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Bibliometric Analysis of Road Damage Due to High Rainfall Intensity in Mountainous Areas Using VOSviewer

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Abstract: *Road damage is one of the many things encountered in the world of construction. Road damage must require prompt handling, so as not to interfere with every activity and safety of road users. Therefore, road damage must require rapid handling. This research uses bibliometric analysis related to road damage in mountainous areas, capturing research data for the period 2000 to 2023. Research on road damage aims to determine the development of research from year to year. This research uses keywords to get the closest indicators related to the research topic. The relationship between keywords and research topics is significant to get accurate data on previous to current research topics. This bibliometric research was sourced from the Crossref database on November 23, 2023. This research uses the Research Information System (RIS) format to capture data using Publish or Perish software. The format is filtered again using VOSviewer software. VOSviewer aims to visualize the results of data processing that has been netted. The netting results were obtained from several dominant keywords, namely Asphalt, Pavement Material, Pavement Design, and Road Material. This research nets 993 documents out of 1000 research documents netted from 2000 to 2023. The documents netted include 1 grant, 31 standards, 10 components, 2 datasets, 3 reports, 859 journal-article, 2 journals, 49 book chapters, 30 proceedings articles, 1 posted content, 1 book, 1 other, 3 proceedings. This research was carried out to analyze the development of previous research up to the present.*

Keywords: *Road, Road Damage, Rainfall Intensity, Road Pavement.*

INTRODUCTION

In an era that continues to develop, transportation is one of society's needs. The success of transportation is measured by the availability of transportation facilities and infrastructure, including roads. Roads are essential, especially in implementing inter-regional development, equitable distribution of development results, and strengthening defense (Hendrawan et al., 2022). Roads are needed for humans to move from one place to another to fulfill their needs (Kanwal et al., 2020). Roads play a role in supporting economic and social activities. Given the vital role of road infrastructure in promoting economic growth supported by adequate road infrastructure, every stage of road planning, implementation, and maintenance must be appropriately managed to ensure that road services can function adequately to meet the expectations of road users (Kanwal et al., 2020).

As a developing country, Indonesia continues to improve and build roads every year. In Indonesia, transportation infrastructure development is aimed at reducing congestion, especially road network infrastructure development in several major cities in Indonesia, is increasing along with economic growth and demographic trends (Aryasatya, 2023). Transportation infrastructure supports economic, social, and other activities. Therefore, good roads are needed so that the movement of community activities can be safe, comfortable, and smooth. Various factors, including vehicle overload, high rainfall, and poor road drainage, can cause road damage. Poor road quality and road damage can hamper human activities, endanger road users, cause accidents, and affect the comfort of road users. Road damage can cause losses that road users directly feel because road damage can cause problems that authorized government agencies cannot directly handle. In addition, road damage in mountainous areas is more dangerous and requires special handling.

There are many damaged roads in Indonesia. These include moderate and severe damage. In mountainous areas, landslides caused by heavy rains often damage roads. Road damage caused by heavy rains can also cause landslides on slopes, leading to drainage problems. If the drainage system is covered with soil fill, rainwater will not drain properly and may be prevented from flowing through the drainage system. Regular road maintenance and inspection are also necessary to maintain the condition of roads in mountainous areas. Timely maintenance can avoid significant repair costs in the

future and ensure better road safety.

Road damage is an ongoing problem both globally and regionally. Road damage causes losses for road users, such as longer travel time, traffic congestion, traffic accidents, and others (Abdulrazzaq et al., 2020). Road damage must indeed be considered for the smooth running of human activities. This bibliographic analysis of road damage aims to understand and identify various aspects and take the necessary steps for improvement, maintenance, or better planning in road infrastructure management. This research analysis is the basis for better decision-making to improve road infrastructure. This research analysis can be used as a basis for better decision-making in road infrastructure improvement. So, with this research, safety, comfort, security, and smoothness in traffic are even better.

This research required bibliographic analysis to help understand the complexity of road damage research and scholarship. This analysis provides important insights into the development of science, the productivity of researchers, the relationships between research topics, and the impact of publications in the field of science. Bibliometric analysis uses data on the number and authors of scientific publications and cited articles to measure the output of individuals or teams of researchers, institutions, and countries. In addition, bibliographic analysis allows for identifying national to international networks and mapping the development of scientific fields (Zakiyyah et al., 2022). Bibliometric analysis in this study was carried out using VOSviewer. VOSviewer is very useful in academic research, significantly helping researchers understand citation networks and trends in scientific literature. VOSviewer is very helpful in identifying key concepts, influential researchers, and the most relevant topics in a field of research.

