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# Soil legacy data: An opportunity for digital soil mapping

**Beatriz Macêdo Medeiros[(1,2)*], Letícia Sequinatto Rossi[(1)], Alexandre ten Caten[(3)], Gustavo Eduardo Pereira[(3)], Elisângela Benedet da Silva[(4)] and Kelly Tamires Urbano Daboit[(1)]**

[(1)] Universidade do Estado de Santa Catarina, Departamento de Solos e Recursos Naturais, Programa de Pós-Graduação em Ciência do Solo, Lages, Santa Catarina, Brasil.
[(2)] Universidade Federal de Lavras, Departamento de Ciência do Solo, Programa de Pós-Graduação em Ciência do Solo, Lavras, Minas Gerais, Brasil.
[(3)] Universidade Federal de Santa Catarina, Departamento de Agricultura, Biodiversidade e Floresta, Programa de Pós-Graduação em Ecossistemas Agrícolas e Naturais, Curitibanos, Santa Catarina, Brasil.
[(4)] Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina, Centro de Informações de Recursos Ambientais e de Hidrometeorologia de Santa Catarina, Florianópolis, Santa Catarina, Brasil.

**ABSTRACT:** Soil legacy data is past information on soils available from various sources (e.g. survey reports and maps). When compiled and organized, data obtained through historical retrieval can be used as basic input or validation data for digital soil mapping. A bibliometric analysis of this topic can reveal research patterns, evolution, and scientific contribution, thus mapping the science produced in a specific period and determining the trend in research topics based on search terms. This article presents the characterization of international scientific production on soil legacy data using a set of bibliometric indicators. The study was developed with the bibliometric analysis of scientific articles indexed in the Web of Science and Scopus data platforms regarding the use of soil legacy data published online from 1979 to 2022. The following were extracted from the articles: authors and co-authors, year and country of publication, index words used, and abstracts, which were submitted to bibliometric analysis in R. Bibliometric analysis revealed publication of 242 scientific articles in 117 journals involving 1223 authors throughout the world in the last 43 years, with an average frequency of 12.66 citations per article. Australia (10.33 %), the USA (8.68 %), and Brazil (7.85 %) were the countries with the greatest scientific contributions. The most cited studies refer to databases, demonstrating the ease of access to information contributes significantly to new local studies. Due to pedometrics importance for soil science, there is constant revision to available legacy data for new hypotheses and research in soil science. And also, for the monitoring of soil attributes for the conservation and preservation of natural resources.

**Keywords:** bibliometric analysis, pedometrics, scientometrics, soil survey.

*** Corresponding author:**
E-mail: bemacedom@gmail.com

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## INTRODUCTION

Soil legacy data are products of traditional soil surveys and consist of information available on soils, such as maps and profiles (Odeh et al., 2012; Sarmento et al., 2017; Hendriks et al., 2019). Over the years, countless institutions have produced such data using different methods, standards, scales, and taxonomic classification systems (Arrouays et al., 2017a), ranging from local approaches to national databases (Filippi et al., 2016). These soil legacy data provide valuable information about soil properties, classifications, and spatial distribution (Lucà et al., 2018).

Soil legacy data is defined by Filippi et al. (2016) as any existing observations that can be used to detect or assist in the verification of spatiotemporal soil properties variations. Soil legacy data consists of forgotten information collected using traditional technology at the time, without detailed, refined documentation, and may be difficult to process using current technological methods (Omuto et al., 2013). Moreover, they serve as a foundation for building predictive models and generating soil survey maps (Kimsey et al., 2020).

In recent years, efforts have been made to store information on a digital platform (e.g., databases and digital maps) (Shangguan et al., 2014; Arrouays et al., 2017a; Samuel-Rosa et al., 2020). Several organizations have been storing, coding, and harmonizing information from legacy soil data on a regional to global scale (Omuto et al., 2013). About 6 million legacy pedon data are estimated globally (Arrouays et al., 2017a; ISRIC, 2023). In addition to the intrinsic value in the use of these data, such data can produce new information (Sarmento et al., 2017).

Legacy data use in digital soil mapping presents several challenges. Uneven distribution of samples, limited resolution, inadequate soil complexity expression, incorporation of legacy soil maps into digital soil mapping workflows, data extraction, and the process of disaggregating soil maps are some of the limitations cited in the literature (Carré et al., 2007; Sanchez et al., 2009; Mayr et al., 2010; Nussbaum et al., 2018). However, reusing this information along with auxiliary data is promising in digital soil mapping on the intermediate scale, especially in environments with little data or limited resources for new surveys (Hendriks et al., 2019).

With regard to the first efforts made to reuse soil legacy data, it is worth highlighting the generic structures for soil mapping proposed by McBratney (2003), Chagas et al. (2004) and Sanchez et al. (2009). Several digital platforms have been developed to make this data globally accessible, such as GlobalSoilMap (Arrouays et al., 2017c), SoilGrids (Hengl et al., 2014, 2017), Brazilian Soil Spectral Library (Demattê et al., 2019) and SoilData MapBiomas (2023). This has been possible due to greater efficiency and technological advances, coupled with increased popularity due to easier access to the necessary tools. In recent years, several articles have used soil legacy data, most notably the study by Smit et al. (2023), which proposes a downscaling approach for reproducibility of soil legacy data that contains its spatial distribution to obtain more accurate soil mapping. Delcourt et al. (2023) applied the methodology of bibliometric analysis to explore the evolution and strategic orientation of research into the temporal dynamics of land-use, highlighting the need to consider the effect of soil legacy data in the context of climate change on a regional and global scale.

