

The application of Vetiver grass in natural disaster mitigation and environmental protection in Vietnam: A bibliometric analysis and literature review

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Abstract: *Vetiver grass (*Vetiveria zizanioides* or *Chrysopogon zizanioides*) is a versatile tropical plant widely recognized for its applications in environmental protection and natural disaster mitigation. In Vietnam, where natural disasters such as floods and landslides are frequent, particularly along highways, Vetiver grass has proven to be an effective bioengineering solution. This paper provides a comprehensive review of the applications and benefits of Vetiver grass in preventing soil erosion and stabilizing slopes along Vietnam's transportation systems. A bibliometric analysis of 555 Scopus-indexed publications (2000–2024) was conducted using VOSviewer software to identify research trends, key themes, and knowledge gaps. The findings emphasize the significant environmental and economic benefits of Vetiver grass, including its ability to enhance soil stability, control erosion, and treat polluted environments. Case studies in Vietnam further demonstrate its successful integration into slope stabilization projects, riverbank reinforcement, and flood mitigation strategies. The paper advocates for the broader adoption of Vetiver grass in sustainable infrastructure development and disaster risk reduction, while identifying future research directions to expand its applications.*

Keywords: *Vetiver grass; soil erosion; landslides; environmental protection; bibliometric analysis.*

1. Introduction

Vetiver grass has a long history of use in soil enhancement, erosion prevention, slope stabilization, and environmental conservation. Its popularity has grown recently, driven by advancements in understanding vegetation's role in engineering and the low-cost, eco-friendly benefits of this "soft" bioengineering solution. Originally used by Indian farmers over two centuries ago, Vetiver grass gained broader attention for soil and water conservation in the 1980s when the World Bank promoted its use in India. Today, it remains valuable in agriculture and environmental management. Research from the past 20 years highlights vetiver's unique properties, making it an effective bioengineering tool for slope stabilization, wastewater treatment, pollution remediation, and environmental enhancement ([1~2]). Fig. 1 shows the annual publication trends on vetiver research from 1990 to 2024, based on a statistical review of 555 articles indexed in Scopus. It's important to note that only Scopus-indexed journals are included, so the actual publication count may be higher. Between the 1990s and 2004, fewer than 10 articles were published per year. However, global interest in vetiver has since surged, leading to a steady rise in publications. Since 2005, the number of articles has grown to about 30 per year, reflecting an ongoing demand for further research on this topic.

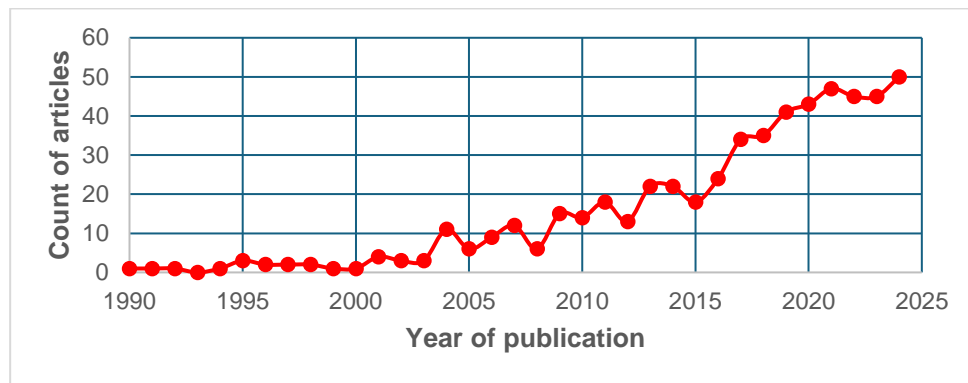


Fig. 1. Number of publications on Vetiver grass from 1990 to 2024 according to the Scopus Portal [3] (<https://www.scopus.com/home.uri> Accessed August 28, 2024)

