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Bibliometric Review on the Use of Internet of Things Technologies to Monitor the Impacts of Wind on Trees and Forests †

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Abstract: The presence of trees brings several health benefits to urban populations. However, wind damage is an important cause of falling trees, causing considerable damages. This study involved a bibliometric review on the use of Internet of Things technologies for monitoring trees. A research protocol was designed and implemented, involving a thorough search of the Scopus database. After applying the exclusion criteria and content filters, the abstracts and titles of the resulting 313 documents were analyzed. Two analyses were performed; (i) an analysis of the evolution of the area based on the study metadata; (ii) a cluster analysis of the words present in the abstracts and titles of the identified documents. The first analysis showed: (i) the current growth of this area of research; (ii) that the most important fields of study were agricultural, biological, environmental, and terrestrial and planetary sciences; (iii) that the most relevant journal was *Ecology and Forest Management*. The second analysis resulted in the identification of three clusters: (i) wind impact; (ii) variables and experiments; (iii) forest management. The main gap observed was that few studies have used IoT technologies as tools for preventive or corrective actions related to wind and storm impacts on trees and forests.

Keywords: bibliometric review; Internet of Things; monitoring; tree; windthrow

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1. Introduction

There are several advantages to the afforestation of cities. Some of those advantages are: (i) reductions of more than 90% in terms of sun incidence, consequently reducing temperature and light exposure [1]; (ii) absorption of carbon dioxide [2]; (iii) filtration of particulate matter (which may cause lung diseases) [2]; (iv) oxygen release [2]. These aspects help to improve a city's air quality. Inadequate maintenance of urban trees can result in trees falling, damaging property and people [3], both in rural and urban areas [4]. In urban areas, fallen trees can bring the urban infrastructure to a standstill, limiting the access and use of buildings, streets, pipelines, and public transportation, among others, and can expose lives and properties to several risks [3,5]. The monitoring of trees using Internet of Things (IoT) technologies can assist in analyzing and predicting the risk of falling trees in urban environments, making it possible to collect and store useful data in real time using wireless sensor networks [6]. The concept of IoT can be described as the combination of sensors, actuators, and network devices in a unique relationship and environment. These objects are considered intelligent and can store and transmit essential information to improve decision-making [7]. IoT technologies allow the connection between intelligent objects and people, collecting and transmitting information anywhere, anytime, and through any medium [8]. This study aims to conduct a bibliometric review on the use of IoT technologies to monitor

the impacts of wind on trees and forests. The main studies, keywords, journals, and events will be identified. We will also identify and describe the main keyword clusters and how they are associated in the relevant knowledge domains.

2. Methodology

This article uses the bibliometric review methodology [9], following the study by Silva [10]. The methodology used was composed of six steps: (1) Keyword identification, based on an in-depth literature review and the study by [11]. The keywords used were: trees, forest, wind, windthrow, windstorms, drag, IoT, accelerometer, and anemometer. (2) Database selection and research strategy, using the Scopus database [12]. (3) Definition of the research protocol and exclusion criteria. The following filters were used: language (English), subject areas (agriculture, among others), and period (2010 to 2020). (4) Evaluation of the resulting works, based on the titles, keywords, and abstracts. (5) Quantitative analysis and identification of the most important works, events, journals, and the evolution of the use of IoT for the monitoring of trees and forests. (6) Clustering and data visualization, identifying the main keywords in each cluster. For the cluster analysis, we used the VosViewer software [13].

3. Results and Discussions

Before the application of the exclusion criteria and filters, the keywords search resulted in 1031 documents. Then, the content filters were applied, resulting in 440 documents. The exclusion criteria were then applied to eliminate non-relevant papers, resulting in 313 documents. These were then analyzed. Figure 1 illustrates the growth in the number of published studies throughout the years in this final dataset.

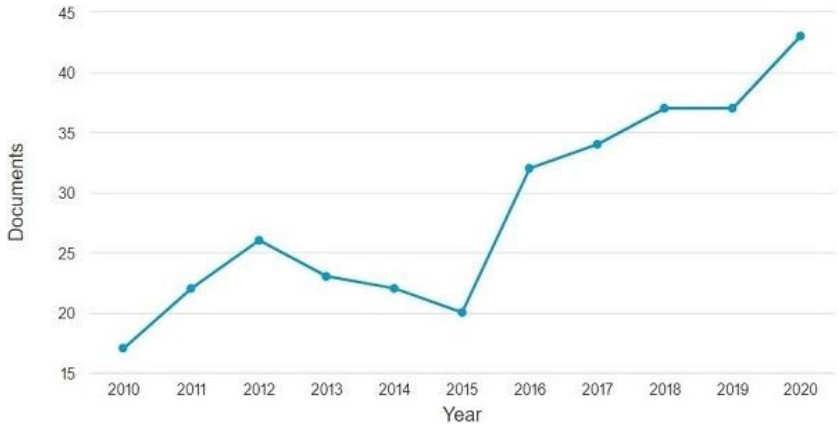

Figure 1. Number of published studies per year in the final dataset.

