clay content, soil organic carbon	soil management
[119]	(Cao, 2017)	landscape patch change	remote sensing
[120]	(Tamene et al., 2017)	rainfall erosivity, soil erodibility, 3D terrain representation, land use/cover, conservation/management factor.	soil erosion
[121]	(Ali et al., 2017)	soil aggregate stability, penetration resistance, soil shear vane strength	ecology
[122]	(Berendt et al., 2017)	soil texture	ecology
[123]	(Munoz et al., 2017)	water-stable aggregates	agriculture
[124]	(Read et al., 2016)	aerial cover for rain interception, litter cover, origin and degree of incorporation, cryptogram cover, deposited materials, soil crust type and degree to which it was disturbed, surface crust resistance and slake test, time that soil aggregates retain integrity in water	ecology
[78]	(Xuan et al., 2016)	instability patch area ratio, dispersion, uniformity, uniformity shape coefficient	ecology
[125]	(Geraei et al., 2016)	carbon pools in uncultivated and cultivated soils	land use change
[126]	(Mirmousavi, 2016)	soil erodibility index of the texture classes, wind condition, vegetation and land cover	soil erosion
[127]	(Bast et al., 2015)	mean weight diameter (MWD), aggregate stability coefficient (ASC)	soil structure
[128]	(Reid and Brierley, 2015)	river style, potential for adjustment	fluvial geomorphology
[56]	(Store et al., 2015)	scenic attractiveness or quality, visibility of landscape, the number and type of viewers	ecology

Table 7. *Cont.*

Article		Parameters of Quantification of Soil and Landscape Stability/Sensitivity	Research Field
[129]	(Reinhart et al., 2015)	soil aggregate stability	ecology
[130]	(Ladanyi et al., 2015)	soil moisture regimes, groundwater resources, biomass production of vegetation, levels of wind erosion hazard.	ecology
[79]	(Guo et al., 2015)	type of soil	ecology
[131]	(Safeeq et al., 2015)	watershed drainage area, principal component, regression coefficients a, b, c	fluvial geomorphology
[132]	(Pulido Moncada et al., 2014)	particle size distribution (%clay and % soil) and soil organic carbon	soil structure
[133]	(Fultz et al., 2013)	mean weight diameter (MWD)	agricolture
[58]	(Zhang et al., 2013)	rainfall erosivity, soil types, relief, vegetation coverage (%)	soil erosion
[134]	(Roy et al., 2012)	base cations to aluminum ratio, aluminum to calcium ratio, pH, and aluminum concentration	soil properties
[135]	(Munro et al., 2012)	rain splash protection, perennial vegetation cover, leaf litter, cryptogram cover, crust brokenness, soil erosion, deposited material, soil surface roughness, resistance to disturbance, slake test, soil texture	ecology
[136]	(Sharma et al., 2012)	soil depth, soil texture, surface texture, erosion, stoniness, slope, drainage, hydraulic conductivity	landslide
[137]	(Schacht et al., 2011)	buffering capacity for inorganic adsorbable pollutants, slaking of the upper soil layers, salinization, buffering capacity for boron, buffering capacity for non-adsorbable substances, soil surface area	agriculture
[138]	(Dexter et al., 2011)	clay dispersion from soil	soil structure
[139]	(Rozsa and Novak, 2011)	constants of climatic condition (Kc) and relief condition (Kr)	geomorphology
[140]	(Nichols and Toro, 2011)	soil aggregate stability	soil properties
[141]	(Bhardwaj et al., 2011)	soil aggregate stability	ecology
[80]	(DeJong et al., 2010)	undrained shear strength (Su), remolded undrained shear strength (Sur)	geotechnics
[91]	(Carpenter and Chong, 2010)	resistance of soil samples to slaking	soil biology
[142]	(Washington-Allen et al., 2010)	bands of Landsat MSS data, soil taxonomy	soil erosion
[143]	(Zink et al., 2010)	precompression stress	agriculture
[144]	(Du et al., 2010)	rate of dispersion of soil aggregates in water	soil erosion
[82]	(Chaudhary et al., 2009)	in-field aggregate stability test	soil biology
[83]	(Derbel et al., 2009)	rainsplash protection, perennial vegetation cover, leaf litter, cryptogram cover, crust brokenness, soil erosion, deposited material, soil surface roughness, resistance to disturbance, slake test, soil texture	ecology
[145]	(Pohl et al., 2009)	stability of soil aggregate	soil structure
[146]	(Whicker et al., 2008)	dust flux (HDF)	restoration
[147]	(Bayramin et al., 2008)	percentage of silt and sand, percentage organic matter, structure and permeability	soil erosion
[148]	(Czyz and Dexter, 2008)	readily dispersible clay	soil properties
[149]	(Bowker et al., 2008)	soil aggregate stability	soil erosion
[150]	(Belnap et al., 2007)	soil aggregate stability	soil biology
[151]	(Rezaei et al., 2006)	individual soil surface features comprising soil cover, litter cover, cryptogam cover, crust brokenness, erosion features, deposited material, microtopography, slake test, and soil surface texture	soil quality
[63]	(Kheir et al., 2006)	vegetal cover, drainage density, slopes maps	soil erosion
[90]	(Marquez et al., 2004)	mean weight diameter (MWD), water stable aggregates (WSA), stable aggregates (SAI), stable macroaggregates index	soil structure
[34]	(Orwin and Wardle, 2004)	resilience and resistance index	soil biology
[152]	(Bowker et al., 2004)	soil aggregate stability	soil biology
[153]	(Pernes-Debuyser and Tessier, 2004)	soil surface, aggregate stability, soil water dispersion index (DI)	soil treatment
[154]	(Koptsik et al., 2003)	soil acidity, cation exchange capacity (CEC), degree of base saturation, base content	soil properties
[64]	(Tao et al., 2002)	base saturation (BS), cation exchange capacity (CEC),	soil properties
[155]	(Herrick et al., 2002)	soil aggregate stability	ecology