Vetiver grass is a proven bioengineering solution for disaster mitigation and environmental protection due to its deep, durable root system and high adaptability. International studies have demonstrated its effectiveness in slope stabilization, erosion control, improving agricultural soil productivity, and treating pollution from sources such as landfill leachate, acid mine drainage, and wastewater with excess nutrients. Its resilience to extreme weather conditions further highlights its value in combating climate change and protecting resources from natural disasters like floods and landslides. In Vietnam, the application of Vetiver grass is increasingly urgent as the country faces severe challenges from natural disasters and environmental degradation. Domestic research has shown its high effectiveness in stabilizing slopes, reinforcing riverbanks, controlling soil erosion, and treating agricultural and industrial wastewater. Vetiver grass has also been utilized to strengthen sea dikes against rising sea levels and to prevent landslides, addressing the escalating impacts of climate change. This paper will examine various case studies and research outcomes to emphasize the environmental and economic benefits of Vetiver grass, promoting its broader adoption in sustainable infrastructure and disaster risk management strategies nationwide.

2. Methodology

This review combines a systematic approach to literature searching, filtering, and bibliometric analysis to pinpoint key themes. It includes a narrative review to synthesize findings and highlight research gaps within each theme. Keywords such as “Vetiver grass,” “*Chrysopogon zizanioides*,” “Soil erosion,” “Flood mitigation,” “Landslide prevention,” “Environmental protection,” and “Vietnam” were used, incorporating Boolean operators for a comprehensive search in the Scopus Portal Core Collection.

The expanded 24-year search identified 1,020 publications, which were systematically refined according to the framework in Fig. 2. This framework shows a structured, three-tiered screening process applied to the Vietnam-focused literature in the Scopus Core Collection. Starting with 1,020 articles, filters for keyword relevance, publication year (1990–2024), language (English), and document type (articles) reduced the dataset. The first tier excluded conference proceedings, the second tier filtered out articles lacking relevance to the research keywords after a full-text review, resulting in 555 articles, and the final tier identified articles with Vietnam-specific case studies, further narrowing the dataset to seven articles. These articles were then subjected to bibliometric analysis for trend identification, network visualization for keyword mapping, and content analysis to extract thematic insights.

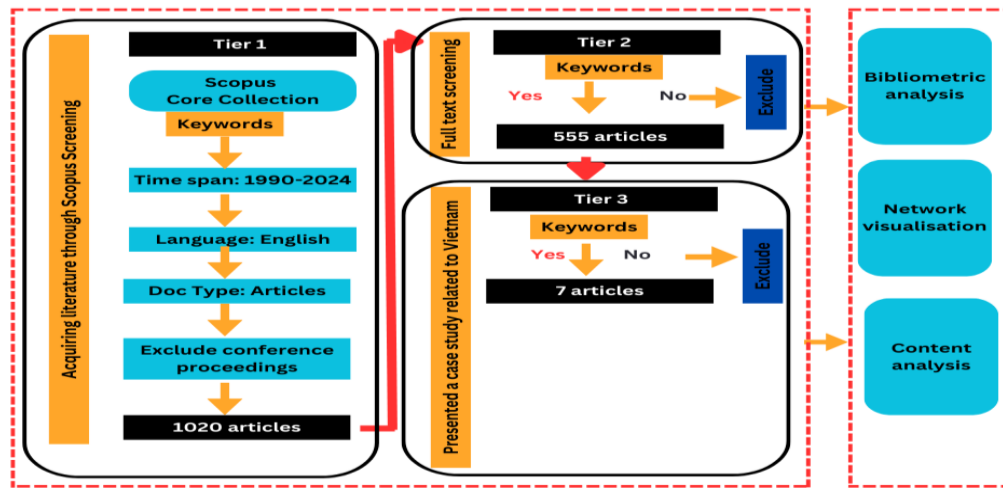


Fig. 2. Flowchart illustrating literature selection and data extraction process

3. Results and Discussion

VOSviewer is a software tool designed for analyzing and visualizing bibliometric networks, widely used in scientific research to uncover patterns and relationships within large datasets. It processes data exported from bibliographic databases like Scopus, Web of Science, or PubMed to construct networks based on connections between authors, articles, journals, keywords, or citations. Using the VOS (Visualization of Similarities) algorithm, VOSviewer clusters entities and represents them in two- or three-dimensional spaces, where the size of nodes reflects their significance (e.g., number of publications or citations), and the distance between nodes indicates the strength of their relationships. The software offers various visualization options, such as overlay maps to show temporal changes in research focus and density maps to highlight densely connected areas of the network. Researchers can adjust parameters to fine-tune clustering and visualization, making it a flexible tool for exploring bibliometric data. Results can be exported as interactive visualizations, textual summaries, or tabular data, providing valuable insights into trends, collaborations, and knowledge structures within specific fields of study [3~4].

