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Geospatial and Environmental Science Perspectives on Green Finance in East Africa: Integrating Climate, Hydrological, and Policy Analysis

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Abstract

Green finance has emerged as a critical instrument for advancing climate mitigation and sustainable development; however, its application in East Africa remains fragmented and insufficiently aligned with environmental system dynamics. This study examines the intersection of green finance, environmental processes, and geospatial analysis through a systematic bibliometric review using the PRISMA framework, supported by VOSviewer-based network and thematic analyses of 110 Scopus-indexed publications (2013-2025). The study further integrates a geospatial and environmental systems perspective, focusing on the climate-hydrology-land nexus. The study's results indicate three key problems. Firstly, most studies have taken place in developed or emerging countries, and very few have included countries in East Africa. Secondly, most green finance studies have examined financial tools and policy implementation, but have not considered hydrology, water stress, or land-use change, all of which are important for sustainable development. Thirdly, techniques such as GIS and remote sensing, which can be used to evaluate environmental effects on projects under green finance, have been underused. Four major thematic areas emerged from this analysis: green finance and policy systems, climate change and sustainability, hydrological risk and geospatial monitoring; these are highly disconnected, indicating we need to explore ways to integrate these approaches. The study finds that, to have an impact on the ability to fund green projects in East Africa, it will require integrating financial instruments, environmental processes, and spatial analytical tools. The recommendations include using hydrology and land use as decision criteria when making financial investments, increasing transparency through enhanced geospatial monitoring, and improving governance, regulations, and financial inclusion. This study provides a basis for addressing significant gaps in current knowledge on how to develop green financing options tailored to a region's specific geographic conditions, particularly for regions vulnerable to climate change impacts.

Keywords: *Green Finance, Geospatial Analysis, Hydrological Impacts, Carbon Sequestration, Remote Sensing, Climate Modeling, East Africa.*

Introduction

Climate vulnerability in East Africa has been growing internationally in recent years, due to increased frequency of more severe droughts, variable precipitation events, increased frequency of soil erosion, increasing restrictions on energy access, and an increase in the rate at which ecosystems are degrading throughout the region (Christopher C. Funk et al., 2012; Dai, 2013; IPCC, 2007; Nicholson, 2014; Samatar, 2025). Both the emerging environmental stressors in East Africa and their impacts, either internally (hydrologic cycle) or externally (terrestrial carbon stocks), are connected to a variety of other natural systems, including exchanges of gases with the atmosphere and geomorphologically related processes, including erosion of soils (IPCC, 2007; Ludwig et al., 2011; Palutikof et al., 2008). Therefore, reducing overall environmental vulnerability in East Africa will require more than "ambition" in policy; it will also require

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financial institutions to direct capital toward measurable environmental objectives (Pandey et al., 2026; Stern, 2014). As a result, Green Finance has emerged as a key strategy for promoting investment in renewable energy, restoring ecosystems, and improving the sustainability of land uses and the resilience of its infrastructure (Flammer, 2021; Michaelowa et al., 2021; Pauw et al., 2016; Tolliver et al., 2020; Zhou & Zhou, 2024).

Over the last 50 years, global natural resources use has increased significantly more than three times and continues to grow each year at a greater than 2.3% per annum rate, causing additional stress to areas already experiencing high levels of environmental strain (UNEP, 2024). As such, to mitigate some of these effects, the world community is turning to green finance to fund low-carbon transition and climate adaptation efforts. Green finance includes various funding mechanisms that support investment in renewable energy, energy efficiency, and sustainable infrastructure, such as green bonds, concessional financing, and development assistance (Flammer, 2021; Jinping et al., 2024; Kumar et al., 2025; Umar & Safi, 2023; Yardımcı & Oskay, 2025). Research conducted in emerging economies provides empirical evidence that green finance can positively impact the environment over extended periods, but may be negatively affected in the short run due to institutional weakness, limited absorptive capacity, and poor governance structures (Nabi et al., 2025; Yardımcı & Oskay, 2025). These findings align with the load capacity curve (LCC), which posits a non-linear relationship between financial inflows and their impact. Initially, the inflows will create additional environmental stressors; however, once structural changes occur and technology begins to adapt, the overall level of sustainability will begin to improve (Razzaq & Yang, 2023; Ulussever et al., 2024).

