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A Scientometric Review of Climate-Induced Road and Pavement Deterioration in South Africa

Nura Shehu Aliyu Yaro[a], Jacob Adedayo Adedeji [a], Ashiru Mohammed[b], Zesizwe Ngubane[a]

[a] *Durban University of Technology, Durban, South Africa*
[b] *Ahmadu Bello University, Zaria 810107, Nigeria*

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Corresponding author:
nura_19001733@utp.edu.my

ORCID ID
Nura Shehu Aliyu Yaro: 0000-0002-7780-9620
Jacob Adedayo Adedeji: 0000-0002-3222-7846
Ashiru Mohammed: 0000-0001-5186-5926
Zesizwe Ngubane: 0000-0001-5379-2580

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ABSTRACT

One of the key challenges in the South African construction industry is road and pavement deterioration driven by harsh climatic conditions, particularly heavy rainfall and flooding, which adversely affect both infrastructure performance and road users.While this area needs further studies, the extent of the research is still unmapped. Consequently, this article employs a scientometric analysis to critically visualise the research trends and examines the body of research on climate-induced road and pavement deterioration in South Africa. The Scopus database was utilised to retrieve publication from 2000 to 2025. The research literature retrieved was then analysed using VOSviewer to identify the trends, research clusters, emerging thematic areas, and future directions. The findings demonstrated a steady increase in research activity with literature on flooding, climate change, and risk assessment. The top 5 keywords in this field of study were discovered to be South Africa, rainfall, floods, roads and streets, and flooding. The study also discovered that major areas like the Western Cape and KwaZulu-Natal, particularly Durban, are prominent regions severely affected by climate change. As a result, extreme weather events like floods and heavy rainfall have seriously damaged roads and infrastructure. Also, key publication sources were found to be Water (Switzerland) and Water SA. This review offers a knowledge roadmap to support additional research and emphasises the need for awareness and sustainable practices to improve resilience in South Africa's roads and flood management frameworks by incorporating quantitative findings into ongoing research.

1. Introduction

Road infrastructure is essential to social integration, economic growth, and mobility networks (Hapriyanto & Azmi, 2025; Varghese & Pradhan, 2025). The availability of infrastructure and transport facilities, such as pavements, is a key indicator of the success of a transport system (Dokyi, Tookey, Rotimi, & Osei, 2024; Hapriyanto & Azmi, 2025). Pavements are crucial, particularly for carrying out interregional development, distributing development outcomes fairly (Dokyi et al., 2024; Swarna & Hossain, 2022). This infrastructure plays a vital role, but it is becoming more susceptible to climate stresses like rising temperatures, varying precipitation patterns, stronger storms, and sporadic drought cycles (Das & Devadas, 2025; Liu, Yang, Jiang, Liao, & Castillo-Camarena, 2023). Long-term network resilience and sustainability are threatened by the functional and structural deterioration of pavements under climate change, which imposes high financial costs through higher maintenance costs, asset devaluation, and decreased serviceability (Hirwa & Mostafa, 2025; Liu et al., 2023; Swarna & Hossain, 2022). In South Africa, climate change presents serious concerns to the development and socioeconomic stability (Dube & Nhamo, 2025; Matsa, Chapungu, & Nhamo, 2024) and causes both economic and infrastructural damages (Coetzee et al., 2023; Scott, 2025). Climate change contributed to a considerable decrease in pavement service life, requiring pavement maintenance to occur 8%-16% earlier (Swarna & Hossain, 2022). Thus, pavement should receive regular maintenance earlier than anticipated in order to preserve its service life (Liu et al., 2023).

South African roads and pavement systems facilitate freight movement, commuter mobility, and regional connectivity throughout a variety of climatic zones, from arid inland regions to humid coastal areas, with an estimated network spanning more than 750,000 km (Rust et al., 2024; Sefolo et al., 2024). Every year, the number of vehicles rises, making it more difficult to keep pavements in good shape (Scott, 2025; Yaro et al., 2022). In order to guarantee user safety and comfort, a well-performing pavement must have structural integrity, smooth surfaces, and sufficient drainage (Blaauw, Maina, Mturi, & Visser, 2022; Scott, 2025). Over the past few years, there has been an increase in scholarly interest in the relationship between pavement engineering and climate change (Liu et al., 2023; Swarna & Hossain, 2022). Research has developed on a global scale to measure the effects of climate change on pavement performance, create predictive models for climate-responsive design, and suggest adaptation techniques to reduce environmental concerns (Liu et al., 2023; Palu, Garcez, & Brito, 2025; Swarna & Hossain, 2022). However, the literature demonstrates regional bias, methodological discrepancy, and fragmentation in area focus, with a disproportionately significant number of studies coming from temperate regions in contrast to the Global South.