Table 7. *Cont.*

Article		Parameters of Quantification of Soil and Landscape Stability/Sensitivity	Research Field
[156]	(Barlow and Nash, 2002)	soil water characteristics curves (between 0 and 3 kPa)	soil properties
[157]	(Gordon et al., 2002)	vegetation type and strength of the root mat, regolith cohesion and soil properties, topographic position, degree of exposure	ecology
[158]	(Herrick et al., 2001)	soil aggregate stability	soil structure
[33]	(Six et al., 2000)	aggregate distribution before and after disruption	soil structure
[159]	(Martínez-Mena et al., 1998)	aggregate stability RSSI	soil structure
[160]	(Hodson et al., 1998)	short-term acid buffering capacity	soil properties
[161]	(Dodds and Fey, 1998)	soil score, lithology score, land use score, rainfall score	soil properties
[162]	(Curtin et al., 1996)	pH	soil properties
[163]	(Hodgkinson and Thorburn, 1996)	total suspended clay and silt as a result of aggregate disruption by mechanical factors	agriculture
[164]	(Watts et al., 1996)	turbidity index, tensile strength index	soil structure
[165]	(Hornung et al., 1995)	base saturation and pH	soil properties
[37]	(Lal, 1993)	rates of new soil formation or soil restoration (Sst), which include organic matter, texture properties, soil biodiversity, and climate, vegetation; susceptibility of soil to degradation (Ssu) based of its parent material, climate, pedogenetic processes	soil properties
[84]	(Friedman and Zube, 1992)	land use	landscape dynamics
[166]	(Wace and Hignett, 1991)	dispersible clay content at 10Kpa	soil properties
[167]	(Gobran and Bosatta, 1988)	cation depletion	soil properties
[168]	(Levine and Ciolkosz, 1988)	pH, soil solution Al concentration	soil properties
[94]	(Lau and Mainwaring, 1985)	buffer capacity	soil properties
[169]	(Cass and Sumner, 1982)	water composition volume element which lies below the threshold concentration plane, total volume of the water composition element.	soil structure
[38]	(North, 1976)	energy dispersion	soil properties

4. Discussion

The aim of this study were as follows: to screen and identify current knowledge about sensitivity, stability and resistivity on a landscape scale through a systematic analysis of peer-review articles and fields of research that have had the greatest impact on the topic; to identify the different connotations associated with these terms in various scientific sectors; and to identify the most widely used parameters and methods of quantification.

The annual scientific productivity in these fields was shown to have been increasing exponentially since 1976 (Figure 2), highlighting growing interest due to the ever greater importance of environmental issues and sustainability.

Our bibliometric analysis identified the most productive and influential authors in terms of numbers of publications: J. Belnap and Matthew A. Bowker, with five articles, followed by Hossein Bashari, Gary J. Brierley and Anthony R. Dexter, with three. Each of these authors studied soil and landscape stability/sensitivity from a distinct perspective. Jayne Belnap and Matthew A. Bowker, who co-authored some articles, focused their studies on soil biology and stability. Hossein Bashari focused on assessments of soil quality indicators, while Gary J. Brierley studied fluvial geomorphology and Anthony R. Dexter studied soil properties. Thus, different research fields are involved which are not always connected with each other.