For example, VOSviewer can be applied to vetiver research in Vietnam, where the tool can analyze scientific literature, citation patterns, and keyword trends to provide an overview of this field. By creating co-occurrence maps based on keywords extracted from publications, researchers can identify key terms such as "soil erosion," "flood mitigation," "landslide prevention," "environmental protection," and "Vietnam." This analysis highlights the most extensively studied aspects of Vetiver grass and its environmental applications, while also revealing gaps in the existing literature. These insights can help guide future research and inform strategies for using vetiver in sustainable environmental management.

3.1. Keyword Analysis

Fig. 3 displays a keyword co-occurrence network in environmental science and phytoremediation, highlighting key research themes and trends. Larger nodes, such as "Vetiver grass," "vetiveria zizanioides," "phytoremediation," and "soils," represent frequently occurring terms, indicating central topics in this research area. Lines between keywords show co-occurrence, with thicker lines signaling stronger associations; for instance, "phytoremediation" is closely linked to "soil pollution" and "bioaccumulation," reflecting a focus on using plants to remediate contaminated soils. Keywords are grouped into clusters representing subtopics, such as a green cluster associated with "Vetiver grass," "soil conservation," "runoff," and "erosion," suggesting studies on soil erosion prevention and water quality. Color overlays indicate the average publication year, with darker shades for older research (e.g., "bioaccumulation" and "phytoremediation") and lighter colors for newer topics (e.g., "shear strength," "soil mechanics," and "landslide"), suggesting an emerging focus on soil stability. The visualization underscores a shift from pollutant removal to structural impacts on soils, with Vetiver grass as a primary species in these studies.

"Truong," indicating broader research topics and cross-disciplinary connections. Larger nodes, such as "Truong," "Sarkar," and "Chen," represent highly influential authors based on co-citation frequency. Dense connections within clusters reflect close citation practices, while links between clusters underscore interdisciplinary influence, with certain authors acting as bridges across research topics. This network structure highlights a well-established field, with clear subfields and substantial international collaboration, particularly from Asian institutions (Fig. 4).

3.3. Cluster Mapping

Fig. 5 shows visualization highlights a global network of research collaborations among countries, based on co-authorship in scientific publications. The size of each node represents a country's role in research collaborations, with the United States as the largest and most central node, indicating its key role in global partnerships. Other countries with large nodes, such as China, India, Thailand, and Brazil, also show strong international research connections. Lines between nodes indicate co-authorship relationships, with thicker lines representing stronger collaboration, especially between the United States and countries like China, India, and Brazil. A color gradient reflects the average publication year, where blue shades represent earlier activity and yellow indicates more recent collaborations. Countries such as Ethiopia, Indonesia, and Vietnam appear in yellow, signaling a growing presence in recent research partnerships, while countries like the United States, China, and India in green reflect consistent collaboration over time. Overall, the visualization reveals a strong network, with the United States as a central hub and emerging contributions from countries like Ethiopia and Vietnam (Fig. 5).