Particularly in South Africa, research on road damage brought on by climate change is still in its infancy. There are few attempts to synthesise the breadth of information or track thematic change throughout the larger scientific landscape, and existing works of literature are typically discipline-bound or localised. In countries like South Africa, where rainfall intensity, unpredictability, and extreme precipitation events have increased due to changing climatic regimes, heavy rainfall leads to flooding (Belle, Jordaan, & Collins, 2018; Cilliers, 2019).This has become a significant climatic stressor affecting pavement performance and durability. Heavy rainfall is regarded a severe problem in various South African cities such as Durban, Johannesburg, Cape Town, and Pretoria, exerting pressure on pavement infrastructure and economic activity (Blaauw et al., 2022; Lane-Visser & Vanderschuren, 2023). The synergetic effects of climate change and expanding urbanisation have increased the frequency and intensity of heavy rainfall events nationwide, which are mainly responsible for this growing risk (Mashamaite, 2025; Palu et al., 2025). Additionally, scholarly outputs that specifically address the South African environment are still dispersed among disciplines, techniques, and publication channels, despite a rising body of research addressing climate impacts on pavement systems globally. However, scientometric knowledge-mapping approaches have not yet been employed to evaluate climate-induced road and pavement deterioration, particularly in South Africa. As a result, there have been few studies on research mapping and scientometric analysis, which could drive future research objectives, support, and promote multidisciplinary cooperation, and provide precise information on South African climate issues. Given the rising susceptibility of South African pavement infrastructure to climate-induced rainfall extremes, there is an urgent need to thoroughly assess existing research efforts, emerging themes, and knowledge gaps in this subject, according to the literature. Consequently, to understand the complexities of research on climate-induced road and pavement deterioration in South Africa, this study conducted bibliographic analysis from 2000 to 2025.The bibliography provides valuable insights into examining and identifying the major keywords in the study region, the most significant journals, the publication type, the research topic, and the publication trend, as well as comprehending the development of scholarly discourse while employing VOS viewer for the mapping and visualisation. The following questions serve as the basis for the review:

a) What is the trend in South Africa's research output on climate-induced pavement and road deterioration between 2000 and 2025?
b) During this time, which publication source has contributed the most to climate-induced pavement and road deterioration in South Africa?
c) Which are the most pertinent keywords searched on climate-induced road and pavement deterioration in South Africa?

The study advances both scholarly debate and useful policymaking by synthesising the framework and trajectory of research in this field, and also offers researchers, infrastructure agencies, and climate adaptation experts with a systematic yardstick for climate-induced road and pavement deterioration in South Africa.

2. Methodology

Following the PRISMA 2020 standards, a systematic review was conducted to collect the data needed for this investigation (Page et al., 2021; Yaro et al., 2025). The retrieved publications were subjected to a scientometric analysis, which included contributions from publication sources, the most prominent and prolific authors and nations, and annual publication and citation patterns of studies related to climate-induced road and pavement deterioration in South Africa. Furthermore, network perspectives, including author and source co-citations, bibliographic coupling of authors, nations, and sources, and keyword co-occurrence, were examined. In order to examine trends in climate-induced road and pavement deterioration in South Africa from 2000 to 2025, this study uses a scientometric mapping approach. Large collections of scientific literature can be examined and interpreted using scientometric analysis, a statistical technique that finds connections and trends within the field of study.