Green Finance in Global Economics has demonstrated that it can help reduce emissions and protect the environment with instruments such as green bonds, green credit, and climate-related regulation. This is well illustrated by Lee & Lee (2022), who show that an increase in the use of green finance leads to higher levels of green Total Factor Productivity (TFP) (S. Zhang et al., 2021). They also demonstrate empirically that implementing green credit policies can lead to positive environmental outcomes by increasing the adoption of cleaner production practices. Madaleno et al., (2022) point out an interdependence among green finance, clean energy, and environmental accountability, suggesting that future financial innovation will drive the sustainability transition. Kumar et al., (2025) have also established a positive relationship between green finance and/or green innovation and environmental protection in OECD countries.

Although an increasing number of studies have provided evidence regarding the effects of financial activities on environmental systems, most of the literature available to date has been written from a finance-oriented perspective, which focuses upon institutional or legal aspects of financial regulation, the relationship between financial markets and macroeconomic variables, and the performance of financial markets, and does not focus upon the environmental systems affected by financial activity. As noted by D’Orazio & Popoyan (2019), the development of macroprudential climate policy is essential for mitigating climate-related risks associated with financial activities; however, these policies are typically implemented without environmental monitoring systems. Additionally, Hafner et al. (2020) assert that the "green finance gap" can be closed through the establishment of systematic alignment between the flow of funds and environmental objectives; however, there is a need for more consistent empirical evidence supporting the environmental impacts of financial activities, especially in countries such as those within the East African region, which have a high level of ecological vulnerability and limited environmental data infrastructure.

The expansion of renewable energy and the ecosystem-based initiatives are two examples of

how green finance could be used to impact specific environmental systems in the East African region. Pan et al. (2023), have demonstrated that a combination of environmental regulations and green innovation will support the transition to renewable energy. Xu et al., (2022), showed that environmental regulations affect the path of the development of green financial instruments. Additionally, as shown by Zahoor et al., (2022), the relationship between clean energy investment, financial development, and environmental quality is positively related to a reduction in emissions intensity. Together, these studies provide evidence that financial instruments can affect atmospheric emissions, energy systems, and carbon dynamics; however, few use geospatial, hydrologic, or land-use data to evaluate the environmental effectiveness of such instruments across spatial contexts.

There is a growing body of research that identifies regional and institutional variability in the successful implementation of green finance. (Irfan et al., 2022) emphasize how regional policy initiatives affect the relationship between green finance and green innovation, and suggest that governance capacity and regulatory consistency will determine the success of environmental policy interventions. Similarly, (Lee & Lee, 2022) emphasize the role of an institution's architecture in translating financial products into productive gains and environmental benefits. However, a bibliometric analysis of the literature on green finance in East Africa indicates relatively low levels of regional research activity and lower institutional integration than in other leading countries and regions, including China and OECD economies. These disparities raise concerns about the uneven distribution of climate finance and the potential to further exacerbate environmental inequality.

From an environmental science perspective, green finance should be viewed as both a mechanism of investment and as an intervention into Earth's Systems. Green investments in renewable energy, for example, affect the trajectory of atmospheric emissions; green investments in reforestation and sustainable land use practices can affect carbon sequestration and soil stability; and green investments in watershed protection affect hydrologic regimes and watershed water retention capacity. In order to assess whether green finance produces long-term ecological benefits or simply redeploys capital with no systemic change, geospatial monitoring, hydrologic modeling, and environmental performance measures will need to be used to evaluate the effectiveness of green finance programs.

The success of green finance in both climate change mitigation and adaptation will also depend on demonstrable, quantifiable environmental impacts. For example, as demonstrated by Zhang et al. (2021), the linkage between regulatory oversight and the attainment of environmental objectives suggests that the application of policy-based green credits can yield environmentally significant results. Additionally, D'Orazio & Popoyan (2019) emphasize that the framework of financial governance should integrate climate risk assessments into macroprudential policy. In this case, in East Africa, the intersection of drought cycles, flood risks, land degradation, and energy deficiencies creates an environment that necessitates the integration of environmental vulnerability analysis, hydrologic data, climate models, and spatial analysis beyond financial metric analysis.