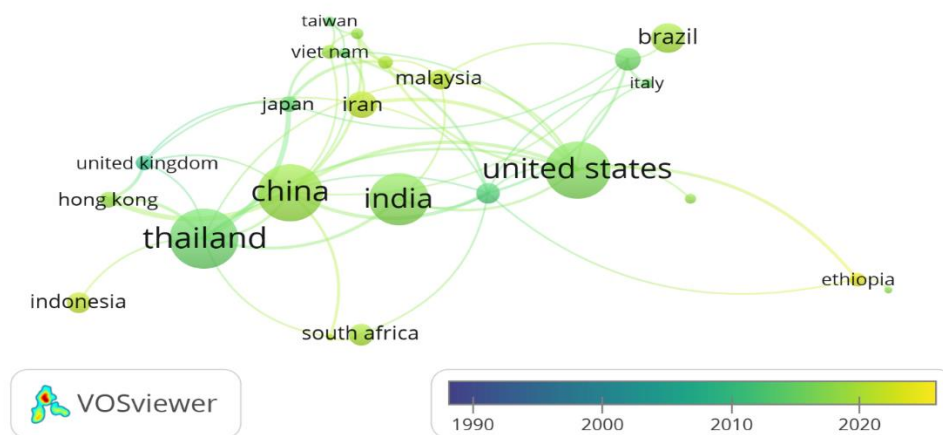


Fig. 5. Visualization of the network of research collaborations between countries based on co-authorship in academic publications by Vosviewer

3.4. Literature Review Approach

The research on Vetiver grass underscores its vital role in natural disaster mitigation and environmental protection, as evidenced by insights drawn from 555 studies. A structured literature review approach was adopted to ensure the inclusion of reliable, high-quality sources. Peer-reviewed studies and reports were prioritized, with a focus on those relevant to Vietnam, while global research was incorporated for a broader perspective. The review emphasized publications from the past 20–30 years to balance foundational knowledge with recent advancements. Selected studies were required to present clear methodologies, findings, and implications to maintain academic rigor and transparency.

The findings are categorized into three key themes: (1) Slope Stabilization and Erosion Control, examining the capacity of Vetiver grass to prevent landslides, stabilize slopes, and enhance soil cohesion through its deep and durable root system; (2) Water Treatment, focusing on its phytoremediation capabilities to absorb pollutants and manage wastewater in agricultural and industrial settings; and (3) Soil Remediation, highlighting its effectiveness in rehabilitating

contaminated soils, improving fertility, and restoring degraded ecosystems. This systematic approach provides a comprehensive synthesis of current knowledge, offering valuable insights and identifying gaps for future research.

Studies by [6] and [7] show the grass's ability to enhance soil stability, while [8] emphasize its hydraulic efficiency on flood plains. Vetiver grass has also proven useful in agricultural landscapes; [9] demonstrated its ability to increase soil accumulation and crop yields, and [10] reported long-term improvements in soil water retention and productivity on sloping cropland.

Vetiver also plays a significant role in phytoremediation, helping to detoxify polluted environments. Research by [11] and [12] demonstrates its potential to absorb contaminants such as landfill leachate and neutralize acid mine drainage. [13] expand this application to marine environments, exploring its use in coastal bioremediation. Additionally, [14] and [15] highlight Vetiver's effectiveness in controlling nutrient runoff and improving soil structural quality, further contributing to ecosystem health and resilience.

Furthermore, Vetiver grass has shown adaptability to extreme climate conditions. [16] used remote-sensing techniques to study Vetiver's flood mitigation capabilities, while [17] examined its resilience to submersion and wave action. This adaptability makes Vetiver a valuable tool in climate change adaptation strategies, as illustrated by [18] and [19], who showed its potential in protecting agricultural and environmental resources from extreme weather events. The collective findings underscore the versatility of Vetiver grass in mitigating natural disasters and promoting environmental sustainability.

In Vietnam, a summary of the seven cited articles regarding the application and environmental impact of Vetiver grass can be listed below. Several studies have highlighted the significance of Vetiver grass in various environmental protection and disaster mitigation projects. [20] explored the combination of soil nailing with Vetiver grass to enhance slope stability, demonstrating its effectiveness in Vietnam's infrastructure projects. [21] focused on the application of Vetiver grass in removing organic matter from contaminated surface water, which showcases its potential in water treatment systems. Furthermore, [22] evaluated the capacity of Vetiver and reed grass in nutrient removal through constructed wetlands, emphasizing its role in phytoremediation and nutrient management in agricultural and industrial wastewaters.

In the context of soil conservation, [23] studied the redistribution of radioactive cesium and soil components on slopes with hedgerows, including Vetiver grass, noting its contribution to erosion control. [24] analyzed the impacts of sea-level rise on sea dike stability along the Vietnamese coast and suggested Vetiver-based solutions for dike reinforcement. Similarly, [25] investigated the structural performance of ecological revetments in sub-tropical regions, with Vetiver playing a role in strengthening riverbanks and preventing erosion.