2.1. Data retrieval

The Scopus database was chosen as the primary data source due to its vast coverage of peer-reviewed research and solid metadata, which provide a solid foundation for analysis (Yousafzai et al., 2025). On October 28, 2025, a methodical keyword-based search strategy was used to retrieve the data. To ensure that pertinent papers were included, the keywords "road" OR "roads" OR "pavement" OR highway OR "transport infrastructure" AND "rain" OR "rainfall intensity" OR "precipitation" OR "storm" OR "flood" OR "extreme weather" AND "South Africa" were entered into the title, abstract, and keyword fields (TITLE-ABS-KEY) of Scopus. An initial dataset of 128 records was obtained from the search. As indicated in Table 1, well-defined inclusion and exclusion criteria were methodically applied to guarantee the literature's quality and relevance. Following the application of these criteria, the dataset was reduced to 62 documents, and the selected dataset was used for the scientometric analysis.

Table 1. Data screening criteria for inclusion and exclusion

Criteria	Inclusion	Exclusion
Country	South Africa	Countries other than South Africa
Publication year	2000-2025	Before 2000
Language	English	Non-English
Subject area	Environmental Science and Engineering	Studies not related to Engineering and Environmental Science
Article type	Journal, conference paper, books, review	Concept paper, editorial, and retracted paper
Publication stage	Published	Article in press

2.2. Analysis

The data for this study was analysed using a scientometric mapping technique to examine contributions and trends in research related to climate-induced road and pavement deterioration in South African research between the years 2000 and 2025. The study used VOSviewer and Microsoft Excel to examine important scientometric variables such as publishing trend over time and document type. Furthermore, by tracking the occurrence of author keywords over time, the study looked for fluctuations in the field's thematic focus. These evaluations show important research trends, emerging areas of interest, and interaction dynamics (Yousafzai et al., 2025). VOSviewer (Version 1.6.18), a freely available visualisation software, was utilised to evaluate and visualise author and source co-citations, bibliographic coupling of authors, nations, and sources, and keyword co-occurrence. One of the most important steps in filtering and improving scientometric mapping in VOSviewer is to establish a threshold, such as a minimum number of co-citations, publications, or occurrences. The co-occurrence network was shown using nodes and links.

The size of each node represented the frequency with which a specific keyword appeared in relation to others, and the connections between nodes demonstrated the degree of association. Thicker links indicated more robust associations between concepts (Baffa et al., 2025). Each cluster was assigned a unique hue to represent research themes and collaborative groups. Different areas of interest within the dataset were indicated by the high thematic similarity seen among nodes in the same cluster.

3. Results and discussion

3.1. Annual publication trend

The dataset's statistical analysis tracked trends in climate-induced road and pavement deterioration in South Africa research from 2000 to 2025. Despite occasional fluctuations, this quantitative analysis showed that academic interest has generally increased over time. Figure 1, which shows the annual distribution of published articles with certain numerical growth metrics, provides a visual representation of the findings. The data demonstrate that there are some years like 2002, 2004, 2006, 2007, and 2010 where there is no activity in the field, with zero (0) annual publication counts. Nonetheless, academic output began to be consistent in 2011 with four (4) publications. The number of annual publications increased from one (1) to five (5) in 2012, a significant rise from 2008, with 1 publication. The average of at least two (2) publications from the year 2016 indicates that climate-induced road and pavement deterioration in South Africa has grown in importance in response to the pressing issues of climate change and its effect on roads and pavement. There were seven (7) publications by 2025 compared to four (4) in 2024. In light of expanding urbanisation and climate variability, this increase demonstrates a greater understanding of the significance of research relating to climate-induced road and pavement deterioration in South Africa.