A methodology that establishes an intersystemic framework for digital soil mapping was developed by Yang et al. (2022), allowing the conversion and application of legacy data into a new classification system. This standardization considerably facilitates the reuse of soil legacy data, since much of this information was generated from different versions of soil classification systems. When information on soil legacy data is lacking, Vasconcelos et al. (2023) developed a method for mapping soil classes at the second categorical level (suborder) by joining different sources of soil legacy data and environmental covariates.

Studies that emphasizing the impact and the principle of international publications related to the application of legacy data are scarce. When comparing soil science scientific production of main authors, their respective countries and the national and global research characteristics can be identified, in addition to enabling the prediction of future scenarios (Cancian et al., 2018).

This article aims to characterize international scientific production on soil legacy data by applying a set of bibliometric indicators. Primary goals of this study were: 1) to assess the global evolution and contribution of the use of soil legacy data in the published scientific research; 2) to identify key research groups and institutions, along with their collaborative efforts; and 3) to identify the primary research fields and comprehend their evolutionary trajectory over time.

## MATERIALS AND METHODS

This study was developed through the bibliometric analysis of scientific articles on the use of soil legacy data published online, as shown in the methodological flowchart (Figure 1). Terms were searched from 1979 to December 2022 and needed to be present in the title, abstract, or keywords. The research was refined in terms of type of document, considering only articles published in scientific journals. Authors, year, country of publication, index words, and abstracts of the articles were analyzed. Articles were retrieved from the Scopus and Web of Science databases, in which all records of the production of scientific articles were evaluated through consultation in fields related to agricultural sciences.

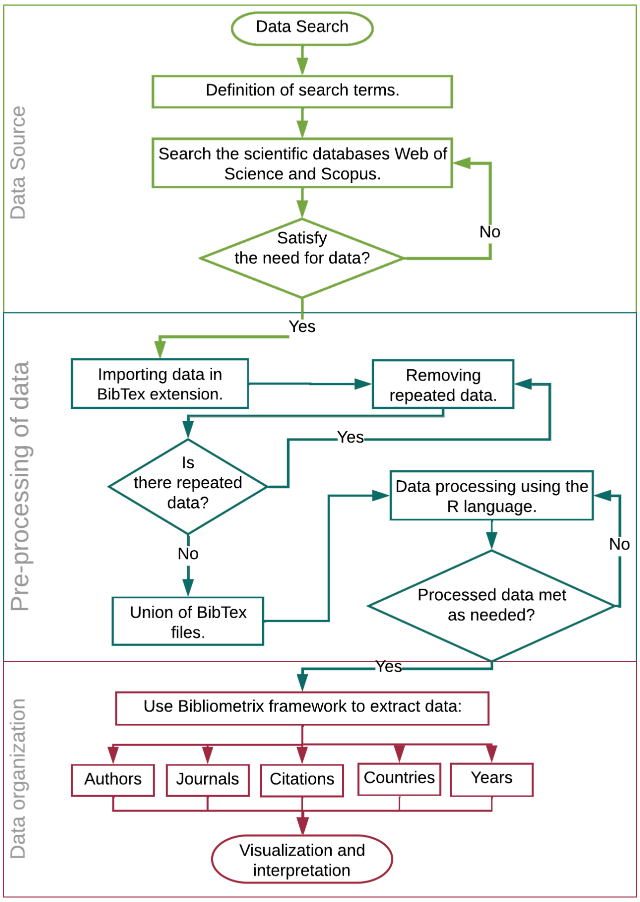


**Figure 1.** Methodological flowchart of the study. Steps performed in gray, and all processes necessary to obtain the results are in black. Convex rectangles correspond to the beginning and end of the methods. Rectangles describe the processes, and diamonds correspond to the decision process.

Keyword definitions were based on reading the most relevant scientific articles in the field of Soil Science, so that most of the articles of interest were included, with some terms similar to “soil legacy data” being used as synonyms. The keywords used in the search were: “soil legacy data”, “legacy soil data”, “legacy soil map”, “soil legacy” AND map, “legacy soil” AND map, “legacy soil”, “soil data recovery”, “legacy soil profile data”, “existing soil data”. All search terms included the word “soil” and “legacy” as well as the term “data” and its variations: “database” and “datum”. The term “map” and its variation “mapping” were also used as search terms to refine the search for works related to soil mapping.

Search results were exported to a BibTeX file, covering all information in the articles. As the possibility of duplicated articles is greater when using two databases, merging the data and excluding repeated files is necessary. Data were processed in the R language through the RStudio integrated development environment (Rstudio Team, 2020) and using the Bibliometrix Comprehensive Science Mapping Analysis framework (Aria and Cuccurullo, 2017), which enables a joint analysis of the data.

The units of analysis were authors, journal, country, year, paper, and citations. Data analysis was based on bibliometric laws and principles to characterize the current state of research carried out on soil legacy data. The principles used to analyze the bibliometric data were Lotka’s Law (Lotka, 1926) and Zipf’s Law (Zipf, 1970). Lotka’s Law was used to analyze the most prestigious research authors, as they produced many studies compared to lesser-known researchers who produced little. Zipf’s Laws were used to analyze the content of the keywords, whereby if the words are repeated in several documents, it means that the concepts are related to them.