Finally, [26] examined the bacterial endophytes associated with Vetiver grass roots grown in contaminated soils at Bien Hoa airbase, highlighting its potential for bioremediation in polluted environments. Collectively, these studies demonstrate the multifaceted applications of Vetiver grass in environmental protection, erosion control, and disaster mitigation.

3.5. Critically Evaluate Existing Research

Research on Vetiver grass highlights its versatility in environmental applications, including soil stabilization, erosion control, disaster mitigation, and phytoremediation. Its adaptability to extreme weather conditions and cost-effectiveness makes it valuable for climate change adaptation and sustainable development. However, existing research exhibits geographic bias, with significant contributions from countries like China, India, and Vietnam, while other regions remain underrepresented. Additionally, studies often focus on short-term benefits, with limited long-term assessments of environmental impact or standardized methodologies for broader application. Economic evaluations, though critical, are sparse, leaving gaps in understanding its cost-effectiveness compared to engineered solutions. Potential applications, such as coastal protection and biodiversity enhancement, are underexplored, as is the integration of advanced technologies like remote sensing to monitor its effectiveness. Addressing these gaps through global

collaboration, longitudinal studies, and economic analyses would enhance the understanding and scalability of Vetiver grass in environmental management

4. Case Studies in Vietnam

4.1. Using Vetiver grass in Bioengineered Revetment Measures in Thanh Mai, Bac Kan, Vietnam [27]

Fig. 6 shows a project that demonstrates the use of Vetiver grass and other bioengineering techniques for riverbank stabilization in Thanh Mai commune, Bac Kan province, Vietnam. The project, titled "Promoting Climate Resilient Rural Infrastructure in Northern Vietnam," is funded by the Global Environment Facility through the Asian Development Bank and UNDP. The demonstration site is located along a 2.42 km stretch of a tributary of the Cau River, where a combination of vegetative treatments, including brush layers, live fences, live poles, fascines, and vegetated riprap using local plant species like *Homonoia riparia* and *Ficus benjamina*, as well as Vetiver grass (*Chrysopogon zizanioides*), have been applied (Fig. 7). While it was still too early to fully assess the effectiveness of the bank protection techniques, the initial observations showed that the toe protection measures had survived a flood during construction. The document highlights the benefits of this bioengineering approach, including its environmentally friendly nature, relatively short construction time, use of local labor, and cost-effectiveness, costing only 20-40% of conventional measures. The project recommends continued monitoring and bringing in visitors to raise awareness about the use of Vetiver grass and other bioengineering techniques for riverbank stabilization in the region.