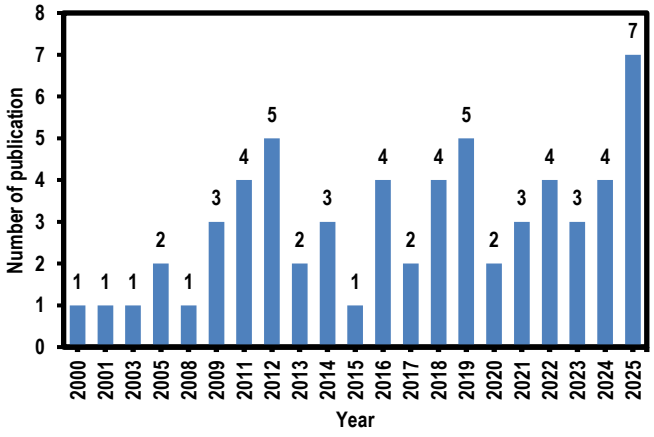

Figure 1. Research publication distribution trend from 2000 to 2025

3.2. Document type

Figure 2illustrates the variety of document types on climate-induced road and pavement deterioration in South Africa between 2000 and 2025. The distribution of publications reflects an expanding and diverse research landscape. 46 peer-reviewed journal papers, which account for 74.19% of all publications and contribute more to all document categories. Then, conference papers make up roughly 24.19% of the document type, with 13 articles that include early research ideas and a simple way to spread research that hasn't yet been developed into journal publications. These sessions provide early indicators of research trends, particularly in areas where applied research is rapidly increasing. Finally, review articles with one publication provide 1.62% of the total publication, presenting challenges, summarising the body of knowledge, and recommending topics for further research. The prevalence of journal publications reflects the scientific capabilities of the area, but the range of publication approaches dictates ongoing knowledge expansion and the need for more research.

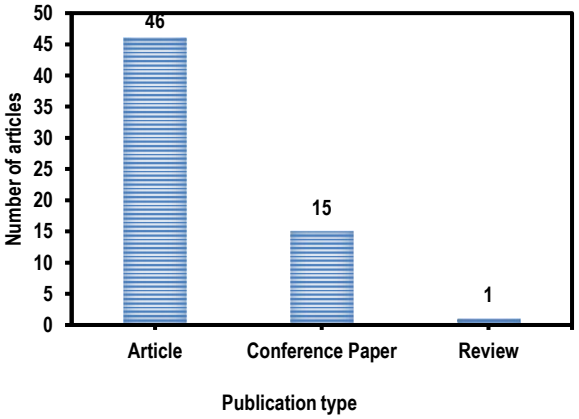

Figure 2. Document type and distribution related to the research area

3.3. Keywords co-occurrences

Keyword analysis provides crucial insights into the development and thematic organisation of research on climate-induced road and pavement deterioration in South Africa from 2000 to 2025. Table 2 shows the top 25 keywords used by authors. The co-occurrence and temporal visualisations highlighted the field's evolving goals while revealing unique regions of research concentration. Five prominent clusters of study themes were found by the co-occurrence network, which is depicted in Figure 3. Nodes indicate the frequency of keyword usage, and links indicate the strength of correlations between terms. Keywords such as "South Africa," "rainfall," "flood," "roads and streets," " flooding," and "KwaZulu-Natal" are prevalent in one of the biggest clusters, which focuses on the effect of rainfall and floods on South African pavement and roads.

The foundational work in this cluster aims to improve the technical synergy and impact of climate-induced damages on South Africa's pavement infrastructures in the field. The various colours represent clusters of terms that are used together by authors in their publications, showing dominating theme groups in the literature. All detected clusters are associated with climate-induced degradation to South African road and pavement infrastructure.

Figure 3(b) depicts an overlay visualisation of current research patterns, with “KwaZulu-Natal” and “flooding vulnerability” surfacing as major recent clusters. These include phrases like "Durban," "flooding," "informal settlement," and "risk assessment." In the framework of sustainable urban planning, this cluster highlights the growing use of green infrastructure solutions to mitigate urban flood risks.