Speaking of transportation, we cannot avoid the development of research on roads and their facilities. Roads are one of the most crucial land transportation infrastructures, so good pavement design is essential. The road network plays an important strategic role in development and must be managed effectively (Sasmito et al., 2023). Indonesia's road network is snowballing to increase infrastructure and land transportation needs, so road construction is significant in daily operations to minimize damage to the road surface (Purwanto et al., 2023). Thus, highways are very useful in supporting all kinds of human activities.

Roads are the most common transportation infrastructure people use for their daily activities. Therefore, the number of vehicles passing through a road section affects the road's carrying capacity and carrying capacity (Lioris et al., 2017). Given the population growth that is increasing from year to year, the condition of the road is expected to be in good condition (Tandiongan et al., 2023). A good road is a road that is in good condition and free from damage or deterioration. To maintain good (stable) road conditions, it is necessary to periodically evaluate road conditions and carry out road maintenance actions according to the results (Budiman et al., 2023).

In the transportation system, it is expected that roads are always maintained and in good condition. Good road conditions are the dream of all road users. The purpose of a good road is to avoid negative impacts on the transportation system. Road damage is one of the traffic problems, namely traffic accidents, that need to be addressed immediately because it affects the safety of road users (Wildi Kusumasari, 2022).

In the context of this research, analyzing road defects is crucial for the smooth operation and safety of the transportation system. This study draws conclusions from the analysis of the road defects investigated. This research also incorporates previous and current research on road defects. Therefore, road deterioration research requires up-to-date road data to draw conclusions that serve as benchmarks for future research.

In general, road damage is caused by various reasons, including the age of the road plan that has been passed, the accumulation of water on the road surface due to transverse slope (drainage), road damage due to repeated traffic loads (overloading), which causes the life of the road to be shorter than the planning life (Shim et al., 2021). A flat and smooth road condition is the dream of every vehicle driver [13]. Good road conditions facilitate people's economic and social movement (Heriyanto et al., 2023). However, as they are used, they can cause damage to the road (Issa et al., 2022).

Road damage causes inconvenience to road users when used at high speed due to uneven road surface conditions due to damage such as collapse, potholes, crocodile cracks, and others (Wibowo & Despa, 2023). As the region develops, human activities such as transportation activities are

increasing, so road conditions that often experience increased traffic can reduce the quality of the road surface and damage its structural and functional conditions (Rabiupa et al., 2023). Road damage can be reflected in damage to the road structure. Road damage can also vary in each segment of the road.

Several factors can cause road damage. High levels of rainfall can also cause roads to deteriorate. Heavy rainfall can cause water to pool, eventually loosening the asphalt layer and causing the asphalt particles to separate. Therefore, research into the condition of the road surface and other parts of the road is essential to understand the extent of the damage (Feriska et al., 2023).

By its characteristics, the road tends to deteriorate, which is indicated by damage to the pavement. To slow down the damage and keep the road in good condition, the road must be well-maintained and always functioning correctly (Manurung et al., 2022). Road construction planning without adequate road maintenance, both routine and periodic, will cause damage to the road so that it will quickly lose its function (Safitri & Septian, 2023). Therefore, solving these problems requires accurate road damage data and rehabilitating the road.

Pavement is a structure designed for strength, durability, and rigidity and installed on a subgrade (Bamher, 2020). Each road is designed with a specific pavement design to withstand certain loads and certain conditions so that as Indonesia's population increases, most vehicles that cross the load will have an allowable load, so the number of vehicles is increasing (Arsita et al., 2023). The types of road pavement can be Flexible Pavement, Rigid Pavement or cement concrete pavement, and Composite Pavement, which combines rigid and flexible pavement (Arsita et al., 2023). This type of pavement has its advantages and disadvantages (Harizalsyah et al., 2023).

In road conditions, it is necessary to re-plan the pavement. This re-planning refers to the road that is experiencing damage (Lorinanto & Siswoyo, 2023). A road with a stable pavement structure can provide safety and comfort for its users (Bariq Al Salam et al., 2023). Proper design is required when designing the road surface. In addition to good planning, the road must be adequately maintained to accommodate the increase in traffic volume over the planning period (Frangopol & Liu, 2019).