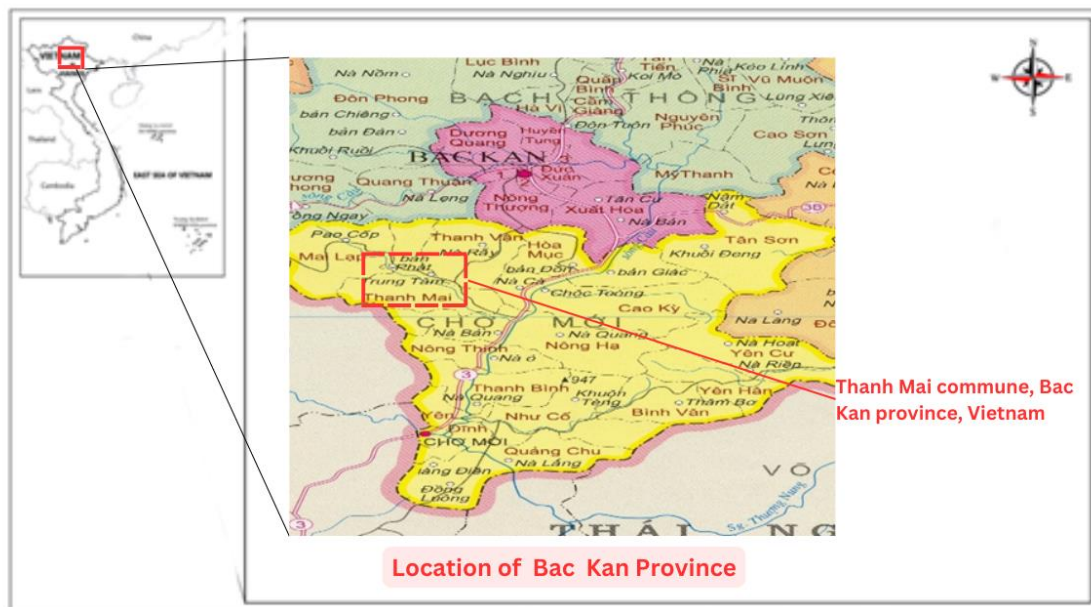


Fig. 6. The location of the vetiver site at Thanh Mai commune, Bac Kan province, Vietnam.

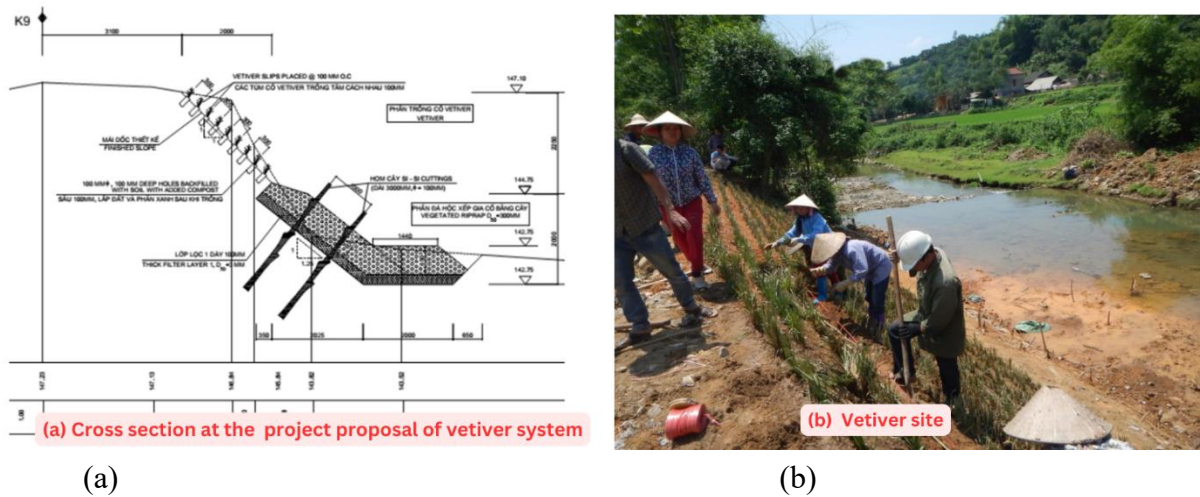


Fig. 7. (a) Proposed solution using Vetiver grass system in the project; (b) Vetiver site ([27])

4.2. Application Of Vetiver grass To Protect Riverbanks In Hoa Phong Commune, Da Nang City [28]

In recent years, the problem of riverbank erosion in the downstream area of the Vu Gia - Thu Bon River basin, Da Nang City, has been quite serious, significantly impacting the socio-economic development of the city. The largest erosion point is located on the left bank of the Yen River, which is heavily affected by the basin flow regime from the Vu Gia River (Fig. 8). The land stratigraphy mainly consists of sandy soil, and sandy clay, while deeper below the river there is sandy soil mixed with gravel or sandy clay. In this project, [28] conducted an experimental reinforcement section by planting Vetiver grass 20 m long in combination with other solutions such as bamboo piles and steel anchors. The advantage of this method is that it utilizes the shear resistance and tensile resistance of the vetiver root system, as well as stabilizes the bank area during the first 1 to 2 years (Fig. 9).

