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Remote Sensing in Human Health: A 10-Year Bibliometric Analysis

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Abstract: A mixed methods bibliometric analysis was performed to ascertain the characteristic of scientific literature published in a 10-year period (2007–2016) regarding the application of remote sensing data in human health. A search was performed on the Scopus database, followed by manual revision using synthesis studies' techniques, requiring the authors to sort through more than 8000 medical concepts to create the query, and to manually select relevant papers from over 2000 documents. From the initial 2752 papers identified, 520 articles were selected for analysis, showing that the United States ranked first, with a total of 250 (48.1% of the total) documents, followed by France and the United Kingdom, with 67 (12.9% of the total) and 54 (10.4% of the total) documents, respectively. When considering authorship, the top three authors were Vounatsou P (22 articles), Utzinger J (19 articles), and Vignolles C (13 articles). Regarding disease-specific keywords, malaria, dengue, and schistosomiasis were the most frequent keywords, occurring 142, 34, and 24 times, respectively. For some infectious diseases and other highly pathogenic or emerging infectious diseases, remote sensing has become a very powerful instrument. Also, several studies relate different environmental factors retrieved by remote sensing data with other diseases, such as asthma exacerbations. Health-related remote sensing publications are increasing and this paper highlights the importance of these related technologies toward better information and, ideally, better provision of healthcare. On the other hand, this paper provides an overall picture of the state of the research regarding the application of remote sensing data in human health and identifies the most active stakeholders e.g., authors and institutions in the field, informing possible new collaboration research groups.

Keywords: bibliometric analysis; remote sensing; healthcare; medicine

1. Introduction

Remotely sensed data are extensive exploited for the estimation of environmental variables of relevance to human health. Since the launch of Landsat-1 in 1972 [1], an increasing number of health studies have used remotely sensed data for monitoring, surveillance, or risk assessment. This data, associated with image processing techniques, is very helpful to understand the transmission mechanisms of several diseases and could be used to develop satellite data-based early warning systems [2].

Most of the health studies involving remote sensed data were related to parasitic diseases and refer to the pathogen, studying the presence or absence of the specific vectors [2]. Malaria is one of the most common vector-borne diseases in the world, with an estimated 214 million new cases and 438,000 deaths in 2015 [3], and therefore is one of the most studied diseases from the remote sensing point of view (e.g., [4,5]). For some infectious diseases of major public health importance (e.g., Dengue fever) and other highly pathogenic or emerging infectious diseases (e.g., Ebola fever), remote sensing has become in recent years a very powerful instrument [6,7]. Also, an extensive use of remote sensing data is recorded in the study of neglected tropical diseases [8]. Recently, several studies have related different environmental factors (e.g., humidity, temperature, particulate matter of 10 micrometers or less (PM10), Nitrogen Dioxide (NO_2)) retrieved by remote sensing data with other diseases, such as asthma exacerbations [9], preterm birth [10], circulatory mortality and ischemic heart disease [11], or diabetes [12].

During the last years, the quantity and variety of remotely sensed and in situ environmental data (e.g., measuring human activity) [13,14] have greatly increased. This growth was followed by a significant increase in the scientific publications associated with these works [15]. Several studies show that the analysis of published literature could provide critical information about the research production and the scientific quality [16–19]. Moreover, we believe that describing trends and characteristics of the articles from a scientific field can trigger the future research and collaborations between authors and institutions.

There are already bibliometric analyses of global remote sensing [15]. However, there is no study, to the best of our knowledge, that has specifically investigated its relation to health.

The goal of this paper was to perform a bibliometric analysis, using a systematic review approach, regarding the application of remote sensing data to human health to appraise the publication, research trends, and characteristics in this field.

2. Material and Methods

2.1. Bibliographic Database

Scopus is one of the world's largest abstract and citation databases of peer-reviewed research literature, with over 22,000 titles from more than 5000 international publishers. Furthermore, Scopus has a wide coverage, currently counting 22,794 peer-reviewed journals; it has efficient tools for retrieving and aggregating information; and it exports data in multiple formats based on previously defined output variables and provides extensive information for analysis [20]. For these reasons, Scopus was the database of peer-reviewed literature chosen for this research.