High rainfall intensity is one of the factors that can cause pavement damage. However, various drainage channel utility problems during rain interfere with the smooth traffic flow on the road, such as sediment, blockages, and puddles. Water puddles are caused by the non-optimal function of drainage channels, which interferes with traffic flow and road user comfort (Norhadi et al., 2023). High rainfall intensity can cause stagnant water and cause road pavement damage.

A method called PCI (Pavement Condition Index) is required to understand the state of pavement damage. Assessment of pavement damage conditions developed by the U.S. Army Corp of Engineers, expressed in the Pavement Condition Index PCI (Pavement Condition Index), is a system of assessing the condition of road pavement based on the type, level of damage that occurs and can be used as a reference in maintenance efforts (Rinaldi et al., 2022). A good pavement must resist erosion due to traffic, weather changes, and other adverse influences (Sutapa et al., 2022).

MATERIALS AND METHODS

In this research, the type of methodology used is to use bibliometric analysis. In using the bibliometric analysis method, it is necessary to conduct research relevant to the research being conducted. The selection is taken from trusted, qualified, and accurately considered sources so that the bibliometric method is needed in the research process. This research examines the issue of road damage from year to year. One of the methods used in this research is bibliometric methods using Harzing's Publish or Perish and VOSviewer software.

Harzing's Publish or Perish is used to collect the development of scientific publications on topics related to road damage research worldwide. To conduct research, mapping is also carried out, which will produce a result in this study. The mapping is based on the author and keywords of the collected scientific publications (Maulinda & Fathaddin, 2023). This research also uses Mendeley software to cite and get quality scientific papers. This method is used to visualize the results of data analysis obtained from Publish or Perish (PoP).

The research used keywords in the Crossref database to identify internationally published research. Crossref was chosen because it is one of the most widely used databases for researching and producing scientific papers. In addition, Crossref is also used because of its easy access to scientific works in the world. Crossref also makes it easy for users to collect data. In the database review, it is searched based on the author's keywords. These keywords are used to narrow down publications more relevant to road damage. The following research flow chart explains how to visualize the research presented in Figure 1.

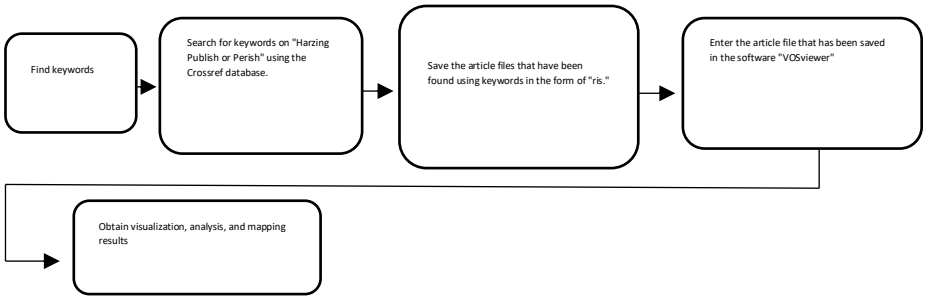

Figure 1. Research Flow Chart

The author focuses on research using the keywords Road, Road Damage, Rainfall Intensity, Road Maintenance, and Pavement. The range of scientific papers published on Harzing's Publish or Perish software contains 1000 scientific papers from 2000 to 2023. Data was collected using Harzing's Publish or Perish software and VOSviewer from August to December. In the data collection process, the author uses the Publish or Perish (PoP) software version (XXX), VOSviewer version 1.6.19, and Mendeley version 1.19.8. Based on the results of data searches using PoP, 993 documents were obtained from 2000-2023. After this search, data visualization was carried out using VOSviewer. This software is used to get data visualization with various exciting visuals.

RESULTS AND DISCUSSION

Keywords are essential before conducting research. Keywords help users or searchers to get information about the content that best suits their needs (Gusenbauer & Haddaway, 2020). In this study, the keyword search resulted in 993 research documents. The research documents obtained are the results of publications from 2000 to 2023.

Research Publications per Year

one of the analyses related to bibliometric analysis. The analysis of research data per year is processed to find the most recent years related to the research topic. The results of this research data collection illustrate the visualization results that can be understood. The results of research data processing per year are presented in the following graph (Figure 2.).