A map of the co-occurrence of terms was created to complement the interpretation of the metadata. Kinship analysis of the research topics was established according to the frequency by which the terms occur, which is widely employed in scientometrics to investigate conceptual structures in research fields (Mora-Valentín et al., 2018). This analysis was performed using the VOSviewer open-source software (van Eck and Waltman, 2009). From the metadata, a co-occurrence map of terms was created based on distance, in which the terms retrieved from the titles and abstracts were grouped and mapped according to the kinship of a similarity matrix to obtain data-based information on how keywords relate to conceptual structures in the present study. Five minimum occurrences were defined as a threshold to include terms in the analysis. Among the 965 keywords cited in the articles, 15 reached the threshold and were selected based on the relevance score calculated by the software. This relevance score is used for filtering terms that inform most, such that these terms best represent specific topics (van Eck and Waltman, 2009).

## RESULTS AND DISCUSSION

### Soil Legacy Data worldwide

In the global scenario, a total of 966 articles were retrieved: 541 from Scopus and 425 from Web of Science. Excluding repeated files, 242 publications were analyzed from 117 periodical journals, with 1223 authors and an average of 12.66 citations per article. Figure 2 shows the spatial distribution of article publications in different countries in the period studied, which can be used to identify countries that use legacy data in their published articles.

Most studies were concentrated in Australia, the United States of America (USA), Brazil, China, and Germany. These are countries with a large territorial extension, a great diversity of soils, and a high local demand for agricultural production (NLWRA, 2002; Boddey et al., 2003; Guo et al., 2003; ELD, 2015; Kassam et al., 2015; Techen and Helming, 2017).

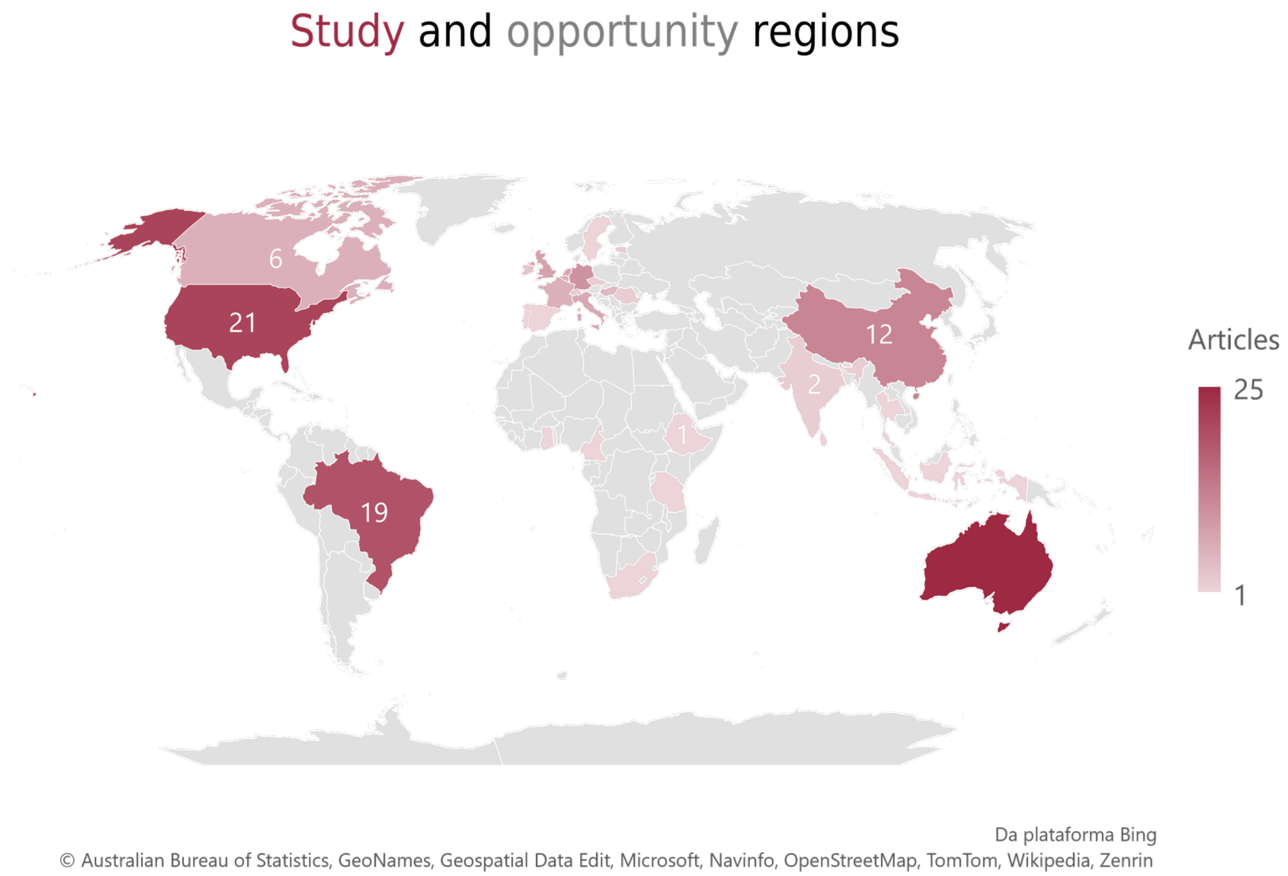


**Figure 2.** Geographical distribution of the absolute number of articles published by country.

Therefore, they have a great interest in natural resource availability and are developing scientific research and innovation. Countries with more researchers may naturally have more soil legacy data studies due to increased research activity. Factors such as research investment, infrastructure, and institutional support also play pivotal roles in influencing the actual extent of data reuse.