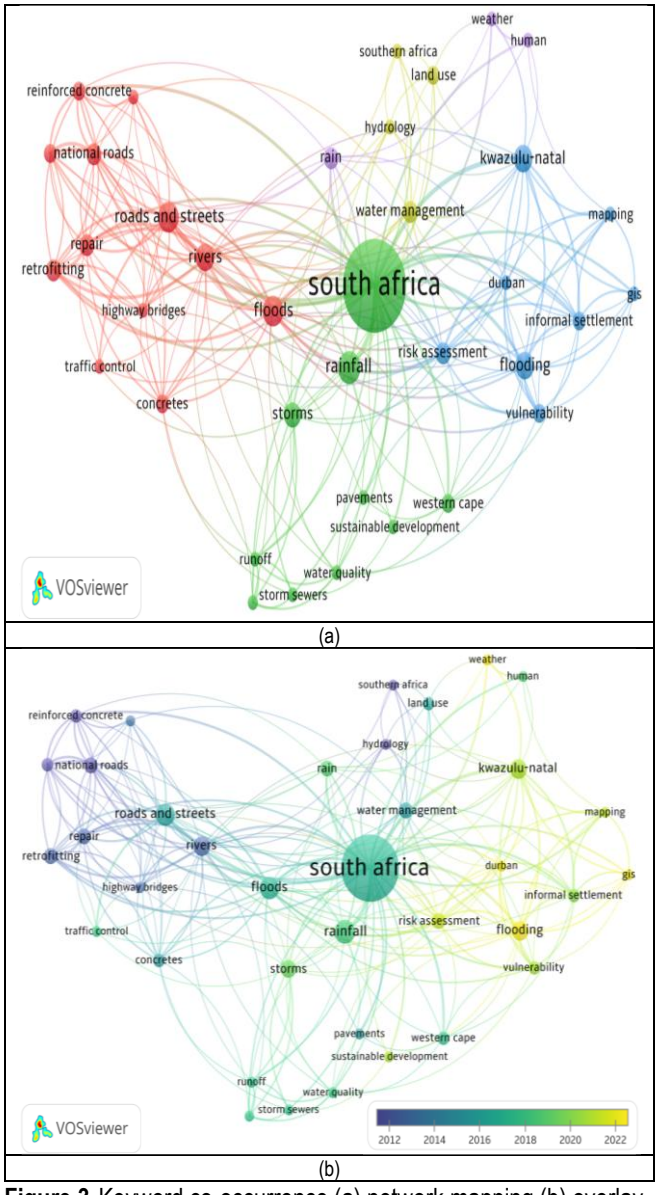

Figure 3. Keyword co-occurrence (a) network mapping (b) overlay visualization

Table 2. Major keywords related to the study

S/N	Keyword	Occurrences	Total link strength
1	South Africa	39	134
2	Rainfall	9	23
3	Floods	8	43
4	Roads and streets	8	40
5	Flooding	7	34
6	Kwazulu-Natal	7	42
7	Rivers	7	38
8	Storms	6	23
9	National roads	5	24
10	Rain	5	17
11	Repair	5	31
12	Retrofitting	5	31
13	Risk assessment	5	34
14	Water management	5	23
15	Bridges	4	23
16	Concretes	4	22
17	Informal settlement	4	25
18	Land use	4	9
19	Reinforced concrete	4	23
20	Vulnerability	4	24
21	Western Cape	4	14
22	Durban	3	23
23	Flood damage	3	20
24	Highway Bridges	3	19
25	Hydrology	3	17

The necessity for innovative, multidisciplinary methods on climate-induced road and pavement deterioration in South Africa from 2000 to 2025 is driving a dynamic and changing research scene, as reflected in the keyword analysis. These results not only demonstrate how adaptive the profession is to emerging challenges, but they also offer a direction for further research.

3.4. Publication sources

The predominant platforms for sharing research in this discipline were further clarified by the examination of published sources. The most well-known journals and proceedings that advance the area were identified using the data. The Water (Switzerland) and Water SA were two prominent publications, with five (5) and four (4) articles, respectively (Figure 4). These journals are essential for the spread of developments in water, rainfall since they focus on hydrology and water resources. Other important sources were Natural Hazards, land, geotechnical special publication, and Journal of Arid Environments, with 2 publications each. These sources emphasise how climate-induced road and pavement deterioration in South Africa is interdisciplinary because it touches on hazard mitigation and environmental sustainability. This statistical analysis highlights the relevance of the topic in South Africa by providing and in-depth review of the increasing scholarly interest in this field. The results also point to key areas that researchers should focus on when sharing important findings in this developing field. Table 3 shows the top six (6) publication sources.

Additionally, Figure 4(b) provides a density map that graphically highlights areas where research on climate-induced road and pavement deterioration in South Africa from 2000 to 2025 is concentrated. The density images that follow are based on the VOSviewer visualisation findings. Areas with active cooperation and notable research outputs are represented by high-density zones, which are shown in darker shades. The density is represented by a bright yellow colour in the density visualisation data. The brighter colour indicates regions where more research has been published. Conversely, publication sources where less research was done were presented by a dimmer colour.