The research, therefore, develops an environmental science and geospatial-informed approach to green finance in East Africa. As such, this research is based on empirical evidence of what has been written by other scholars in the area of green finance (Hafner et al., 2020; Irfan et al., 2022; Lee & Lee, 2022; Madaleno et al., 2022; Umar & Safi, 2023), which this research then uses to reframe green finance as an interaction with measurable earth systems. This research will be based on the integration of financial governance with environmental science components

(climate change dynamics, hydrology processes, renewable energy geophysics, and carbon management). Therefore, this research aims to address the gap between financial policy discourse and environmental effects on the Earth system in East Africa by using spatially specific environmental conditions to inform the location of green finance.

The study has used a PRISMA-guided systematic literature review process, which enables a transparent, rigorous, and replicable methodology for identifying and selecting papers most appropriate to this investigation. Additionally, this methodology provides a strong analytical foundation by enabling the interdisciplinary collection of evidence across green finance, climate science, hydrology, and geospatial fields. In addressing the three main research questions posed in the paper, it specifically addresses each. These include (a) how does the green finance literature describe or conceptualize environmentally and earth system processes within East Africa; (b) what role do different financial instruments play in shaping the climates, hydrology and land use systems; and (c), what institutional and data governance barriers exist to allow for the effective integration of environmental science and green finance across the member states of the East African Community? The application of an interdisciplinary methodological approach to address these issues will add to the bodies of work in both Earth Sciences and Environmental Science. It will provide an evidence-based framework for decision-making related to sustainable development and climate resilience across East Africa.

Literature Review

Evolution of Green Finance within Climate-Water-Development Systems

The development of green finance (GF), therefore, can only be appropriately viewed through a lens of its interactions with other climate-water-development factors that are continually evolving to become defining characteristics of sustainable developments in developing countries. Early sustainable development frameworks (Stern, 2014; The UN, 1987; Nordhaus, 1976) framed environmental damage as an external cost of economic development, but more recent cross-disciplinary research has shown that climate change, water shortages, and economic instability are mutually dependent (Ludwig et al., 2011). In water-scarce regions, hydrologic decline and increased climate variability have emerged as significant stressors affecting food production systems, economic output, and social stability (Alcamo et al., 2003; Giorgi, 2006; Palutikof et al., 2008). As such, these findings support increasing research on green finance, which frames financial systems as key mechanisms for mitigating and allocating capital to address environmental risks (Raman et al., 2025). While international agreements such as the Paris Agreement and the Sustainable Development Goals (SDGs) highlight the need for integrated solutions, much of the empirical work continues to isolate various aspects of finance, climate, and water systems into separate domains rather than viewing them as interdependent systems.

The effects of this fragmentation can be seen mostly within East Africa. Within East Africa, the primary driver for economic and environmental changes resulting from climate variability is drought. The historical record has shown an increase in the frequency, duration, and variability of drought across long time scales due to temperature increases and evapotranspiration (Nicholson, 2014; Samatar, 2024), specifically with greater frequency beginning around the late 1980s. In addition to climate impacts being generated through drought events, research has also found that the social/economic vulnerability to these impacts are enhanced by poor land use/management decisions as well as weak institutions (Christopher C. Funk et al., 2012; Dai, 2013). Green finance is increasingly being identified as a means to mitigate systemic risk.

However, existing research on green finance rarely addresses hydrologic variability (i.e., drought cycle, water shortages, and evapotranspiration variability) in its sustainability models. As such, the capability of green finance to provide solutions to real-world sustainability issues in areas characterized by fragility and significant water stress is greatly diminished. Environmental risk is created by interactions between climate and water systems rather than being based upon either financial or technical considerations.

Theoretical Foundation: From Economic Growth to Systemic Sustainability

Theoretical foundations of green finance have roots in classical endogenous growth theory, and sustainability transitions remain a point of contention. Traditional models by Romer (1986), Schumpeter (1934), and Solow (1956) illustrate that capital accumulation and technological innovation are both key drivers of growth. However, these traditional models largely neglect environmental constraints and resource limitations. The Environmental Kuznets Curve (EKC) hypothesis is an attempt to bridge this gap by proposing a non-linear model that illustrates the relationship between economic growth and environmental degradation (Grossman & Krueger, 1995). While empirical studies support the existence of the EKC, results vary widely depending on region, especially for developing economies (Bektaş & Ursavaş, 2022; Ibrahim et al., 2023, 2023; Mosconi et al., 2020). Criticism of the traditional models arises from their failure to recognize the structural realities of resource-dependent and climate-vulnerable economies. In many resource-dependent / climate-vulnerable economies, environmental degradation will continue or increase even when economic development occurs.