Scopus also provides relevant functionalities, namely the field "source type", in which the user is able to refine search results by the type of data source, such as journal publications, books, book chapters, and conference proceedings. In this study, we limited our analysis to journal publications and reviews. Conference proceedings, books, and book chapters were not considered for analysis because they include works that might have been published more than once, in different sources. For instance, books or book chapters usually contain one or more studies that might have been published elsewhere and conference proceedings include abstracts that might have been published in scientific journals. Thus, limiting our analysis to journal publications was essential for addressing potential bias caused by duplicate publications, minimizing false positive results. Synthesis studies e.g., systematic reviews, comprise studies published elsewhere; however, they were included in our analysis because they are regarded as original studies.

2.2. Search Strategy and Validity

Besides limiting our search to reviews and journal publications, we only considered documents whose publication year occurred between 2007 and 2016 (a 10-year study). We selected only studies regarding the application of remote sensing technology in human health, including healthcare services.

In order to retrieve complete and suitable publications data from Scopus, we built the search query based on two main pillars regarding medical and remote sensing as two broad concepts.

The search firstly accounted for remote sensing publications and was implemented as follows: retrieve all documents either containing "Remot* sens*" or "satellite imag*" or "aerial photograph*" or "space-borne sensor*" or "Earth Observation Satellite*" or "Earth Resources Satellite*" in the title, abstract or keyword, in which the wild card "*" was used to address plurals and certain word variations (e.g., sensing, sensors, and sensor). The implementation of the search within the medical field combined two approaches in order to maximize sensitivity. The first approach implemented a broader search aimed to retrieve all journal publications that presented "Health Care" or "HealthCare" terms in the title, abstract or as keyword, combined with an extensive list of diseases and medical conditions. This list of diseases and medical conditions was obtained through the aggregation of all diseases defined by the International Classification of Diseases 9th Revision Clinical Modification (ICD-9-CM) terminology, a list of diseases from the Centers for Disease Control and Prevention (CDC), and an additional list of Medical Subject Headings (MeSH) terms under the C category, which describes all diseases in the mesh tree structures of PubMed. Common diseases among ICD-9-CM terminology, CDC, and Category C of Mesh terms were merged, and non-specific disease terms such as "eye" and "arm" were removed. It is important to highlight that limiting the search to title, abstracts, and keywords was necessary to increase specificity and due to the exhaustive list of diseases included in the query.

We conducted a manual review of all retrieved documents in order to address word ambiguity issues. For instance, several terms related to the medical field, such as depression, AIDS, and burns, may overlap with concepts from other scientific fields, retrieving false positive results. Additionally, the search results from "remote sensing" might include publications on remote monitoring of devices, which are not related to the concept of remote sensing in the context of our study.

The systematic review was conducted independently by six reviewers. All documents resulted from our search were reviewed under two perspectives: four reviewers performed the review under the medical perspective and two under the remote sensing perspective. Under the medical perspective, the inclusion criteria were: "any publication related to human health, which comprised those articles with a main focus on human health, any specific disease or medical condition, risk factor for disease or healthcare services".

Under the remote sensing perspective, the reviewers used as inclusion criteria "any publication regarding any imagery obtained by Earth observation systems". Divergences between the two remote sensing reviewers were resolved through reaching a consensus. Under the medical perspective, each article was analyzed by two reviewers and a third reviser resolved divergences. Only the papers that were accepted by the remote sensing reviewers and by healthcare reviewers were included in the final analysis.

2.3. Software and Data Analysis

At the manual review stage, Cohen's kappa statistics was calculated to appraise interrater reliability.

All articles that were included after the manual review were analyzed by authorship, country, sources, affiliation, and citations. Individual keywords were assessed by frequency and a ranking of publication sources was performed by relevance. A list of diseases or human conditions were also selected from the keywords and analyzed. Productivity analysis was conducted by author and country rankings. Total and average number of citations was analyzed by country.

Authorship analysis was carried out by computing the number of single-authored articles and multi-authored publications. We also calculated the rate of articles per author, authors per article, and co-authors per articles. Overall collaboration and the frequency publications cited together i.e., co-citations, were also analyzed.