It can be observed in Figure 1 that the number of relevant published studies has increased considerably since 2015. This demonstrates an increasing interest by the academic community in studying the impacts of wind on trees and forests. The institutions, foundations, and countries with the most cited documents were from developed nations, such as the United States and countries in the European Union. Two areas of study prevailed in the surveyed documents, namely agricultural and biological sciences and environmental science, both linked to the rural and urban environments. Based on the analysis of the main sources of the studies in the final dataset, it is important to note that: (i) journals presented a considerably higher number of citations; (ii) the most relevant journal was *Forest Ecology and Management*; (iii) the most relevant conference was the 6th Intl Conf. on Internet of Things: Systems, Mgmt., and Security (IOTSMS). These observations are essential for researchers, pointing out relevant journals and conferences that should be considered for identifying or publishing research in the researched domain. A cluster analysis was then conducted. The following hyperparameters were considered: (i) the clustering was

conducted on the titles and abstracts of the relevant works; (ii) only words that appeared more than fifteen times in the text corpus were considered. These hyperparameters were selected based on a series of experiments with different values and configurations. The final cluster analysis identified 37 keywords, divided into three clusters. Figure 2 illustrates the clusters identified and their related keywords. In the three clusters, the researchers were looking for ways to identify and reduce the damage caused by wind in the trees and forests, focusing on the rural environment.

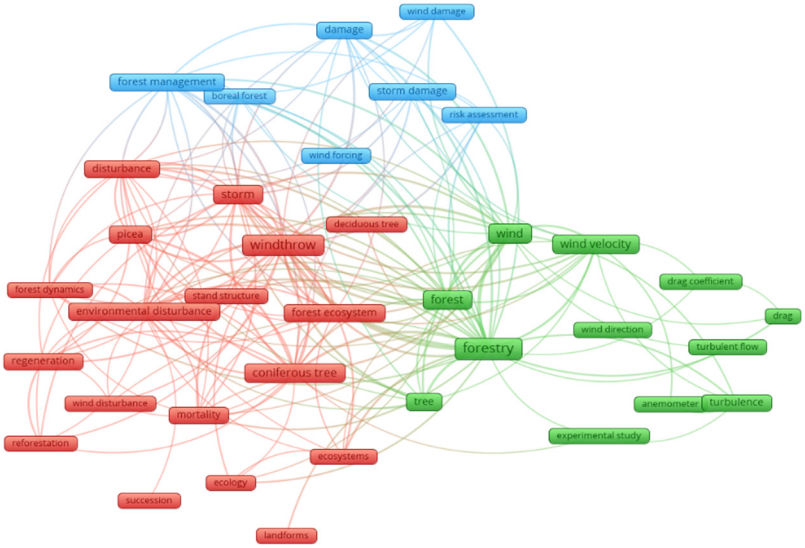

Figure 2. Visualization of the results of the cluster analysis in the final dataset.

The first cluster was called "wind impact". This cluster represented (i) the impacts of wind and storms on forests and trees and (ii) how the wind, in its various forms, leads to tree rupture. This cluster's main keywords are shown in Figure 2. The majority of the studies were related to the rural environment. The second cluster was called "variables and experiments". This cluster represented several experiments carried out in the field and laboratories to estimate the impacts of wind and storms on trees and forests. Additionally, it also considered the modeling of tree species and their behavior when impacted by wind and storms. Its main keywords are shown in Figure 2. The third cluster was called "Forest management". It was related to the different strategies and methodologies used for managing the damage caused by wind and storms in forests. Therefore, its focus was on dealing with the events after they have happened, mitigating their impacts. Additionally, a number of papers dealt with risk analysis, using this approach to evaluate tree rupture problems. The main keywords are shown in Figure 2.

It is vital to note that we found few studies in cities and urban environments. However, the results obtained for rural environments and the models used for monitoring the impacts using IoT technologies could be adapted to the urban environments. Nevertheless, this would demand an assessment of the different models and technology. The study by [14] is one of the most relevant ones related to the use of the IoT paradigm and its technologies for monitoring trees and forests, focusing on the detection of forest fires. However, it can also be adapted to monitor the impacts of wind and storms on forests. The main limitations observed in the present study were: (i) the lack of studies considering trees and forests typical of the southern hemisphere; (ii) the lack of studies using IoT technologies to monitor the impacts of wind and storms on trees and forests.