Green finance is an extension of those conceptual models in the way it incorporates environmental elements into financial systems, thereby changing the relationship between growth, innovation, and sustainability. Studies have found that, empirically, green finance policy can be effective at promoting sustainable economic growth while also reducing negative impacts upon the environment by channeling investment into low-carbon technologies and improving resource-use efficiency (Ibrahim et al., 2023; Shi et al., 2026). The success or failure of these mechanisms will depend on how well financial systems interact with technological innovation and institutional arrangements. An example would be that green finance has improved improve green total factor productivity (GTFP) in some countries as a result of the ability of green finance to provide access to financing options for firms engaged in low-carbon activities and as a result of technological innovation; however it should be noted that the effect of green finance varies considerably depending upon the level of financial development and regulatory capacity. Therefore, this implies that green finance is not transformative per se but rather operates under a set of structural and institutional conditions that are similar across all jurisdictions.

Green Finance-Innovation Nexus: Mechanisms and Contradictions

The relationship between green finance and innovation has been considered a key element of the sustainability transition in the literature, yet existing research presents both converging and diverging perspectives. However, while many scholars find commonality in the perspective that green finance can spur technology innovation by facilitating access to funding, reducing the cost of capital for companies investing in sustainable technologies, and providing incentives for these investments (Chen et al., 2023; Liu et al., 2025; Wang, 2025; Q. Zhang et al., 2024), some researchers present differing views on this issue. In fact, empirical research demonstrates that financial tools (such as green bonds), along with government-based credit programs, are able to provide significant increases in green technological innovation and overall environmental

performance, especially when there is an adequate institutional framework supporting these efforts (Flammer, 2021; Zhao et al., 2022). Additionally, research shows that policy-driven green finance initiatives have had direct positive effects on regional green growth, improved resource allocation efficiency, and stimulated innovation systems (Liu et al., 2025).

Apart from the above backdrop, a growing body of literature demonstrates considerable structural limitations and contradictions within this nexus. While green financing stimulates the emergence of new technologies, its implementation is frequently constrained by high transaction costs, inadequate regulatory frameworks, and insufficient institutional capacity, particularly in developing economies. Furthermore, technology has two sides to the same coin. Technology can increase efficiency and competition, but it can also create rebound effects that lead to greater resource use and additional environmental pressure (Razzaq & Yang, 2023; S. Zhang et al., 2021). The existence of contradictory forces illustrates an important omission from the current literature: the absence of comprehensive or holistic models that incorporate both positive and negative feedback mechanisms connecting finance, technology/innovation, and their respective impacts on the environment. Therefore, in situations like those found in East Africa, where economic structures are underdeveloped and environmental risks are very high, constraints are expected to be exacerbated.

Financial Systems, Environmental Risk, and Structural Constraints

The role of financial systems is increasingly recognized by the literature as having two roles in relation to the sustainability transitions. On one hand, they can be considered as an “enabler” for transition, while on the other, they could also act as a barrier. There are several types of green financial products, including green bonds, climate finance, and sustainability-linked lending. Tolliver et al. (2020) Highlight that these financial products help to mobilize capital for investments into projects that are environmentally sustainable and contribute to achieving the Sustainable Development Goals (SDGs) (Ahmad et al., 2025; Fatica & Panzica, 2021). In addition to supporting SDG achievement, green financial products contribute to the development of renewable energy, investment in new infrastructure, and mitigation of climate change risks, all of which help align financial flows with environmental goals (Raman et al., 2025).

Although there has been enormous progress in green finance, some fundamental structural obstacles remain. The high transaction costs associated with providing green finance products and services to small businesses and other organizations, along with the lack of standardized performance metrics to measure success, will continue to impede green finance's ability to scale globally, especially within the global south. Additionally, financial institutions are generally driven by profit, leading to underinvestment in sustainability-focused projects that require long periods to generate a financial return. In addition, while there is growing literature regarding the relationship between environmental risk and financial systems, such as the influence of climate variability, drought, and water scarcity, etc., the majority of this literature does little to consider how best to address the impact of these types of environmental risks when making financial decisions. For example, the effects of climate-related droughts and water stress can include decreased agricultural production, increased competition for resource and potentially destabilizing social and political (Choukr-Allah et al., 2012; IPCC, 2007; Ludwig et al., 2011), yet many financial decision-makers do not factor these types of risks into their financial decision-making models.