Legacy soil data availability in a country facilitates subsequent research, enabling the use of this data in other studies and increasing collaboration between soil scientists (Cambule et al., 2015; Hengl et al., 2015; Hounkpatin et al., 2022), as it can reduce the need for extensive new data collection (Hendriks et al., 2019). In a previous study characterizing scientific production on digital soil mapping (DSM), Cancian et al. (2018) found that the number of papers was increasing at an accelerated pace, with the most significant contributions also coming from Australia, the USA, China, Germany, and Brazil.

The information presented in figure 2 is confirmed by looking at the ten countries that published articles listed in table 1. Australia has the largest number of articles published using legacy data and the largest total number of citations (686). Australia leads in the number of publications and total citations, with several studies developed by researchers at University of Sydney (USYD), a fact observed in this analysis of the most productive authors who published articles of this type. The authors A. McBratney, B. Minasny, I. Odeh, from the same USYD university, together with P. Lagacherie (French National Institute for Agriculture, Food, and Environment - INRAE), form a large team of qualified professors and researchers who join forces in the development of new techniques in the field of digital soil mapping (Cancian et al., 2018) and are also authors of reference books on pedometric studies. This reveals partnerships between institutions and research groups, strengthening the groups and putting researchers in a prominent position in publications.

**Table 1.** Comparison of the ten countries that most publish scientific articles on soil legacy data reuse organized by number and percentage of articles, total citations, and average citations

| Rank | Countries | Articles | % Articles | Total citations | Average article citations |
|---|---|---|---|---|---|
| 1 | Australia | 25 | 10.33 | 686 | 26.38 |
| 2 | United States of America (USA) | 21 | 8.68 | 275 | 12.50 |
| 3 | Brazil | 19 | 7.85 | 199 | 9.95 |
| 4 | China | 12 | 4.96 | 180 | 13.85 |
| 5 | Germany | 10 | 4.13 | 63 | 6.30 |
| 6 | United Kingdom | 8 | 3.31 | 113 | 14.12 |
| 7 | Italy | 7 | 2.89 | 184 | 26.29 |
| 8 | Netherlands | 7 | 2.89 | 329 | 47.00 |
| 9 | Belgium | 6 | 2.48 | 22 | 3.67 |
| 10 | Canada | 6 | 2.48 | 224 | 28.00 |

The USA is ranked second based on the number of articles published, with 21 topic-related studies, but third place in the total number of citations, behind the Netherlands in second place. Regarding the number of citations and comparisons to other countries, American researchers were cited 275 times, with an average of 12.50 citations. Researchers from the USA were highly cited and had the third-highest total number of citations (Table 1). Justifying this fact, the National Cooperative Soil Survey (NCSS), which is a research organization of the USDA Soil Conservation Service (United States Department of Agriculture), developed a data record of computerized soil information in 1975 (United States Department of Agriculture, Natural Resources Conservation Service, 2017). Six years after such an initiative (1981), researchers used the Database Management System (DBMS technology) (Shofiyati et al., 2011). In the 1990s, initiatives were also implemented in the database for georeferencing such data as a stage of a national Geographic Information System of the soil (Hartung et al., 1991).

Moreover, the USA is one of the countries most cited for using the National Soil Information System (NASIS software), which provides soil data that researchers from different parts of the country use as input data for their studies. The NASIS software was released throughout the country with a manual containing all guidelines for using the software – the National Soil Survey Handbook of 2017, with several editions published over time based on software updates.

Although studies conducted by researchers from the Netherlands are widely cited, the number of articles published is smaller compared to the other countries analyzed. Regarding other countries beyond where the research in pedometrics is most often conducted, Germany, Italy, Belgium, France, and Netherlands are on the European continent and have a significant number of studies. This is due to the strong efforts by the official European working group on Digital Soil Mapping founded by the European Union. European Soil Bureau Network (ESBN) was created in 1989, formalizing existing contributions among soil surveys initiated in 1959 by the Food and Agriculture Organization (FAO) (Montanarella et al., 2005). The ESBN provides information on the fully harmonized geographical database on a nominal scale of 1:1,000,000 free of charge, denominated European Soil Data Center (ESDAC) (Panagos et al., 2012).

In studies carried out by Dutch authors, most are professors at the University of Wageningen and are part of the team of researchers at the International Soil Reference and Information Center (ISRIC), working on the retrieval of information on world soils. The ISRIC is an independent scientific foundation founded in 1966 whose mission is to serve the international community with information on the world's soil resources to help solve global problems. After decades of scientific contributions to soil research, ISRIC has evolved from the International Soil Museum to a global reference and soil information center (Sombroek, 1980; Batjes, 2009).