VOSviewer program, a software tool designed specifically for bibliometric analysis, was employed for the visualization of the retrieved data. This tool provides a density map in which a color represents

clusters (e.g., countries or authors) connecting lines to indicate certain parameters (e.g., strength of collaboration between countries or authors are measured and represented by the thickness of connecting lines). The circle size or font size indicates the level of productivity or citations. On selecting the unit of analysis, thresholds were imposed for the visualization to be intelligible.

The software Microsoft Excel was used to rearrange the data and perform the analysis of the exported data (i.e., comma separated values' table) from Scopus and the software R was used to plot charts. Moreover, for network visualization of the analysis, the software VOSviewer was used.

2.4. Statistics and Ethical Considerations

This study was exempted from ethical approval as no human individuals were included and only publicly available electronic data was used for analysis.

3. Results

3.1. General Information

A total of 2752 documents were retrieved. A manual review of all retrieved documents (title and abstract) was performed under the medical and the remote sensing perspectives in order to exclude potential false positive results. Under the medical perspective, the Cohen's kappa statistics was 0.78 (95% confidence interval (CI) = 0.75–0.81), whereas under the remote sensing perspective reviewers reached a similar level of interrater reliability with a Cohen's kappa statistics of 0.75 (95% CI = 0.72–0.79). The final set of articles was of 520 articles (19.9% of total). Figure 1 shows a summary of the review process results.

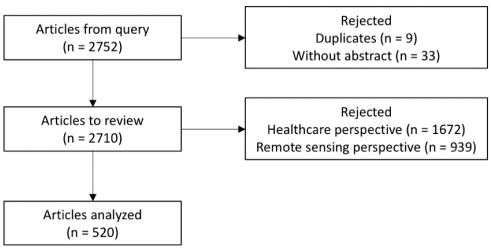

Figure 1. Review process flow diagram.

The vast majority of the retrieved documents were published in English (505 documents; 96.7%), though other common languages were encountered, followed by Portuguese (six documents; 1.1%), Chinese (four documents; 0.8%) and French (four documents; 0.8%). Retrieved articles received a total of 8034 citations, corresponding to a mean of 15.5 citations per document. A total of 472 (90.8%) articles were cited at least once, while the remaining 48 (9.2%) publications were not cited at all.

Regarding disease-specific keywords, malaria, dengue, and schistosomiasis were the most frequent keywords, occurring 142, 35, and 34 times respectively. More disease-specific keywords can be seen in Table 1.

Table 1. Frequency of disease-specific keywords found either in Index or Author's keywords.

Keyword	Occurrences as Index or Author Keywords *n* (%)
Malaria	142 (27.3)
Dengue	34 (6.5)
Schistosomiasis	24 (4.6)
Cholera	16 (3.1)
Cardiovascular disease	15 (2.9)
Asthma	14 (2.7)
Schistosomiasis japonica	10 (1.9)
Chagas disease	9 (1.7)
Obesity	6 (1.2)
Pregnancy	2 (0.4)

3.2. Trends and Citations

Throughout the period considered in our study, the average number of publications was 52 documents per year. An increasing trend of the number of publications was observed over the years (Table 2). The peak of productivity was observed in 2015, with a total of 80 publications, which comprised 15.4% of the total productivity in the studied period. Table 2 summarizes yearly scientific production and citations, while Figure 2 shows the growth rate of publications (referenced to 2007), comparing the growth between health and remote sensing, the publications indexed in Scopus with the subject area: Medicine, and the total publications indexed in Scopus.

The article that received the highest number of citations was "Mapping H5N1 highly pathogenic avian influenza risk in Southeast Asia", with a total of 196 citations published in the Proceedings of the National Academy of Sciences of the United States of America in 2010. A list the most referenced publications by articles in field of remote sensing applied to human health is presented in Table 3. Figure 3 shows a network for co-citation analysis.

Table 2. Yearly summary of publish articles in the field of remote sensing applied to human health. Articles—number of articles publish per year and percentage from the total of articles retrieved (520), ACLO—Articles cited at least once, ACLO %—percentage of articles cited at least once when compared to total annual publication, ACY—average citation per year.