Although these were the most productive authors, the articles that have received the greatest success in terms of citations are attributed to other authors. In particular, 'Brunsden and Thornes, 1979' is the most globally and locally cited paper. Moreover, it was the first to provide a definition and a method of quantification of landscape sensitivity in the context of geomorphology. 'Six et al., 2000', the second most cited research paper, focused on soil aggregate distribution, which has since received great interest, as it is one of the most widely used methods to assess soil and landscape stability (Table 7). In third position concerning citations is 'Orwin et al., 2004', who proposed a new method to quantify the stability of soil biota to exogenous disturbance based on the resistance and resilience indexes. As highlighted above, this bibliometric analysis was multidisciplinary, and hence, involved the work of authors whose specializations cover a range of sectors, from ecology to assessments of soil properties.

Our analysis of productivity, as illustrated in Figure 4, indicated that the majority of authors have published only one article (91.4%). Only 7% of authors have published two articles, and less than 1% have published three or more. This indicates that only a few authors deal with the topic over long periods of time, and suggests that most authors are not specialized in this topic, but rather, encounter it from time to time in respective specific fields of research. One advantage of this is that when many authors from different fields deal with a topic, completely independent and new ideas can arise; however, it also has the disadvantage that less long-term experience is obtained.

Analyzing the productivities of different countries, a broad contribution of different countries and continents was observed. This shows that this topic is of great interest around the world, albeit with a slight prevalence of the United States and Europe. It is interesting to note that the two most productive countries were also those with the highest number of citations per article (Table 3), indicating not only a high quantity but also quality of their scientific contributions. In contrast, other countries characterized by a high number of articles had comparatively few citations per article (e.g., China, with, on average, 1235% fewer citations than the United States and United Kingdom). Nonetheless, since most of these papers were published in esteemed journals such as Catena, Geoderma, Science of the Total Environment, Pedosphere, Environmental Earth Science, Ecological Engineering, Environmental Science and Pollution Research and Journal of Soil Science and Plant Nutrition, the determining factor for the lack of citations cannot be the quality of the articles; rather, it may be explained by the fact that eleven of the fourteen articles were published in the last two years, and thus, have not have enough time to receive large numbers of citations. This also indicates that interest in this subject in China has increased exponentially over the past two years.

Our analysis showed that the journal Catena has published the most papers on the topic, with sixteen articles (including the special issue on ‘landscape sensitivity’), followed by Science of the total Environment, with eight, and Geomorphology, with seven. However, these journals tackle slightly different research fields. Catena is mainly focused on geoecology and landscape evolution, evaluating interdisciplinary aspects of soil science, hydrology and geomorphology. Science of the Total Environment is focused on research concerning the total environment, which interfaces the atmosphere, lithosphere, hydrosphere, biosphere and anthroposphere. Finally, Geomorphology publishes research on a broad range of geomorphological issues.

Our co-citation analysis discovered three main clusters, of which the main topics are (i) the macro-area of geomorphology, (ii) fluvial geomorphology and sediment connectivity, and (iii) the structure and stability of soil. The first two clusters were found to be closely connected. These three main clusters of co-cited papers do not adequately represent all the research fields in which the topic is addressed. In fact, the research field of ecology is missing, which points to the fact that there are not many pairs of articles in the ecological field that are cited in turn by a third article present in the database.

Author collaborations showed many small clusters, suggesting that such collaborations are limited in number and extent. This also indicates an absence of large research groups involving many research institutions from the same or different countries. However, all the main research fields were well represented. In fact, clusters were found regarding the study of various topics like soil stability, soil biology, soil structure, ecology, geomorphology, soil properties, etc.

Our analysis of keyword co-occurrences highlighted a cluster related to soil stability and keywords such as soil, soil aggregates, soil organic matter and biogeochemistry; these terms encompass different aspects of soil stability quantification (Table 7). A cluster of sensitivity analysis was associated with keywords like soil pollution, climate change, acidification, ecosystem and agriculture. Finally, a third cluster was found dealing with soil erosion related to sediment transport, land use, soil aggregates, soil stability and soil structure.

Our assessment of the term "soil and landscape sensitivity" showed 34 connotations in the various articles. The first was associated with Brunsden and Thornes, 1979. In subsequent publications, it was not possible to identify evolution of the definition, although later definitions were associated with different research fields. As evidenced by many articles, depending on the response, the sensitivity of a system can be defined based on its resistance or resilience. Resistance or robustness means the ability of a system to withstand a disturbance, while resilience indicates both the ability to prevent and/or to return the pre-perturbative state in response to a disturbance.