African continent has few studies on the subject compared to the countries with the fewest articles. However, the continent has a huge database to help fill the information gap on soil (Hengl et al., 2015). This constitutes a valuable opportunity for studies to fill scientific gaps. The use of soil legacy data for mapping can increase the detail of existing soil maps with few resources and it is particularly important for southern Africa, where resource allocation to new soil surveys is limited (Flynn et al., 2020). In sub-Saharan African countries, such as Benin, mapping from soil legacy data can provide important information to managers; policies can advocate for its use in agriculture and promote sustainable management practices (Hounkpatin et al., 2022).

## Soil legacy data in Brazil

In comparison to the other countries that carry out studies with soil legacy data, Brazil is in the third position regarding the number of articles. Despite the increasing number of publications on the subject, the country has a low average citation rate (8.82). This outcome may be attributed to an "language limitation", as Portuguese-written papers barred the international community to cite national research during the last decade. This dominance of English can create barriers for non-native English speakers, who may struggle to access and understand scientific literature written in English (Keller, 1966; Moore, 2013). Futhermore, the emphasis on English can lead to a preoccupation with style over substance in soil Science literature, as well as the bypassing of relevant old literature and the exaggeration of research achievements (Baveye, 2020). For greater visibility, national scientific journals are migrating from accepting articles in Portuguese to articles written exclusively in English (Gimenez et al., 2015; Viégas, 2018). Oliveira et al. (2017) analyzed Crop Science journals and found that about 38 % only accept papers in English and that about 40 % of journals jointly accept English, Portuguese, and Spanish, demonstrating the growing interest of journals being published in the English language to obtain international visibility.

A large amount of soil legacy data has been produced in Brazil, but the geospatial quality of soil legacy data has its inconsistencies, which underscores a crucial need for feedback from soil survey experts to improve the quality of geospatial data (Samuel-Rosa et al., 2020). The *Empresa Brasileira de Pesquisa Agropecuária* (EMBRAPA [Brazilian Company of Farming Research]) made available an open-access soil database denominated the Brazilian Soil Information System. This database has a set of nine thousand profiles of Brazilian soils (research on the topic began in the 1980s) (Oliveira and Zurmely, 2014) and its purpose is to store detailed data on this natural resource, gathering information from soil profiles, fertility analyzes, and maps of soils collected and analyzed from all regions of the country.

*Instituto Brasileiro de Geografia e Estatística* (IBGE [Brazilian Institute of Geography and Statistics]) also contributes significantly to the processes of compiling, organizing, and distributing soil data. The IBGE periodically updates the taxonomic classification of soils and adds data from new profiles to update and refine the scale of the soil maps (Polidoro et al., 2016). With the support of several institutions, including IBGE, Embrapa has developed *PronaSolos*, whose objective is to resume the conduction of multi-scale pedological surveys throughout the country as well as to establish an integrated, systematized database for public consultation (Polidoro et al., 2016). Moreover, the Soil Data Mapbiomas [Free Brazilian Repository for Open Soil Data] is available nationwide and was created to serve as a means for the compilation, organization, and publication of all types of soil data in Brazil, with an open data policy, thereby facilitating access, maintenance, and use (Mapbiomas, 2023). The Brazilian Soil Spectral Library (BSSL) was developed from legacy databases of physical samples and currently contains more than 50,000 soil samples in all 26 Brazilian states (Demattê et al., 2019).

For the entire country, generating up-to-date soil information requires managing a large volume of data that must be organized and available for easy access. However, considering the number of soil legacy data available for use and the national territorial extension, there are still large areas to be filled. It is estimated that most soil legacy data is scattered in institutional repositories with restricted access to personal computers or analog media (Samuel-Rosa and Vasques, 2017).

Availability and utilization of soil legacy data are crucial for developing national soil science studies. Sulaeman et al. (2013) emphasize the importance of preparing and managing legacy data for digital soil mapping. Hendriks et al. (2019) suggest combining legacy data with a new collection. Odeh et al. (2012) and Pásztor et al. (2014) further underscore the significance of legacy data in digital soil mapping, with the latter proposing its application in elaborating countrywide soil condition maps.

Despite the country being in a prominent position in terms of the number of articles published, no Brazilian researcher was in the most cited position in this bibliometric analysis. We hypothesized that this was due to research investment. The USYD has investment programs in precision agriculture and soil mapping, and consequently, research in these areas is well-advanced and considered a worldwide reference. Not only this institution, but also The Commonwealth Scientific and Industrial Research Organization (CSIRO) and The Australian Government itself.

We hypothesized that the same is not true in Brazil. Investments made by Australian research institutions are not comparable to those made by national institutions such as Brazilian National Council for Scientific and Technological Development (CNPq), Coordination of Superior Level Staff Improvement (CAPES) and EMBRAPA. Retrospective evaluations have demonstrated soil information holds value beyond the initial investment required for its production (Grundy et al., 2012, 2020).