Climate Variability, Water Stress, and Implications for Green Finance

The interaction between green finance, climate variability, and water stress is an important but understudied component of green finance in highly environmentally vulnerable regions. It has been well documented that climate change will enhance hydrological cycles by reducing available water and increasing the frequency of extreme events such as droughts and floods (IPCC, 2007; Kundzewicz et al., 2008; Milly et al., 2005). These changes have very profound implications for economics, especially in agriculture-dependent economies where water availability directly affects productivity and livelihoods.

Despite these findings, the inclusion of climate-water interactions in green financing models has been extremely limited. The majority of the research focuses on carbon footprint and the transition to low-carbon economies, while ignoring other important environmental aspects, including water scarcity and hydrologic variability. This is especially concerning when you consider that areas of high-water stress are also the most vulnerable from both an environmental and economic standpoint. Additionally, the literature states that “water scarcity” can be used as a “multiplier” by creating social tension and economic instability (Ludwig et al., 2011), yet green financing does little to account for this type of systemic risk and mainly focuses on specific sectors as opposed to sustainable solutions across all systems. Therefore, there is a clear need for an interdisciplinary approach to connect green financing with environmental, socioeconomic, and societal dynamics.

Research Gap and Contribution

Green finance has grown rapidly over recent years, yet it still has major gaps. The first gap is that most green finance research studies have been conducted separately from each other and have concentrated upon one particular aspect of green finance, such as innovation or environmental sustainability, but they do not examine these factors within a larger system (Dhayal et al., 2025; Raman et al., 2025). A second significant gap in the current body of knowledge is a geographical imbalance towards developed and developing economies, with an abundance of research on China and few, if any, studies on fragile and climate-vulnerable countries, including those in Eastern Africa. The third and final gap is the integration of environmental variables, particularly water stress and climate variability, into financial frameworks, which remains insufficient, despite their critical importance for sustainability in arid and semi-arid regions.

This research aims to address these gaps through an interdisciplinary and systemic approach to green finance, drawing on knowledge from academic writings, government reports, published articles, and proceedings. Therefore, situating green finance within the broader context of climate-water-economic interactions, the study provides a more holistic understanding of sustainability transitions in fragile and water-stressed environments. The relevance of this contribution to East Africa is significant given the intersection of environmental risks and financial constraints. Institutional challenges and their impact on the effectiveness of green finance interventions.

Conceptual Framework

The literature on green finance has been largely fragmented, as it usually treats financial instruments, policy frameworks, and/or innovation outputs in isolation, resulting in a lack of understanding of how the systemic relationships between financial flows and environmental systems work. In regions vulnerable to climate change, like East Africa, the environmental effects of an area are influenced not just by the money invested into it, but also by climate variation,

hydrologic processes, and land use dynamics, all interacting at different spatial and temporal scales (IPCC, 2007; Ludwig et al., 2011). Additionally, traditional approaches focus on general metrics (e.g., emissions, investment levels) while ignoring spatial differences in local environmental hazards, which has limited the accuracy of assessing real sustainability results. This study addresses gaps in previous research by developing a comprehensive conceptual model for green finance that connects green finance to environmental systems through government structures and geographic/spatial data collection and monitoring, enabling a more contextualized and systems-based analysis.

The five linked areas of the “green finance framework are: green finance inputs, government systems, environmental systems (climate-hydrology-land nexus), geographic monitoring, and sustainability outcomes, depicted in Figure 1 below. Mechanisms of green finance (for example, green bond financing, climate funds) operate within institutional/policy environments that determine their performance (Raman et al., 2025; Tolliver et al., 2020). Green finance investments interact with environmental systems, where climate variability, water availability, and land-use interactions create risk or return opportunities, while geospatial technologies (GIS, Remote Sensing, Climate Models) are used to monitor and validate environmental outcomes. The framework recognizes the non-linear dynamics and feedback loops, in which environmental conditions can affect the profitability of an investment, and the flow of investments into new markets can be shaped by changes in those same conditions. Integrating the three main components of green finance: economic dimension, environmental dimension, and geographic/spatial dimension, this provides an interdisciplinary and policy-relevant way to study and develop green finance in East Africa.