Regarding soil and landscape stability, only 18 definitions were identified, with most referring to resistance and resilience [34,71,77]. This indicates that there is no clear definition of stability, and that it is often used synonymously with sensitivity. However, other connotations of "stability" were observed in relation to specific research fields; some were based on the stability of soil [79,81,82], while others were based on the stability of landscapes, notably in reference to changes in land use [73]. Probably, the absence of a clear definition is due to the fact that "stability" may refer to any of the various properties of soils or landscapes, while "sensitivity" does not change depending on the field of study.

A total of 104 papers were identified in which parameters were proposed to quantify stability and/or sensitivity. Forty research articles proposed the use of soil properties for quantification, mainly focusing on assessments of aggregate stability using different methods. Aggregate stability is a soil property that is easily measurable in the field or laboratory. It is a low-cost technique that is highly reproducible, as documented for different environments and soil typologies. In contrast, in ecology, stability and sensitivity are quantified in different ways, ranging from the chemical soil characteristics (cation exchange capacity, content of elements) [107] to soil properties [79,120,121,128] or landscape properties [105,109,123,134] and even subjective characteristics, such as culture, scenic attractiveness and visibility [43,56]. Sensitivity to soil erosion is quantified in different ways; traditional methods use empirical modelling approaches, such as the Revised Universal Soil Loss Equation (RUSLE) to obtain a map of sensitivity to erosion [103,119], or take into account soil properties [146] such as aggregate stability [143,148] or landscape topography and vegetation. Finally, data coming from remote sensing, such as multi-spectral data, are also used to identify stable areas [141].

Generally, it can be stated that the terms "stability" and "sensitivity" are used in a lot of different research fields, and as such, there are no unique definitions or generally accepted methods to assess them. Often, specific indicator properties are used that vary according to the landscape that is being analyzed.

5. Conclusions

A bibliometric analysis was carried out based on peer-reviewed literature obtained from the Web of Science and Scopus bibliographic databases using landscape stability, sensitivity and resistivity as keywords for research fields such as geoscience, geomorphology, soils and agriculture.

The concluding remarks are as follows:

- Our analysis of publication trends shows that the number of relevant, peer-reviewed papers is undergoing exponential growth, with some fluctuations due to, for example, the publication of the special issue of Catena in 2001 on 'landscape sensitivity'.
- Research on landscape stability, sensitivity and resistivity is widespread globally and is particularly prevalent in the USA and the UK. Authors from these countries were among the first to study the aforementioned topics, while China, which was in third place, has started to study them in recent decades, and as such, still has fewer papers and citations.

- The most popular definition of "landscape sensitivity" was established by Brunsden and Thornes (1979). Those authors applied the term to geomorphological environments. It did not undergo substantial evolution over time. In fact, theirs remains the most widely used definition.
- There is not a clear definition of "landscape stability", and it is often synonymous with "sensitivity".
- A large number of methods were identified for the assessment of soil and landscape stability and sensitivity; however, it was not possible to identify a universal method due to the specific characteristics of each study area and the individual focus of each paper. Quantification methods variously encompass analyses of individual soil physical and chemical properties (i.e., aggregate stability, cation exchange capacity, etc.), of intangible properties (culture, scenic attractiveness and visibility) and of land use change, susceptibility to erosion, etc.
- Quantifications of stability and sensitivity have been carried out in very different landscapes and contexts, ranging from arid and semi-arid environments to agricultural fields, but also fluvial systems, coastal environments, mountain catchments, forests, highland ecosystems and rangelands. Moreover, different spatial scales are covered from very small areas to entire countries.

As demonstrated by Donthu (2021) [170], bibliometric analyses have several limitations, such as errors in bibliographic databases which must be manually corrected. Bibliometric qualitative assertions may be subjective; this is in contrast with the nature of bibliometric analyses, which must be quantitative. Finally, bibliometric studies provide only a short-term overview of a given field of research.

Generally, this study revealed that there is limited collaboration between authors. As such, we stress the necessity to establish international and interdisciplinary research groups to more clearly define the terms landscape stability and sensitivity. The results also indicated a lack of coordination in international interdisciplinary research regarding methods that could be used to assess the terms landscape stability and/or sensitivity. Finally, our study revealed a general need for long-term studies, and hence, the creation of steady research groups that might benefit from long-term experience in this setting.

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