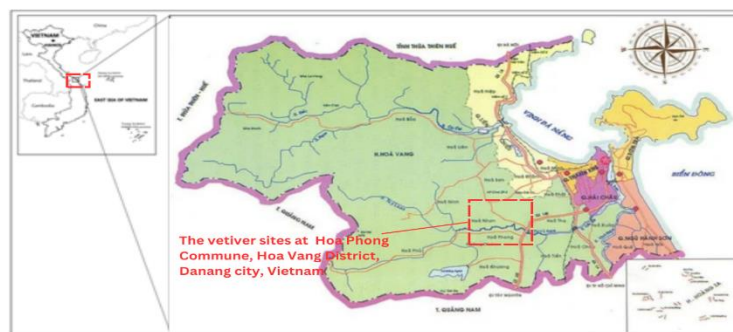
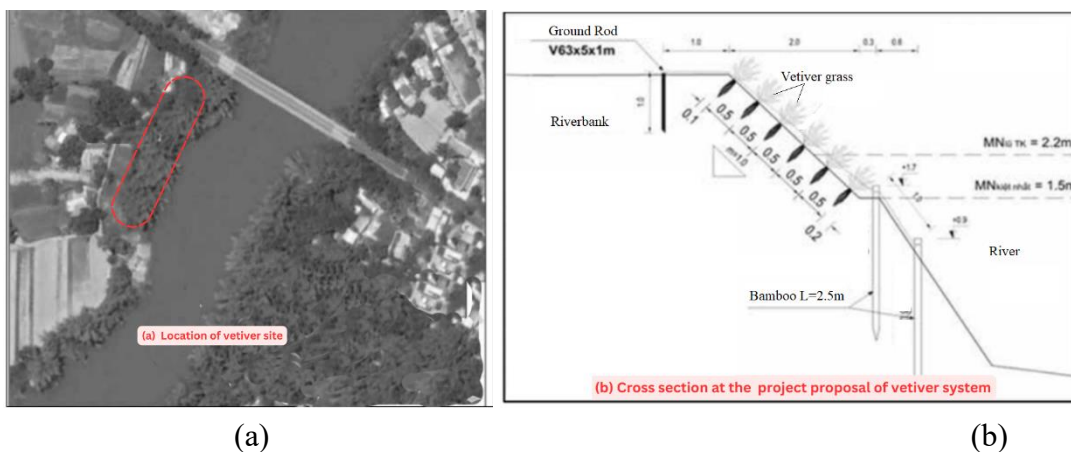


Fig. 8. The location of the vetiver site at Hoa Phong Commune, Hoa Vang District, Danang City, Vietnam



(a)

(b)

Fig. 9. (a) Location of vetiver site; (b) Proposed solution using Vetiver grass system in the project ([28])

4.3. Application Of Vetiver grass To Protect Dyke Banks In An Giang Province [29]

An Giang province, located in the Mekong Delta region and frequently affected by flooding, has faced erosion and weakening of dykes due to strong water flows and natural factors. To protect the dyke system from erosion, Vetiver grass has been tested and proven to be an effective biological solution, offering many benefits to areas prone to flood damage. The results of these trials demonstrated that Vetiver grass not only effectively controls erosion but also helps stabilize the soil, providing significant advantages for vulnerable lands affected by flooding. This highlights the potential of using Vetiver grass to protect and maintain the integrity of dyke systems in areas susceptible to natural disasters (Fig.10a).



Fig. 10. The location of: (a) An Giang Province; (b) Vetiver sites at Tan Chau and Tri Ton District, An Giang Province, Vietnam ([29])

According to [29], two experimental sites were established to test the effectiveness of Vetiver grass in protecting dykes in An Giang Province. At the Tan Chau District site, Vetiver grass successfully adapted to local conditions, even after being submerged during the flood season. However, the experimental plots were destroyed by cattle, which ate the vetiver as it was the only available fodder during the floods. At Tri Ton District, the grass was initially planted during the dry season, but due to a lack of irrigation, it failed to establish and died after the flooding. A second planting in May 2002, with adequate watering, resulted in strong growth, proving the region's suitability for vetiver when properly managed. Authorities in An Giang plan to plant vetiver immediately after the flood season or during the rainy season to utilize natural moisture and reduce irrigation needs. A more recent experimental site at Bay Xa canal in Tan Chau district demonstrated the effectiveness of vetiver in protecting dykes, as the grass was successfully planted along a 10-kilometer stretch and withstood two flood seasons, preventing erosion that has affected unprotected dykes (Fig. 10b).