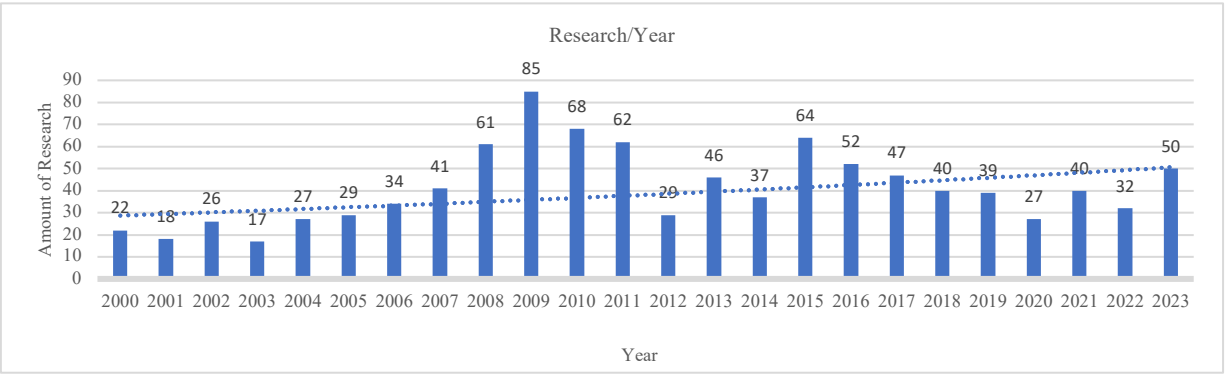

Figure 2. The development of publications on "Road Damage Due to High Rainfall Intensity in Mountainous Areas" 2000-2023 taken from the Crossref database

Figure 2 above shows that research journal documents on the topic "Road Damage Due to High Rainfall Intensity in Mountainous Areas" were produced in 2009 with 85 research journal documents; the lowest research documents were in 2003 with 17 research documents. The research data is taken from the Crossref database and imported from Publish or Perish into Microsoft Excel. The presentation of the figure above shows that the development of research according to the topic progressed from 2000 to 2003.

Network Visualization Based on Writer and Research Keywords

When visualizing research development mapping in the world, VOSviewer is very helpful in visualizing research mapping. VOSviewer helps map starting from authors, research documents, researcher countries, etc. In the visualization of Figure 3 below, there are three clusters (red, green, and blue). Of the three clusters, it indicates that in that cluster, the author did the most research on "Road Damage Due to High Rainfall Intensity in Mountainous Areas."

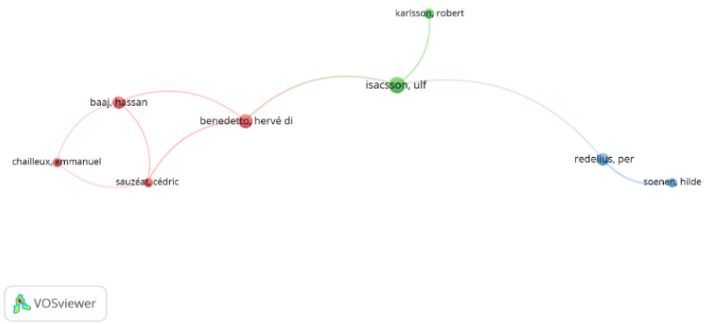

Figure 3. Visualization of network author on the keyword "Road Damage Due to High Rainfall Intensity in Mountainous Areas" in 2000-2023.

In the analysis of the author's research above, it is known that there are several authors related to the research topic. The author also has several documents related to the research topic. The number of studies can be a benchmark for the relationship between research topics and the number of author studies. The following data processing results are presented in tabular form (Table 1.) below.

Table 1. Most authors who published research in 2000-2023

Color	Node	Author	Number of Documents
Red	Big	Benedetto, Hervé Di	11
	Medium	Baaj, Hassan	9
	Small	Chailleux, Emmanuel	5
		Sauzéat Cédric	5
Green	Big	Isacsson, Ulf	15
	Small	Karlsson, Robert	6
Blue	Big	Redelius, Per	8
	Small	Soenen, Hilde	5

Table 1 shows 3 authors on large nodes: Benedetto, Hervé Di, Isacsson, Ulf, Redelius, and Per. Among the three authors, Isacsson Ulf is the author who has the most prominent node and dominates the research topic "Road Damage Due to High Rainfall Intensity in Mountainous Areas," with a total of 15 researchers. From this, Isacsson Ulf is an author often used as a reference in research and is productive in researching "Road Damage Due to High Rainfall Intensity in Mountainous Areas. The number of publications can illustrate the productivity and contribution of authors in research to gain new knowledge.