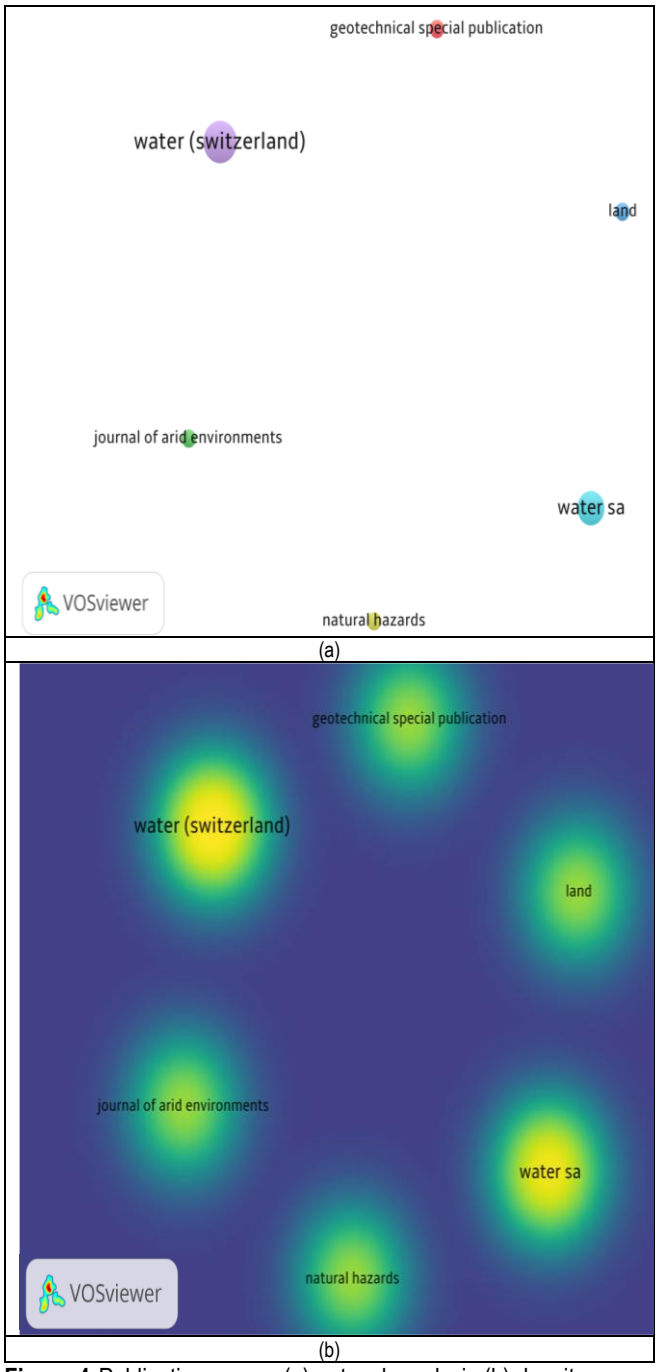

Figure 4. Publication source (a) network analysis (b) density map

Table 3. Major publication source

S/N	Source	Documents	Citations
1	Water (Switzerland)	5	5
2	Water SA	4	156
3	Natural hazards	2	40
4	Land	2	27
5	Geotechnical Special Publication	2	10
6	Journal of Arid Environments	2	3

3.5. Document by citation

The number of citations received by a research article is often regarded as an important indicator of its intellectual significance in the subject area, as highly cited publications are often recognised as pivotal or landmark studies. To analyse documents based on citation relationships, VOS viewer's analysis type was set to bibliographic coupling, and the unit of analysis was designated as document. The citation analysis reveals a clear pattern, with the most referenced work produced by Nekhavhambe, Van Ree, and Fatoki (2014), which earned 66 citations. Following that with 64 citations is a study conducted by Williams, Máñez Costa, Celliers, and Sutherland (2018), next is a study by Fitchett, Hoogendoorn, and Swemmer (2016) with 59 citations.

Other contributions with a moderate number of citations are a study conducted by Seutloali, Beckedahl, Dube, and Sibanda (2016) with 40 citations. Then, a study by Mashao et al. (2023) with 39 citations. Next is a study by Abrams, Carden, Teta, and Wågsæther (2021) with 39 citations (Table 4). A study conducted by Blaauw et al. (2022) had 28 citations, and lastly, a study by Smit and Asner (2012) had 26 citations. These regionally specialised studies make important contributions within their particular disciplinary and geographic contexts even when they don't receive many citations. Their relatively low citation counts are a reflection of the research's specialised and localised nature rather than its limited intellectual significance.