## Research networks

Due to the considerable availability of soil legacy databases internationally (Montanarella et al., 2005; Sanchez et al., 2009; Panagos et al., 2012; Hengl et al., 2015), the number of studies that use these data is expected to increase over time. Figure 3 shows an increasing trend in studies that have used legacy data over the years, demonstrating the strong interest of researchers in reusing previously collected data for different purposes. The period from 2014 to 2016 witnessed noteworthy scientific progress attributed to the initiatives of the GlobalSoilMap.net project in various countries, including Australia, the USA, Scotland, South Korea, Indonesia, Denmark, Canada, Nigeria, France, Tunisia, and Mexico (Arrouays et al., 2017a). Additionally, 2015 was designated as the International Year of Soil (SBCS, 2015).

Published articles increased more than twice from 2013 to 2014, with the largest number of in 2017. This increase may have been due to the need to map large areas, and for this, soil legacy data is necessary to start such mapping (Arrouays et al., 2017a). Faced with this need, there has been a worldwide collaborative effort to compile this soil legacy data.

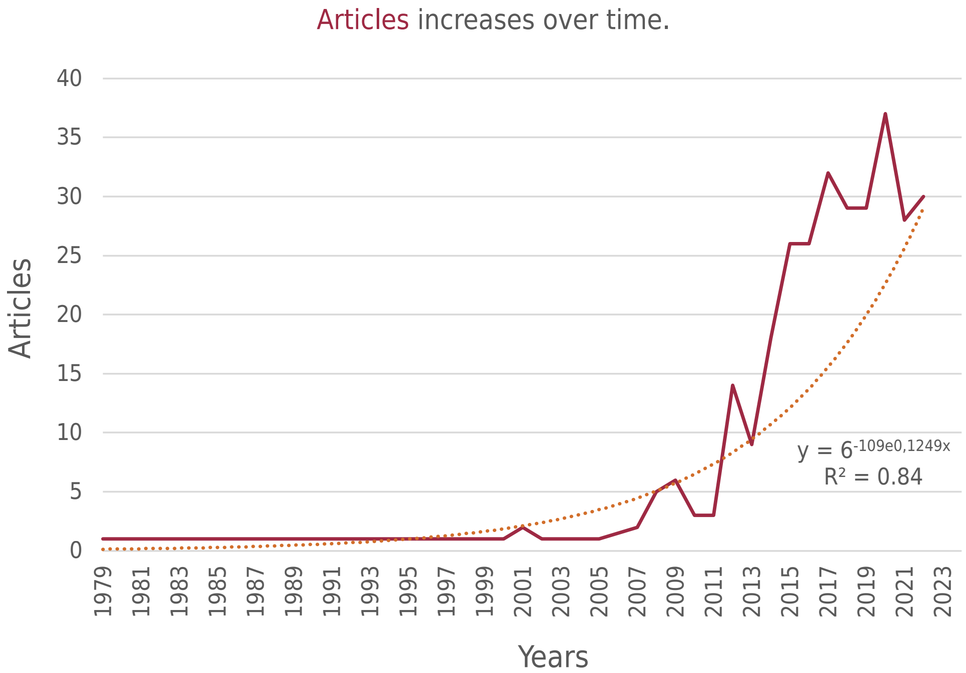


**Figure 3.** Trend in the number of annual scientific publications referring to the use of soil legacy data from 1979 to 2022 worldwide.

Examining data from the past decade reveals an 867 % growth rate in studies utilizing legacy data, coinciding with the United Nations' designation of this period as the International Decade of Soil. Cancian et al. (2018) found that the use of soil legacy data was explored or suggested as input data for digital soil mapping in about 80 studies.

A strong growth in world research on soil spectroradiometry and geostatistics happened between 2007 and 2017 (Santos et al., 2019). Moreover, the development of computing science technology and technological advancements facilitated the creation of a strong network relationship between countries that research the topics (Santos et al., 2019). These results agree with the present study's findings and reveal a wide range of possibilities for studies in the fields of pedometrics and digital soil mapping.

The DSM can use two types of data: soil profile points and soil layer points. Both can be used to produce continuous and polygon maps. The DSM consists of the spatial representation of elevation values, so the quality of the input data strongly influences the accuracy of digital maps. Soil legacy data can significantly improve the quality of DSM (Yang et al., 2022).

Due to the growing number of studies on digital soil mapping, it is necessary to summarize and discuss the important characteristics for mapping different soil classes in Brazil to provide a perspective for future studies (ten Caten, et al., 2012). It is also necessary to analyze the factors used to improve the digital mapping prediction accuracy.

The three most cited articles describe the creation of a world soil database, with the publication of world soil databases and updates of the soil map, in which collaborative work of main professionals and institutions around the world are integrated (Batjes, 2009; Kempen et al., 2009; Shangguan et al., 2014). This justifies the greater citation number, as the authors used these databases in their studies as validation data, which is an object of study for determining other parameters.

Among the articles analyzed, the most cited was "Harmonized soil profile data for applications at global and continental scales: updates to the WISE database" conducted by ISRIC researcher Batjes, referenced in 128 publications and published in Soil Use and Management in 2009, who aimed to update a new version of the World Inventory of Soil Emission Potentials (ISRIC-WISE database) and has collaborated with numerous institutions and individuals worldwide. The database was initiated in 1991 to provide the international community with information on the world's soils, covering 149 countries with more than 10250 soil profiles (Batjes, 2009). China was the country that obtained fourth position in the ranking of countries that most published studies using soil legacy data and had the second most cited article among those analyzed, entitled "A global soil data set for Earth system modeling", published in 2014 by Shangguan and collaborators in the Journal of Advances in Modeling Earth Systems, obtaining 127 scientific mentions. The authors Kempen, Brus, Heuvelink and Stoorvogel published an article in the scientific journal Geoderma in 2009 entitled "Updating the 1:50000 Dutch soil map using legacy soil data: logistic regression approach" and obtained 119 scientific mentions. The study aimed to update the national soil map of the 1990s of the Dutch province Drenthe without additional fieldwork, exclusively through digital soil mapping using legacy data.