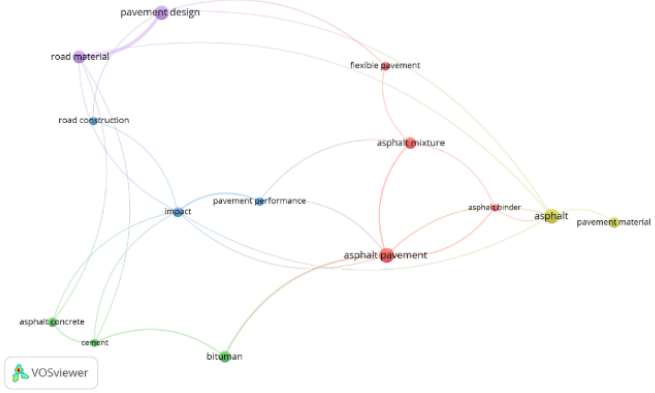

Figure 4. Network Visualization of the keyword "Road Damage due to High Rainfall Intensity in Montainous Areas" in 2000-2023

After analyzing using VOSviewer in Figure 4, 5 clusters (red, green, yellow, purple, blue) are in the research mapping "Road Damage Due to High Rainfall Intensity in Mountainous Areas." Clusters represented by different colors indicate the relationship between one topic and another, and nodes in clusters with the same color indicate similar topics in the publication [33]. Purple, green, and red clusters are widely researched topics of the five clusters. Blue and yellow colors are rarely researched topics. Of the five words in the cluster, the words Asphalt, Asphalt Pavement, and Pavement Design are the most popular because the node size is the largest, which means that Asphalt, Asphalt Pavement, and Pavement Design are the most frequently dominating topics on "Road Damage Due to High Rainfall Intensity in Mountainous Areas."

The relationship between keywords based on relevance can be used as research data processing based on bibliometric analysis. The relationship between keywords based on relevance is presented as a graph (Figure 5.).

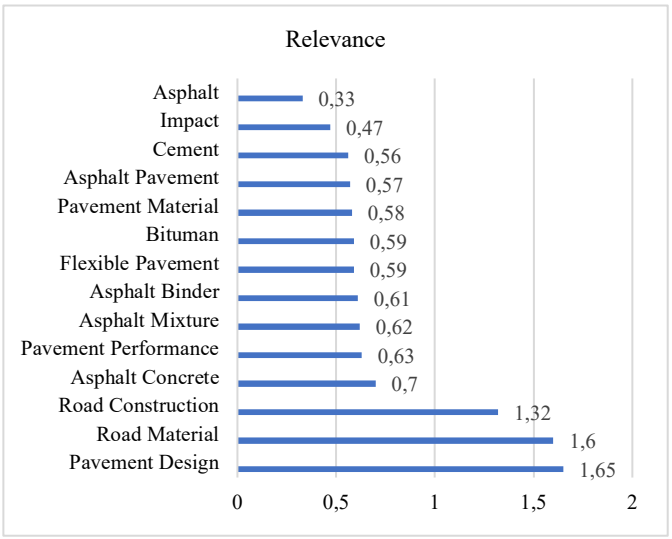

Figure 5. Keyword graph by relevance

Figure 5 above shows the relationship between keywords based on relevance. based on relevance, there is also a relationship based on relevance. This relationship can benchmark the relationship between keywords and research topics. The following keyword linkage based on occurances is presented in graph form (Figure 6.)

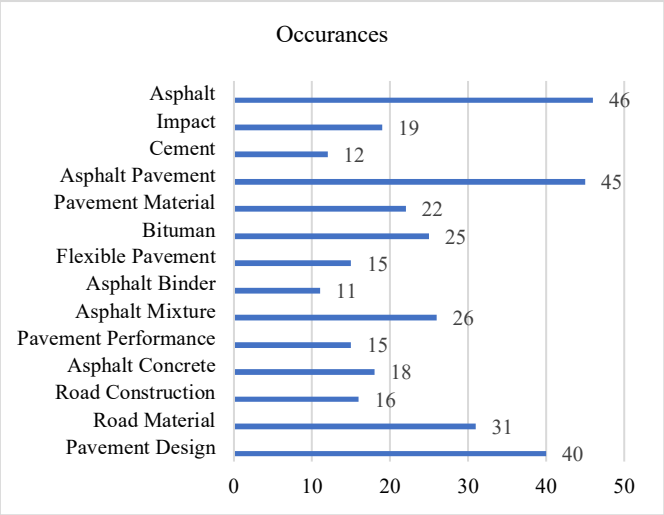

Figure 6. Keyword graph by occurances

Research Citation Author

The number of publications cannot measure the success of an author. The quality of publications can be known from the relationship between research topics and the number of citations. In addition, collaboration between researchers, author involvement with significant research, and recognition from scientific authors can be used as a reference for the success of an author's research. The number of citations and the relevance of significant citations can also indicate the success of scientific research. Research with high citations can be research that is significantly related to the research topic. The following figure shows the number of authors with the most citations.