Year	Articles (%)	ACLO	ACLO %	ACY	Total-Citations	Median (Q1–Q3) of Citations
2007	29 (5.6)	28	96.6%	95.8	1051	30.5 (17.5–52.5)
2008	38 (7.3)	37	97.4%	138.7	1248	22.0 (9.5–39)
2009	39 (7.5)	36	92.3%	144.3	1176	21.5 (10.5–38.5)
2010	42 (8.1)	42	100%	117.4	823	15.5 (8–26)
2011	39 (7.5)	39	100%	110.7	664	9.0 (8–22)
2012	50 (9.6)	49	98.0%	192.4	990	11.0 (6.5–28)
2013	64 (12.3)	59	92.2%	169.5	725	9.0 (5–14)
2014	70 (13.5)	66	94.3%	209.0	633	7.0 (3–12)
2015	80 (15.4)	69	86.3%	266.5	533	4.0 (2–7)
2016	69 (13.3)	47	68.1%	191.0	191	3.0 (1–5)

Table 3. Top 10 most referenced publications by articles in the field of remote sensing applied to human health.

References	Title	Number of Citations
Gilbert et al. (2008)	Mapping H5N1 highly pathogenic avian influenza risk in Southeast Asia	196
Kraemer et al. (2015)	The global distribution of the arbovirus vectors *Aedes aegypti* and *Ae. Albopictus*	186
Reid et al. (2009)	Mapping community determinants of heat vulnerability	180
De Magny et al. (2008)	Environmental signatures associated with cholera epidemics	136
Delfino et al. (2009)	The relationship of respiratory and cardiovascular hospital admissions to the southern California wildfires of 2003	116
Vittor et al. (2009)	Linking deforestation to malaria in the Amazon: Characterization of the breeding habitat of the principal malaria vector, *Anopheles darlingi*	114
Bejon et al. (2010)	Stable and unstable malaria hotspots in longitudinal cohort studies in Kenya	110
Kloog et al. (2008)	Light at night co-distributes with incident breast but not lung cancer in the female population of Israel	99
Chan et al. (2008)	Increasing cardiopulmonary emergency visits by long-range transported Asian dust storms in Taiwan	94
Gilbert et al. (2007)	Avian influenza, domestic ducks and rice agriculture in Thailand	93

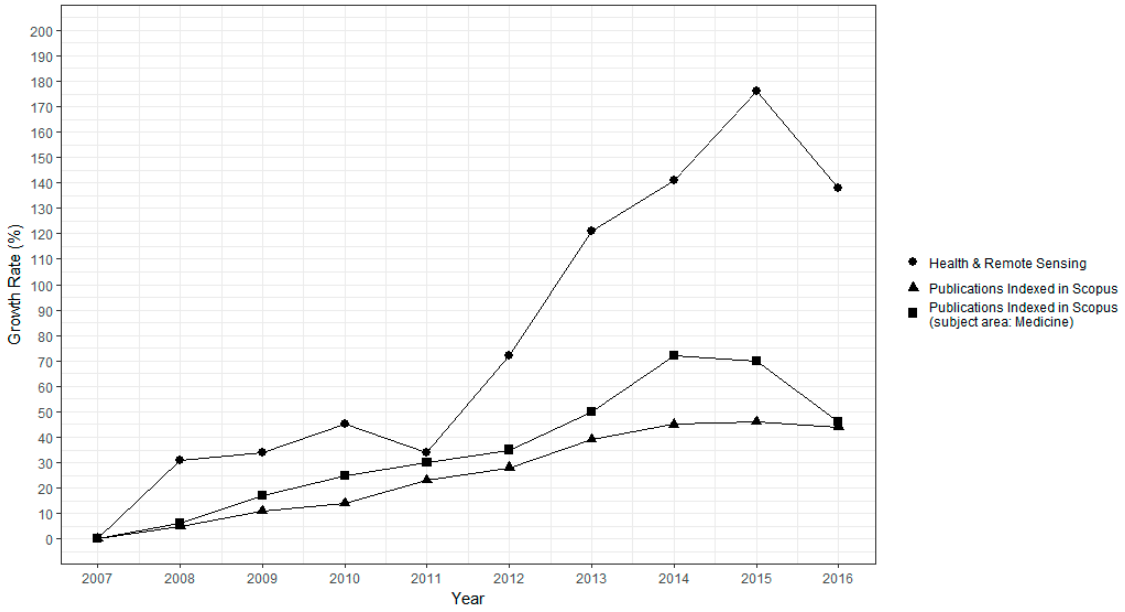

Figure 2. Annual growth rate of publications in health and remote sensing, annual growth rate of all the publications indexed in Scopus and annual growth rate of publications indexed in Scopus in the medical area per year (2008–2016) compared to the reference year (2007).