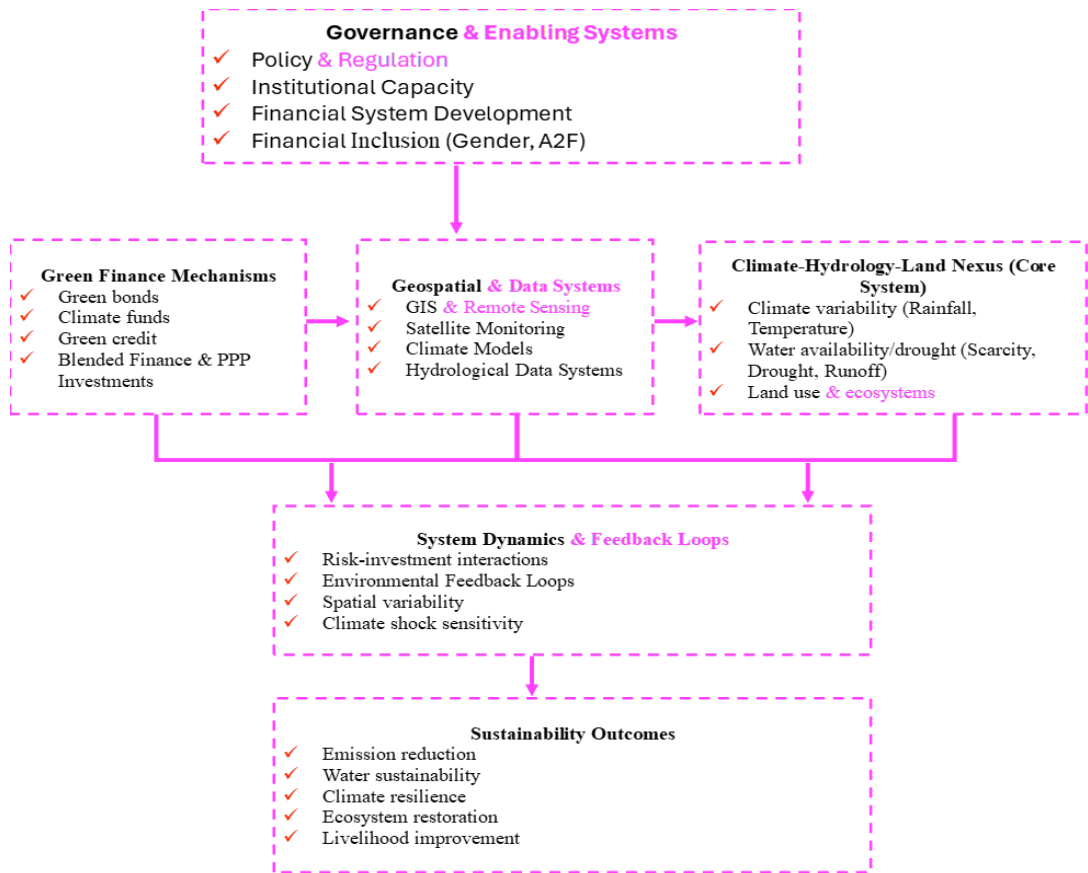


Figure 1 Conceptual Framework
Source: Author's sketch

Materials and Methods

A systematic bibliometric review, combining thematic and conceptual analyses, was conducted in this study to assess the linkages among green finance, environmental systems, and geospatial science in East Africa. Bibliometric methods are integrated with PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) (Moher et al., 2010) to ensure that the systematic review process is transparent, replicable, and sufficiently rigorous. These approaches have become well-established for mapping scientific knowledge structures and identifying emerging trends in interdisciplinary research. To guide the selection of potential studies for inclusion, a structured keyword-search methodology was developed through an iterative process, extracting author and index keywords from the Scopus