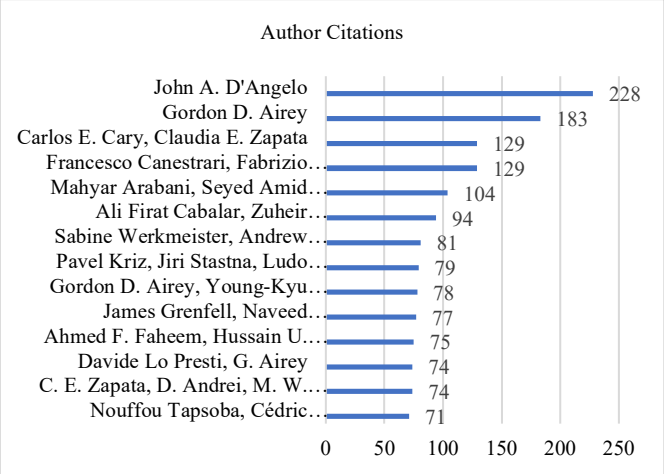

Figure 7: Author graph with the most citations

Figure 7 shows that the author with the highest number of citations is John A. D'Angelo, with 228 citations, followed by Gordon D. Airey with 183 citations, and Francesco Canestrari, Fabrizio Cardone, Andrea Graziani, Felice Ausilio Santagata, Hussain U. Bahia, Carlos E. Cary, Claudia E. Zapata with 129 citations. This means that the research conducted by these authors significantly contributes to research on the topic of "Road Damage Due to High Rainfall Intensity in Mountainous Areas." The article that is the focus of the most citations is The Relationship of the MSCR Test to Rutting," written by John A. D'Angelo.

Visualization of Overlays Based on Research Authors and Keywords

Based on Overlay Visualization using VOSviewer linking keyword years and research authors (Figures 8,9), get visualization results from search results data on Publish or Perish. The following figure shows the results of overlay visualization on VOSviewer.

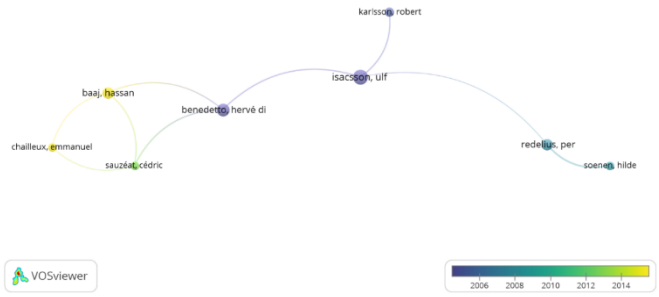

Figure 8. Visualization of author overlay on the keyword "Road Damage Due to High Rainfall Intensity in Mountainous Areas" in 2000-2023.

In the author overlay visualization, the data obtained is processed again in Table 2 below:

Table 2. Visualization results of network author on the keyword "Road Damage Due to High Rainfall Intensity in Mountainous Areas" in 2000-2023.

Year	Color	Authors
2006	Dark Blue	Isacsson, Ulf , Karlsson, Robert, Benedetto, Hervé Di
2008	Light Blue	Redelius, Per, Soenen, Hilde
2010	Dark Green	-
2012	Light Green	Sauzéat Cédric
2014	Yellow	Baaj, Hassan, Chailleux, emmanuel

Figure 8 and Table 2 show the results of visualization data from VOSviewer. The visualization results show that most authors who conducted research were in 2006. These results can be seen from the cluster showing the number of authors who researched "Road Damage Due to High Rainfall Intensity in Mountainous Areas." The cluster is found in dark blue, where the authors who conducted research in the dark blue cluster consist of Isacsson, Ulf, Karlsson, Robert, Benedetto, and Hervé Di. This visualization shows few clusters, which means that very few authors researched this topic.