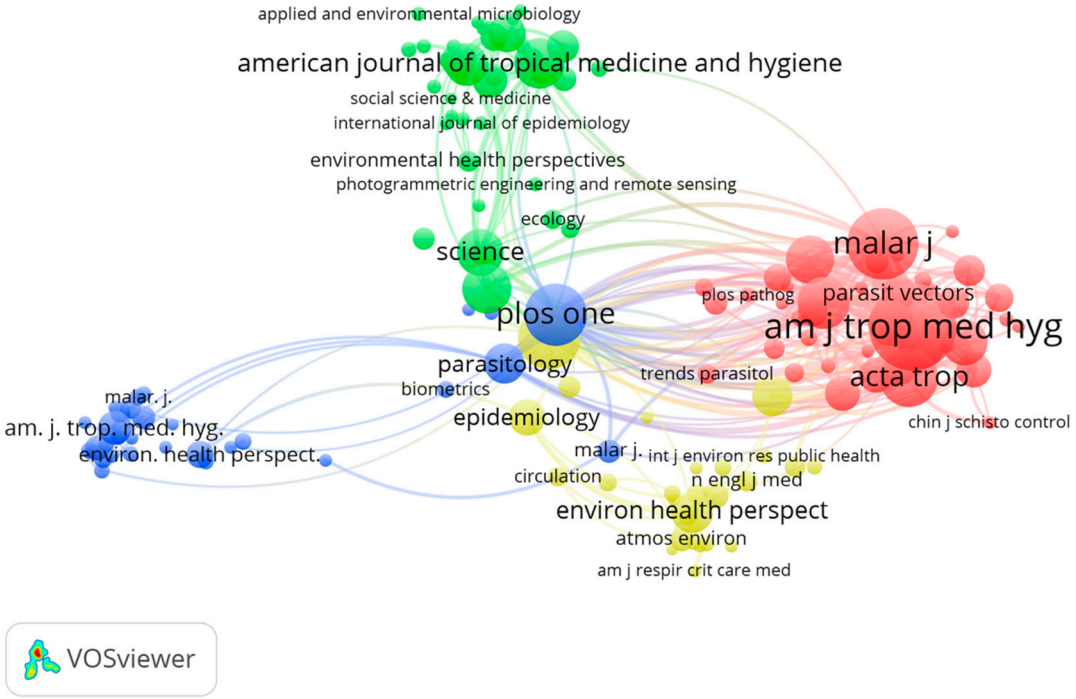

Figure 3. Co-citations relations between sources. Each circle represents a different journal, with the larger circles having the highest number of citations in the field of remote sensing applied to human health. The lines reflect the link strength between the different sources. A minimum of 20 citations per source was considered, with 139 sources meeting this criterion.

3.3. Geographical Distribution

In order to visualize collaboration nets and the distribution of publications across the world regarding publications on the application of remote sensing technology in human health, we constructed a bibliometric network represented in Figure 4. Researchers from 39 different countries

with connections with each other contributed to the publication of the selected documents. The United States ranked first, with a total of 250 (48.1% of the total) documents, followed by France and the United Kingdom, with 67 (12.9% of the total) and 54 (10.4% of the total) documents, respectively. When only the number of citations is considered, the United States (4755 citations; average article citations of 19.0) also presented the highest number, followed by France (1155 citations; average article citations of 17.2) and the United Kingdom (1500 citations; average article citations of 27.8).