"Methods to characterize soil resource variability in space and time" was the first article published using soil legacy data found in searches with certain keywords and was published by the author Bouma (1995), who stated that it is necessary to reanalyze methods for collecting and interpreting soil information for the proper management of land-use. In the 1990s, the author found a shortage of directly measured basic data to feed simulation models. Derivation of pedotransfer functions that relate existing data to unavailable data was proposed to circumvent such a situation. Interestingly, the author refers to the use of soil legacy data and does not use the term "legacy soil data", but "soil data".

The easy access of soil legacy data information greatly contributes to new local studies, which are widely used mainly for studies in the field of pedometrics, serving as a basis for studies in agricultural sciences (Greiner et al., 2018), in the agricultural aptitude of crops (Chakraborty et al., 2020; Hounkpatin et al., 2022; Miti et al., 2023), climatic and agro-ecological zoning (Castro-Franco et al., 2018), etc. Legacy data can also be applied as an alternative method for the lack of information on soils without the need to redo pedological surveys (Sarmento et al., 2014). Hendriks et al. (2019) suggest the use of legacy data to assist in the survey of new data. Thus, the data complement and present a complete work in many fields of knowledge.

In the present bibliometric search using only the term "soil legacy data" and its variations, it was observed that several authors also use "soil data" as a synonym. Hendriks et al. (2019) conducted a literature review on using soil data and found that the studies that used soil legacy data date from the mid-1960s. However, the term "soil legacy data" was not specifically cited in these studies and "soil data" was the only term used.

A second literature search was conducted to identify articles using the term "soil data". This search revealed a lack of awareness of the term itself, although the method for reusing previously collected data was recognized. However, the term "soil data" is quite broad, encompassing various studies beyond the scope of this work – studies with different objectives. A substantial number of studies in this category were not considered in this analysis because they do not explicitly use the term "legacy soil data" to denote the reuse of data from previously surveyed soil profiles and maps. Consequently, it is apparent that significant research and study have been devoted to the reuse of previously collected data, yet limited attention has been given to the specific term "legacy soil data". This poses a challenge for bibliometric analysis due to the diverse terminology employed, despite the underlying convergence on the same topic. Also, it emphasizes the need to create a database so that the scientific community can effectively track related studies (p.e. MapBiomas Solos, ISRIC).

## Future prospects

Indexing words often used in scientific articles can indicate relevant topics and enable the characterization of the current scenario and trends in scientific production. Wang et al. (2015) observed global trends over time in soil monitoring research in addition to the keywords that characterize the study. The authors found an increase in studies focused on heavy metals, soil moisture, and groundwater, revealing the importance of monitoring soils in the environmental conservation scenario.

Figure 4 displays the 15 terms most used in soil legacy data studies in the period analyzed, showing the frequency of occurrence and region of concentration of the keywords "digital soil mapping", "digital mapping", "mapping", "mapping method", and "soil surveys". One can see the direct connection of such studies with modeling and digital soil mapping.

Some studies that used soil legacy data together with mapping present in their goals the words "organic carbon", "prediction", "forecasting", and "soil property". We can infer that a great majority of such studies use legacy data to predict certain properties of the soil, among which the most studied is organic carbon. This is believed to be due to a considerable increase in studies related to the mapping of organic carbon stock using digital mapping approaches. Lamichhane et al. (2019) conducted a review study and found an increase in the number of publications related to soil organic carbon mapping in 2016 and 2017.

The keyword "prediction" was also among the 15 most often used keywords in the study by Cancian et al. (2018) on digital soil mapping. Some terms refer to the methods used in the studies, such as "mapping method", "uncertainty analysis", and "regression analysis". Regression analysis was widely cited and is perhaps the most widely used