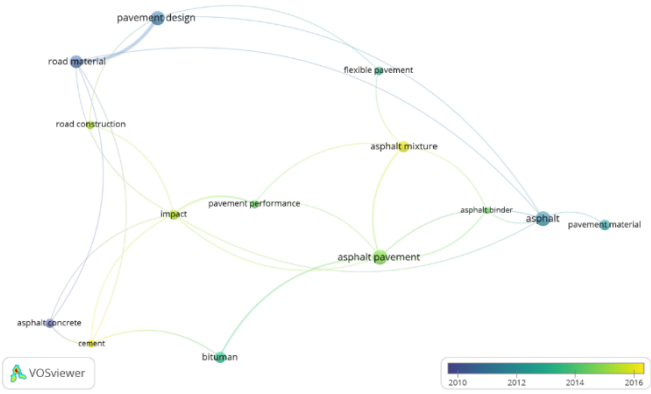

Figure 9. Visualization of the overlay on the keyword "Road Damage Due to High Rainfall Intensity in Mountainous Areas" for 2000-2023.

When viewed in Figure 3, it can be seen that the visualization of cluster colors is dominated by light blue, which links interconnected points. The light blue cluster was dominated in 2012 with several interrelated keywords. These keywords include Asphalt, Pavement Material, Pavement Design, and

Road Material. The results of this visualization are divided into clusters with different topics but still related to the main topic of the research. The results of this keyword overlay visualization can be a reference for the development of further research. Therefore, researchers can consider doing further research on this research topic.

Visualization of Density Based on Research Authors and Keywords

The density visualization data on keywords and research authors (figures 10,11) below shows the density indicated by a bright yellow color. The brighter the color, the more research has been conducted. On the other hand, the dimmer the color visualized, the less research conducted. Several factors can also cause the dim color. These factors can be due to a different research focus, relatively new research, or lack of relevance to the research topic. The following are density images based on the visualization results using VOSviewer (Figures 10,11).

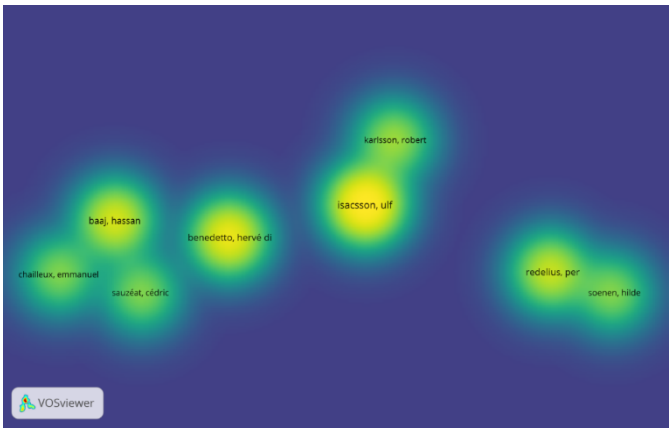

Figure 10. Visualization of Density author on the keyword "Road Damage Due to High Rainfall Intensity in Mountainous Areas" in 2000-2023.

The visualization results of author density with research topics are dominated by Isacsson, Ulf, Karlsson, Robert, Benedetto, and Hervé Di. This shows that these authors have many links to the research topic.

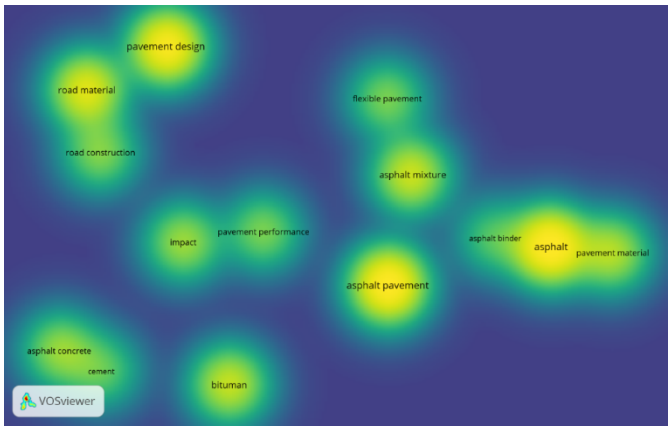

Figure 11 Visualization of density on the keyword "Road Damage Due to High Rainfall Intensity in Mountainous Areas" in 2000-2023

Asphalt, Asphalt Pavement, Road Material, Pavement Design, Asphalt Mixture, and Bituman dominate the Visualization results of author density with research topics human. This shows that these keywords have many links to research topics.

Research by Publisher and Type

After collecting data with Publish or Perish, the research data came from various publishers. This shows that diversity in publishing can support science development in the world's existing publication data related to science in civil engineering. Below is publisher data on survey data from 2000 to 2023, presented in Table 3 below.