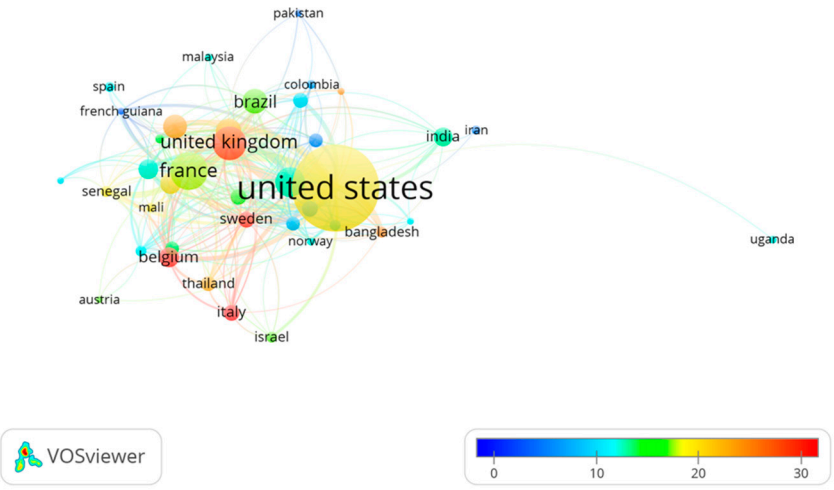

Figure 4. Citation relationships between countries. The size of each circle is proportional to the number of published articles, the color represents the countries' average citations and the lines reflect the citations between countries. Only countries with a minimum productivity of five articles were included.

Taking into account author's affiliation, there are no institutions or organizations that have concentrated most of the publications in the field of remote sensing applied to human health, with 1928 different institutions or organizations having published at least one manuscript in this research field, with was an average of 3.7 institutions or organizations per publication. Swiss Tropical and Public Health Institute, Switzerland and University of Basel, Switzerland ranked first as the most productive institutions. The number of publications per institution is presented in Table 4.

Table 4. Ranking of institutions and organizations with a minimum productivity of 10 publications in the field of remote sensing applied o health. Articles (%)—number of articles per institution and percentage from the total of articles retrieved (n = 520).

Institution	Articles (%)
Swiss Tropical and Public Health Institute, Switzerland	31 (6.0)
University of Basel, Switzerland	22 (4.2)
Johns Hopkins University, United States	22 (4.2)
University of California, United States	20 (3.8)
University of Florida, United States	13 (2.5)
University of Oxford, United Kingdom	13 (2.5)
National Institutes of Health, United States	12 (2.3)
Emory University, United States	12 (2.3)
Columbia University, United States	11 (2.1)
University of Maryland, United States	10 (1.9)
Kenya Medical Research Institute, Kenya	10 (1.9)
Nagasaki University, Japan	10 (1.9)
University of Miami, United States	10 (1.9)

The selected publications on remote sensing applied to healthcare were published by a total of 134 different sources. Table 5 lists all preferred journals, with a minimum productivity of 10 documents.

Malaria Journal ranked first, with 39 (7.5% of the total) documents, followed by International Journal of Health Geographics, with 35 publications (6.5% of the total), and PLoS ONE, with 32 manuscripts (6.2% of the total).

Table 5. Ranking of journals with a minimum productivity of 10 publications in the field of remote sensing applied o health. Articles (%)—number of articles per journal and percentage from the total of articles retrieved (n = 520).

Journal	Articles (%)
Malaria Journal	39 (7.5)
International Journal of Health Geographics	34 (6.5)
PLoS ONE	32 (6.2)
Geospatial Health	31 (6.0)
PLoS Neglected Tropical Diseases	17 (3.3)
American Journal of Tropical Medicine and Hygiene	16 (3.1)
Acta Tropica	13 (2.5)
Environmental Health Perspectives	11 (2.1)
Parasites and Vectors	11 (2.1)
Environmental Research	10 (1.9)
Geospatial health	10 (1.9)

3.4. Authorship Pattern and Collaboration

A total of 2479 researchers participated in the retrieved documents regarding the application of remote sensing technology to human health, which corresponds to a mean of 4.76 authors per document. Single-authored documents comprised a total of 11 (2.11% of the total) publications. Additionally, authors with a minimum productivity of three documents were graphically represented using an algorithm implemented by VOSviewer, as shown in Figure 5. Table 6 lists the top 10 active authors in the field of remote sensing applied to human health.