4. Conclusions and Future Works

There are numerous benefits to having trees and forests in urban and rural areas. However, the impacts of inadequate maintenance may lead to trees falling, causing enormous asset and personal damages. In order to tackle this issue, the main studies in the literature

that used IoT technology to monitor trees in urban and rural areas were identified in this study. It was observed that the number of relevant studies has been increasing considerably since 2015, showing the relevance of the topic. The cluster analysis showed that three main clusters exist, related to: (i) wind impacts; (ii) experimentation in laboratories and fields; (ii) forest management, considering risk mitigation and analysis. These were analyzed, as well as their main keywords. It was observed that most studies have focused on developed countries' species and rural environments. Additionally, only a few studies have used the IoT paradigm and the related technologies to deal with this problem. Future studies should: (i) consider the impacts of wind and storms on trees and forests typical of the southern hemisphere; (ii) adapt the current monitoring methodologies and models for the urban environment; (iii) explore the use of IoT technologies to monitor the impacts of wind and storms on trees and forests in real time.

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References

1. Buckeridge, M. Árvores urbanas em São Paulo: Planejamento, economia e água. *Estud. Av.* **2015**, *29*, 85–101. [CrossRef]
2. Livesley, S.J.; McPherson, E.G.; Calfapietra, C. The Urban Forest and Ecosystem Services: Impacts on Urban Water, Heat, and Pollution Cycles at the Tree, Street, and City Scale. *J. Environ. Qual.* **2016**, *45*, 119–124. [CrossRef] [PubMed]
3. Brazolin, S.; Tomazello Filho, M.; Yojo, T.; de Oliveira Neto, M.A.; Albuquerque, Á.R.; Sette Júnior, C.R. Propriedades físico-mecânicas do lenho deteriorado por fungos apodrecedores de árvores de Tipuana tipu. *CERNE* **2015**, *20*, 183–190. [CrossRef]
4. Danquechin Dorval, A.; Meredieu, C.; Danjon, F. Anchorage failure of young trees in sandy soils is prevented by a rigid central part of the root system with various designs. *Ann. Bot.* **2016**, *118*, 747–762. [CrossRef] [PubMed]
5. Hou, G.; Chen, S. Probabilistic modeling of disrupted infrastructures due to fallen trees subjected to extreme wind in urban community. *Nat. Hazards* **2020**, *102*, 1323–1350. [CrossRef]
6. de Carvalho Junior, A.D.; Hariki, V.S.; Goldman, A. Sensing Trees in Smart Cities with Open-Design Hardware. In Proceedings of the IEEE 17th International Symposium on Network Computing and Applications (NCA), Boston, MA, USA, 31 October–2 November 2018; pp. 1–4.
7. Gubbi, J.; Buyya, R.; Marusic, S.; Palaniswami, M. Internet of Things (IoT): A vision, architectural elements, and future directions. *Futur. Gener. Comput. Syst.* **2013**, *29*, 1645–1660. [CrossRef]
8. Shammar, E.A.; Zahary, A.T. The Internet of Things (IoT): A survey of techniques, operating systems, and trends. *Libr. Hi Tech* **2019**, *38*, 5–66. [CrossRef]
9. Valérie, D.; Pierre, A.G. Bibliometric idicators: Quality masurements of sientific publication. *Radiology* **2010**, *255*, 342–351.
10. Silva, T.C.; Araujo, E.C.G.; Lins, T.R.D.S.; Reis, C.A.; Sanquetta, C.R.; Rocha, M.P.D. Non-Timber Forest Products in Brazil: A Bibliometric and a State of the Art Review. *Sustainability* **2020**, *12*, 7151. [CrossRef]
11. Koizumi, A.; Motoyama, J.; Sawata, K.; Sasaki, Y.; Hirai, T. Evaluation of drag coefficients of poplar-tree crowns by a field test method. *J. Wood Sci.* **2010**, *56*, 189–193. [CrossRef]
12. Baas, J.; Schotten, M.; Plume, A. Scopus as a curated, high-quality bibliometric data source for academic research in quantitative science studies. *Quant. Sci. Stud.* **2020**, *1*, 377–386. [CrossRef]
13. VOSviewer. Centre for Science and Technology Studies. Leiden University. Available online: https://www.vosviewer.com/ (accessed on 16 January 2020).
14. Vega-Rodriguez, R.; Sendra, S.; Lloret, J.; Romero-Diaz, P.; Garcia-Navas, J.L. Low Cost LoRa based Network for Forest Fire Detection. In Proceedings of the Sixth International Conference on Internet of Things: Systems, Management and Security (IOTSMS), Granada, Spain, 19–22 October 2019; pp. 177–184.