Table 3. Data on the Distribution of Publishers and the number of studies in 2000-2023

Publisher	Amount
American Society of Civil Engineers	18
Asian Development Bank	2
ASTM International	3
Atlantis Press	1
Author(s)	1
BSI British Standards	31
Chongqing VIP Information Co.,Ltd.	1
Civilicom	2
CRC Press	31
Elsevier	1
Elsevier BV	4
Emerald Group Publishing Limited	1
ICE Publishing	1
Informa UK Limited	826
Institute of Industrial Applications Engineers	1
International Journal of Advance Engineering and Research Development (IJAERD)	1
Japan Society of Civil Engineers	1
Japan Society of Mechanical Engineers	1
Kardan University	1
Korean Society of Road Engineers	1
MDPI	2
MDPI AG	2
Morressier	1
Moscow State University of Civil Engineering	1
National Bureau of Economic Research	1
Organisation for Economic Co-Operation and Development (OECD)	10
Penerbit UTM Press	1
PT Formosa Cendekia Global	1
Research Publishing Services	1
Ridwan Institute	1
Riga Technical University	11
Saxe-Coburg Publications	1
Science & Engineering Research Support soCiety	1
Seventh Sense Research Group Journals	1
Springer Berlin Heidelberg	3
Springer International Publishing	7
Taylor & Francis	1
The Institute of Industrial Applications Engineers	1
Trans Tech Publications, Ltd.	1
Universitas Islam Sultan Agung	1
University of Zagreb Faculty of Civil Engineering	9
UPT Penerbitan Universitas Jember	1
Whitaker Institute	1
Wiley	1

In addition to capturing publisher types, research types have been successfully netted using Publish or Perish. Of the various types of research, there are grants, standards, components, datasets, reports, journal articles, journals, book chapters, proceedings articles, posted content, books, other, and proceedings. The types of publishers captured are related to the development of existing research. Therefore, the type of publisher and research affect the research development

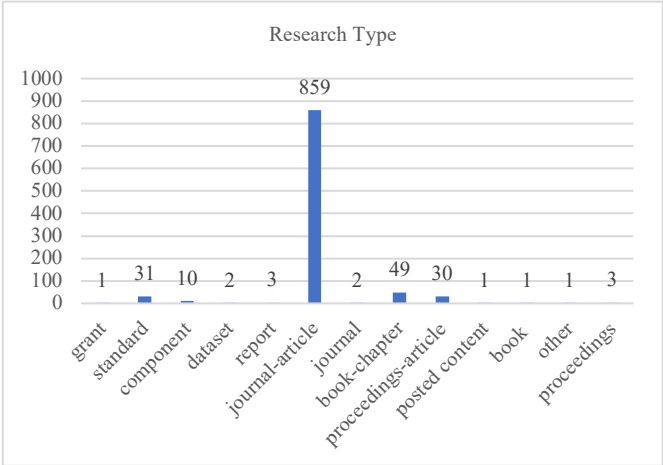

Figure 12: Graph of authors' research type classification from 2000-2023

CONCLUSION

This research uses bibliometric analysis to capture and visualize the topic being researched. This analysis captures the suitability of keywords to the research topic of road damage due to high rainfall intensity in mountainous areas. With the use of Publish or Perish in this research, there are 993 documents in 2000-2023 from the results of 1000 research documents. This research document consists of 1 grant, 31 standards, 10 components, 2 datasets, 3 reports, 859 journal-article, 2 journals, 49 book-chapters, 30 proceedings-article, 1 posted content, 1 book, 1 other, 3 proceedings. From the screening results using VOSviewer, there are 4 dominant keywords: Asphalt, Pavement Material, Pavement Design, and Road Material. Several other keywords are still related to the research topic from these dominant keywords. In addition to data mining based on keywords, data mining based on authors is also visualized in this study. It was found that the authors who researched the dark blue cluster consisted of Isacsson, Ulf, Karlsson, Robert, Benedetto, and Hervé Di, who were most related to the research topic. The visualization results also get influential research authors on road damage due to high rainfall intensity in mountainous areas. From the data mining results from 2000- 2023, the most researched research topic was in 2009. Publisher and type of research also influence the research. After netting and processing the data, there is a publisher that publishes the most research related to civil engineering science, namely Informa UK Limited, with a total of 829 studies. Author citations also influence research. John A. D'Angelo owns the author citation most related to the research topic with 228 citations. With this filtering and visualization, it can be concluded that the research topic on road damage is growing yearly and spreading worldwide, which will undoubtedly further develop the development of science.

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