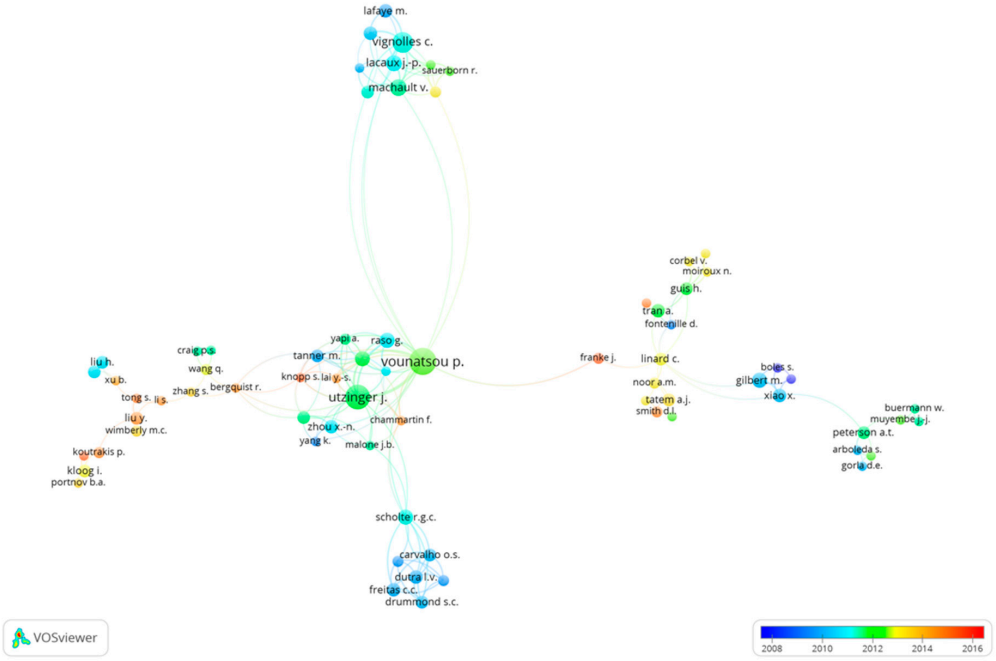

Figure 5. Co-authorship relations between authors. Each author is represented by a circle, where closer circles represent authors with close research collaborations, the size and name of the circle represent the number of publications, and the color represents the average publication year. The selection was made with a minimum of three documents per author, with 162 authors selected. However, the representation depicts 72 authors that had connections among them.

Table 6. Top 10 active authors in the field of remote sensing applied to human health. SCR—Standard Competition Ranking, Articles (%)—number of authorships and percentage from the total of articles retrieved (n = 520), % of Articles from Total—percentage of articles retrieved by the total scientific production within the study period.

Standard Competition Ranking (SCR)	Author	Articles (%)	Total Articles in Scopus within the Study Period	% of Articles from Total
1st	Vounatsou P.	22 (4.2)	129	17.1
2nd	Utzinger J.	19 (3.7)	429	4.4
3rd	Vignolles C.	13 (2.5)	25	52.0
4th	Machault V.	9 (1.7)	20	45.0
5th	Kumar V.	8 (1.5)	84	9.5
5th	Lacaux J.-P.	8 (1.5)	25	32.0
5th	Martin R.V.	8 (1.5)	133	6.0
5th	Shields T.	8 (1.5)	36	22.2
5th	Moss W.J.	8 (1.5)	113	7.1
10th	Bhunia G.S.	7 (1.3)	19	36.8
10th	Gilbert M.	7 (1.3)	74	9.5
10th	Kesari S.	7 (1.3)	28	25.0
10th	Raso G.	7 (1.3)	57	12.3
10th	Scholte R.G.C.	7 (1.3)	18	38.9
10th	van Donkelaar A.	7 (1.3)	85	8.2
10th	Das P.	7 (1.3)	264	2.7
10th	N'Goran E.K.	7 (1.3)	109	6.4

4. Discussion

Remote sensing images are a very useful source of data to understand the transmission mechanisms of several diseases. In this study, we performed a bibliometric analysis with a systematic review of remote sensing research applied to health in order to give a clear overview of research trends in this field. Although a few articles were published using this methodology in remote sensing research [15,18,19], to the best of our knowledge, this is the first one applied to health.

When considering keywords, the most frequent health research areas were related to malaria, dengue, and schistosomiasis, and so these keywords can be used as surrogates to indicate the most common researched diseases, in particular vector-borne diseases.