4.4 Insights from Bibliometric Analysis in Vietnam

The bibliometric analysis emphasizes the alignment of global research trends on Vetiver grass with Vietnam's critical environmental priorities, particularly through its practical applications in disaster mitigation and environmental protection. Case studies in Bac Kan, Da Nang, and An Giang highlight the effectiveness of Vetiver grass in addressing specific regional challenges. In Bac Kan, Vetiver grass was successfully utilized in riverbank stabilization projects, showcasing its cost-effectiveness and environmental friendliness. Similarly, in Da Nang, Vetiver grass was applied to combat severe riverbank erosion in the Vu Gia-Thu Bon River basin, demonstrating its ability to stabilize sandy and clay soils in high-risk areas. In An Giang, located in the flood-prone Mekong Delta, Vetiver grass played a vital role in protecting dykes from erosion, proving its resilience even under extreme flooding conditions. These projects underscore the practicality and versatility of Vetiver in diverse environmental contexts across Vietnam.

Additionally, these case studies highlight significant opportunities for international collaboration and knowledge transfer. By engaging with countries like China and India, which have extensive experience in Vetiver research and implementation, Vietnam can further refine methodologies, adopt advanced technologies such as remote sensing for monitoring, and scale up applications effectively. Strengthening international partnerships and integrating lessons from these projects can enhance Vietnam's capacity to deploy Vetiver grass as a nature-based solution for sustainable development, disaster resilience, and long-term environmental protection.

4.5. Potential Research Directions in Vietnam

□ Vetiver grass has significant potential for addressing environmental challenges in Vietnam. Research directions could include assessing its long-term effectiveness in erosion control, slope stabilization, and flood mitigation across different climate zones, while comparing its cost-effectiveness to traditional methods in projects like riverbank protection. Advanced monitoring using remote sensing and GIS could help track Vetiver grass's performance in real-time, aiding in climate adaptation strategies. Expanding its use in coastal areas, such as in the Mekong Delta for saltwater intrusion, and in urban infrastructure to mitigate flooding and stabilize slopes, could further enhance its applicability. Additionally, Vetiver's role in improving soil fertility, sequestering carbon, and restoring degraded ecosystems warrants deeper investigation, particularly in agricultural areas prone to salinization. Policy integration to scale up Vetiver-based solutions across national disaster management frameworks is crucial, as is promoting local involvement for successful implementation. Finally, research into Vetiver's potential for mitigating climate change by reducing flood risks and rehabilitating ecosystems in extreme weather scenarios could position it as a vital tool for sustainable development in Vietnam.

5. Conclusions

Based on the comprehensive review and analysis of the research on the application of vetiver grass in Vietnam, the key conclusions drawn from this research are:

- This paper explores the application of Vetiver grass in natural disaster mitigation and environmental protection in Vietnam, highlighting its significant role in preventing landslides, protecting infrastructure, and providing a cost-effective alternative to traditional engineering methods.
- Vetiver grass has demonstrated diverse applications, including soil conservation, wastewater treatment, and ecosystem restoration, making it a versatile tool for sustainable development.
- Bibliometric analysis reveals increasing global interest in Vetiver grass over the past two decades, with Vietnam contributing significantly to this research. Case studies in Bac Kan, Da Nang, and An Giang illustrate its practical effectiveness in stabilizing riverbanks, protecting dike systems, and reducing flood damage.

6. Future Research Directions

6.1. Long-Term Research

- Assess Vetiver grass's effectiveness across different climatic regions.
- Utilize technologies like GIS and remote sensing for precise monitoring.
- Expand vetiver applications to coastal and urban areas to tackle diverse environmental challenges.

6.2. Exploring New Potentials

- Investigate vetiver's role in ecosystem restoration, carbon sequestration, and soil fertility enhancement.
- Identify innovative applications to enhance its contribution to sustainable resource management.

6.3 Policy and Community Engagement

- Integrate vetiver solutions into national disaster management frameworks to mitigate environmental risks.
- Encourage community involvement to ensure sustainable and widespread adoption.
- Promote Vetiver grass as a key nature-based solution for Vietnam's sustainable development and climate resilience.

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