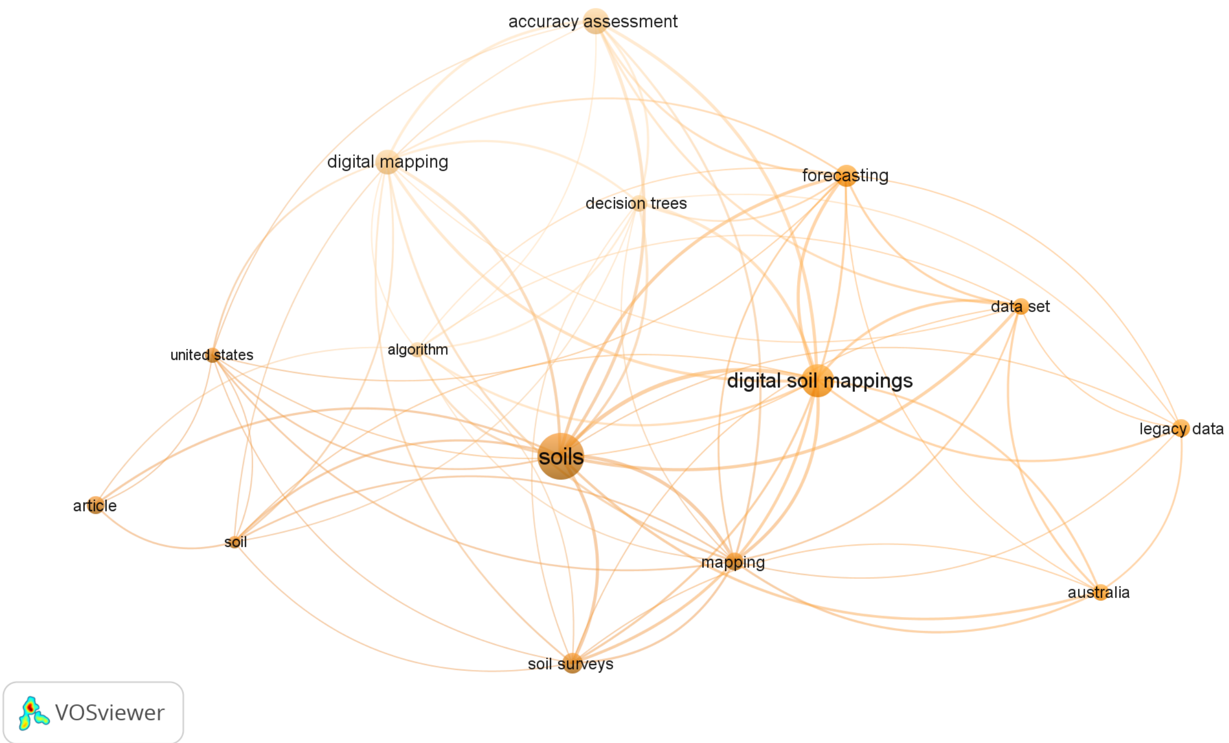


**Figure 4.** Fifteen keywords that are most used in articles on soil legacy data.

method in data modeling, but it is not possible to state this, as we did not address meta-analysis in this study.

It is also possible to observe the use of the keyword "uncertainty analysis", which is widely used in mapping studies and quantitatively presents how much certain information is represented by the modeling performed. Odgers et al. (2015) suggest a method to estimate the uncertainty associated with the predictions, denominated Digital Soil Property Mapping Using Soil Class Probability Rasters (PROPR).

In the international scenario, pedometricians constantly rely on soil legacy data to develop the field further. One can infer that the use of these data is facilitated when governmental efforts organize and make these data available for free access, thereby facilitating reuse in studies with different purposes. Hendriks et al. (2019) suggest the use of soil legacy data to assist in the survey of new data; thus, the data complement each other and present a complete work in a wide range of fields of knowledge.

## CONCLUSION

Researchers are using soil legacy data to gain new insights, especially in digital soil mapping. Digital soil mapping is the most widely used term, and Australia, the United States of America, and Brazil have led discussions on using soil legacy data in a wide variety of studies.

Free-access databases are crucial for these studies, promoting sustainable agriculture and conservation. However, many studies do not focus on creating new databases; instead, researchers rely on existing ones. Free-use databases play a key role in making soil legacy data easily available for local studies, especially in pedometrics.

In summary, our findings stress the importance of both using and creating databases, highlighting the significance of soil legacy data in advancing digital soil mapping and sustainable agriculture in soil science.

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## SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://www.rbcsjournal.org/wp-content/uploads/articles_xml/1806-9657-rbcs-48-e0230130/1806-9657-rbcs-48-e0230130-suppl01.pdf.

## AUTHOR CONTRIBUTIONS

**Conceptualization:** Alexandre ten Caten (equal), Beatriz Macêdo Medeiros (equal), Gustavo Eduardo Pereira (equal), Kelly Tamires Urbano Daboit (equal) and Letícia Sequinatto Rossi (equal).

**Data curation:** Alexandre ten Caten (equal), Beatriz Macêdo Medeiros (equal) and Letícia Sequinatto Rossi (equal).

**Funding acquisition:** Letícia Sequinatto Rossi (lead).

**Investigation:** Beatriz Macêdo Medeiros (equal), Elisângela Benedet da Silva (equal) and Gustavo Eduardo Pereira (equal).

**Methodology:** Alexandre ten Caten (equal), Beatriz Macêdo Medeiros (equal) and Kelly Tamires Urbano Daboit (equal).

**Project administration:** Alexandre ten Caten (equal), Beatriz Macêdo Medeiros (equal) and Letícia Sequinatto Rossi (equal).

**Software:** Beatriz Macêdo Medeiros (lead).

**Supervision:** Alexandre ten Caten (equal) and Letícia Sequinatto Rossi (equal).

**Validation:** Alexandre ten Caten (equal) and Beatriz Macêdo Medeiros (equal).

**Visualization:** Beatriz Macêdo Medeiros (equal) and Elisângela Benedet da Silva (equal).

**Writing – original draft:** Beatriz Macêdo Medeiros (equal) and Gustavo Eduardo Pereira (equal).

**Writing – review & editing:** Beatriz Macêdo Medeiros (equal), Elisângela Benedet da Silva (equal), Gustavo Eduardo Pereira (equal), Kelly Tamires Urbano Daboit (equal) and Alexandre ten Caten (equal).

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