The VOSviewer visualisation outputs are shown in Figure 4, which includes the visualisation and density map of the most cited constitute a peripheral yet thematically cohesive body of literature that addresses flooding, water management, infrastructure resilience, and climate change. This finding highlights the need for greater integration of regional case studies into the broader global research discourse.

The analysis revealed that road and pavement deterioration are accelerated by climate change, resulting in a shorter pavement service life. Pavements must, therefore, be designed and maintained with the future climate in mind in order to retain the design service life. Therefore, it is imperative to optimise adaptation measures to maintain the pavement's service life while reducing costs and promoting sustainability.

Table 4. Document with the most citations related to the review study

Ref.	Citations	Publication article	Journal
(Nekhavhambe et al., 2014)	66	Determination and distribution of polycyclic aromatic hydrocarbons in rivers, surface runoff, and sediments in and around Thohoyandou, Limpopo Province, South Africa	Water SA
(Williams et al., 2018)	64	Informal Settlements and Flooding: Identifying Strengths and Weaknesses in Local Governance for Water Management	Water (Switzerland)
(Fitchett et al., 2016)	59	Economic cost of the 2012 floods on tourism in the Mopani District Municipality, South Africa	Transactions of the Royal Society of South Africa
(Seutloali et al., 2016)	40	An assessment of gully erosion along major armoured roads in south-eastern region of South Africa: a remote sensing and GIS approach	Geocarto International
(Mashao et al., 2023)	39	Extreme Rainfall and Flood Risk Prediction Over East Coast of South Africa	Water (Switzerland)
(Abrams et al., 2021)	39	Water, Sanitation, and Hygiene Vulnerability among Rural Areas and Small Towns in South Africa: Exploring the Role of Climate Change, Marginalization, and Inequality	Water (Switzerland)
(Blaauw et al., 2022)	28	Flexible pavement performance and life cycle assessment incorporating climate change impacts	Transportation Research Part D: Transport and Environment
(Smit & Asner, 2012)	26	Roads increase woody cover under varying geological, rainfall, and fire regimes in African savanna.	Journal of Arid Environments

4. Conclusion

The current article conducted a scientometric analysis of the existing literature related to the knowledge Mapping of climate-induced Road and Pavement Deterioration in South Africa. For the network visualisation, VOS viewer software was used, and pertinent records from the previous 25 years were retrieved from the Scopus database. The study findings thorough quality assessment of the examined literature indicates that the increasing number of publications has increased the relevance and dependability of research findings in this sector with the following key findings: According to a keyword analysis of WCP studies, "South Africa," "rainfall," "floods," and "roads and streets" are the most frequently used terms. Also, the study observed that Water (Switzerland) and Water SA rank with 5 and 4 publications, respectively, as the top two sources of publications.

The data demonstrates a steady rise in academic output, which is suggestive of a stronger focus on reducing the effect of flooding on roads and pavements, which is exacerbated by climate change and rapid urbanisation.

5. Practical and Future Implementation Implications

Building on the scientometric findings of this study, the following practical and future-oriented recommendations are proposed to advance both the research landscape and real-world resilience of South Africa's road and pavement infrastructure in the context of climate change:

5.1. Integrate Climate-Responsive Design into Infrastructure Policy

The prevalence of "floods," "rainfall" and "urbanisation" in the literature indicates a need for government agencies and engineering stakeholders to update national and municipal road design standards. The climatic forecast, the flood-risk zoning, and these water-sensitive design components will achieve a reduction of the aging rates and extend infrastructure lifespan.

5.2. Establish a National Research Collaboration Framework

The scientometric clustering reveals a small though widening network of researchers. A national programme of collaboration or research network could also draw together South African universities, civil engineering companies and climate experts to enhance data sharing, harmonising techniques and addressing regional knowledge gaps (particularly in rural areas) for implementation.

5.3. Strategic Research Investment

Funding Agencies and universities can support under-represented sub-topics, such as material resilience, drainage innovation and GIS-based monitoring tools by strategically targeting high-impact publications (e.g. Water SA) and trending keywords. This bibliometric roadmap demonstrates how targeted funding, postgraduate research topics, and interdisciplinary collaborations can address key challenges in infrastructure sustainability.

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