During the study period, the research productivity regarding remote sensing data to human health had a substantial increase, reaching an increase of 176% (2015) when compared to the initial year. This result is even more impressive when compared to the overall trend of publications in Scopus, which increased 46% (2015), and even when compared to the publications in Scopus in the subject area of Medicine, which increased 72% (2014). This trend reflects a mounting interest and research investment in the field.

The countries who stand out for its volume of research were the United States, France, and the United Kingdom. However, when increasing the granularity of the analysis to the institution, it is clear that Swiss Tropical and Public Health Institute and University of Basel in Switzerland are leading institutions in this field.

The majority of these articles were published in remote sensing and/or technology journals rather than in medical journals, which might reflect the ignorance or the fact that this research topic might be considered less important by the medical field.

Regarding authorship, Vounatsou P. was the most prolific author in this field. However, Vignolles C. made most of her research in the field of remote sensing applied to health, indicating a greater investment and interest in the field.

In fact, the high burden of infectious diseases in developing countries [21], allied to the fact that this disease group can be easily studied by means of remote sensing, might be a good public health indicator for their prevention and control. The timing of this study is important, as bringing attention to this topic might help some countries in their mission to achieve Sustained Development Goals proposed by the World Health Organization to be reached by 2030 [22]. However, the use of

remote sensing data in public health issues (i.e., infectious diseases) has already been pointed out [23]. In so-called "environmental" diseases, geographical information systems (GIS) are highly applicable, while in the non-communicable category its applicability is quite limited. This and the fact that regions such as Africa have a great burden of these diseases can explain the collaboration and location of the research on this field [24].

It is known that health geomatics can be a good tool to improve health resources allocation, as a good relation between location and healthcare triggers disease prevention and improves health planning and policy [25]. Furthermore, GIS are being more often used in public health with a clear advantage of depicting complex analyses on a map, but some disadvantages such as trained staff, appropriate spatial units, and/or patient confidentiality [26].

While developing this paper, we were faced with many challenges, the most difficult one being the establishment of a definition of human health, requiring the authors to sort through more than 8000 medical concepts to perform an adequate search. The search itself presented a challenge because of the massive number of search terms and the search engine limitations. Despite this effort, and due to the duality of some concepts (e.g., burn, depression, and AIDS), we reviewed the abstracts manually to end up with more accurate and appropriate results.

Our study had some limitations. Firstly, we performed this bibliometric analysis only in Scopus. Although Scopus is one of the largest databases, some research in this field might be indexed in other databases, not indexed at all, or might have not yet been published in article format (e.g., only presented in congresses). Furthermore, adding results from searches in other databases would be feasible but very time consuming and, most likely, would not have provided added value to the results. Secondly, a limitation inherent to the query cannot be ignored, as false-negatives might be present with some articles being excluded, though we tried to overcome this limitation by using a sensitive query regarding both health and remote sensing. Moreover, one strength of our study is that all articles were reviewed manually by at least two reviewers in each perspective, minimizing the possibility that a false-positive article would be included. Thirdly, authors and institutions' rankings may not be completely correct, as some have different name spellings or initials. Finally, we used in VOSviewer a minimum threshold number to draw graphics, excluding some items; this choice was made after several iterations, with the aim of maximizing the balance between the amount of information included in the visualization and readability.

5. Conclusions

Earth observation data have demonstrated a great value in providing crucial information to understand health issues. Remote sensing along with GIS has multiple applications in the healthcare area, particularly for vector-borne diseases. In fact, for some infectious diseases and other highly pathogenic or emerging infectious diseases, remote sensing has become a very powerful instrument, providing spatial information on environmental conditions for understanding influences in health. Also, several studies relate different environmental factors retrieved by remote sensing data with other diseases, such as asthma exacerbations. Health-related remote sensing publications are increasing and this paper highlights the importance of these related technologies toward better information and, ideally, better provision of healthcare. On the other hand, this paper provides an overall picture of the state of the research regarding the application of remote sensing data in human health and identifies the most active stakeholders e.g., authors and institutions in the field, informing possible new collaboration research groups.

The present work lays the ground for several research directions, namely systematic reviews comparing methodologies of remote sensing applied to tracking specific diseases, remote sensing's impact on public health, and the evolution of remote sensing methods over the years. Furthermore, and based on the manual classification of articles, other methodological approaches can be explored (e.g., text mining).

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Conflicts of Interest: The authors declare no conflict of interest.

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