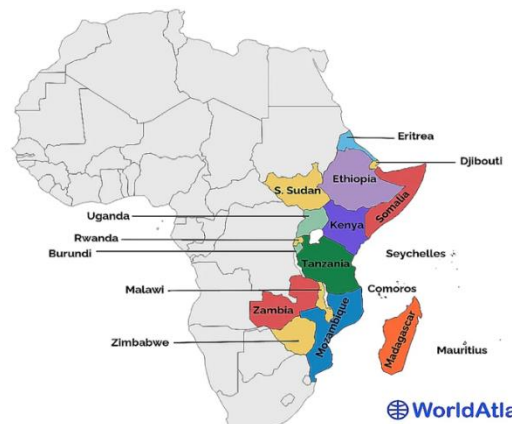


Figure 2 Map of East African countries. Source: WorldAtlas (2023). Retrieved from <https://www.worldatlas.com/articles/which-countries-are-part-of-east-africa.html>.

database and refining them based on the existing literature. Keywords related to green finance, environmental systems, hydrology, geospatial analysis, governance, and geographic region were clustered into a set of themes to align with both the study's conceptual framework and its interdisciplinary breadth.

Table 1 Bibliometric Keyword Search Strategy

Cluster	Keyword Category	Search Terms (Extracted & Expanded from Dataset)
1	Green Finance & Financial Systems	“green finance” OR “sustainable finance” OR “climate finance” OR “green investment” OR “green bonds” OR “green credit” OR “carbon finance”(Flammer, 2021; Raman et al., 2025; Sibandze et al., 2025; Tolliver et al., 2020)
2	Environmental & Climate Systems	“climate change” OR “climate variability” OR “climate resilience” OR “environmental sustainability” OR “carbon emissions” OR “ecosystem services” OR “land degradation”(Dai, 2013; Giorgi, 2006; Grossman & Krueger, 1995; IPCC, 2007; Ludwig et al., 2011; S. Zhang et al., 2021)
3	Hydrology & Water Systems	“water resources” OR “water scarcity” OR “water stress” OR “hydrology” OR “hydrological modeling” OR “drought” OR “watershed management” OR “evapotranspiration”(Alcamo et al., 2003; Kundzewicz et al., 2008; Milly et al., 2005)
4	Geospatial & Spatial Analysis	“geospatial analysis” OR “GIS” OR “remote sensing” OR “satellite data” OR “earth observation” OR “spatial analysis” OR “environmental monitoring”(Chen et al., 2023; Liu et al., 2025; Muchiri et al., 2022)
5	Energy & Green Innovation	“renewable energy” OR “energy transition” OR “green innovation” OR “technological innovation” OR “low-carbon economy” OR “clean energy.”(Ahmad et al., 2025; Wang, 2025, 2025)
6	Governance & Policy	“environmental policy” OR “climate policy” OR “sustainable development policy” OR “governance” OR “institutional capacity” OR “financial inclusion”(Raman et al., 2025; UNEP, 2024)
7	Regional Focus	“East Africa” OR “Sub-Saharan Africa” OR “Ethiopia” OR “Kenya” OR “Somalia” OR “Uganda” OR “Tanzania” OR “Rwanda”(Christopher C. Funk et al., 2012; Nicholson, 2014; Samatar, 2025)

Source: Own Elaboration based on Scopus dataset and literature synthesis.

Data

Derived from the Scopus database, a proven source for high-quality peer-reviewed literature across environmental science, economics, and geospatial domains, this study's dataset included only English-language journal articles published over 2013-2025, providing a target body of work for bibliometric analysis consistent with the above study rationales. The initial search with the keyword strategy in Table 1 netted 873 records; keywords were based on iterative extraction of author words and index terms, and reasoning from established literature, yielding a promising yield across the multifaceted target area of green finance and its intersection with environmental systems and geospatial analysis. The final dataset comprises 110 peer-reviewed publications, representing a cohesive, well-analyzed body of literature.

PRISMA Screening and Study Selection

The study followed the PRISMA analysis approach, transparent reporting during identification, separation into screening and eligibility phases, and the feasibility of replicating the

methodology, with clear guidance on reproducing results and findings as illustrated by Figure 3 below. Of the 873 records, redundant entries were removed, and 573 were selected for screening. Screening of titles and abstracts yielded studies misaligned with the overall research’s core theme (not strikingly enough environmental/hydrological/geospatial in focus, for example, but still out of that overall batch of 573). At that point, the team screened 110 full-text articles for the last time; all that met the inclusion criteria remain in the analysis.

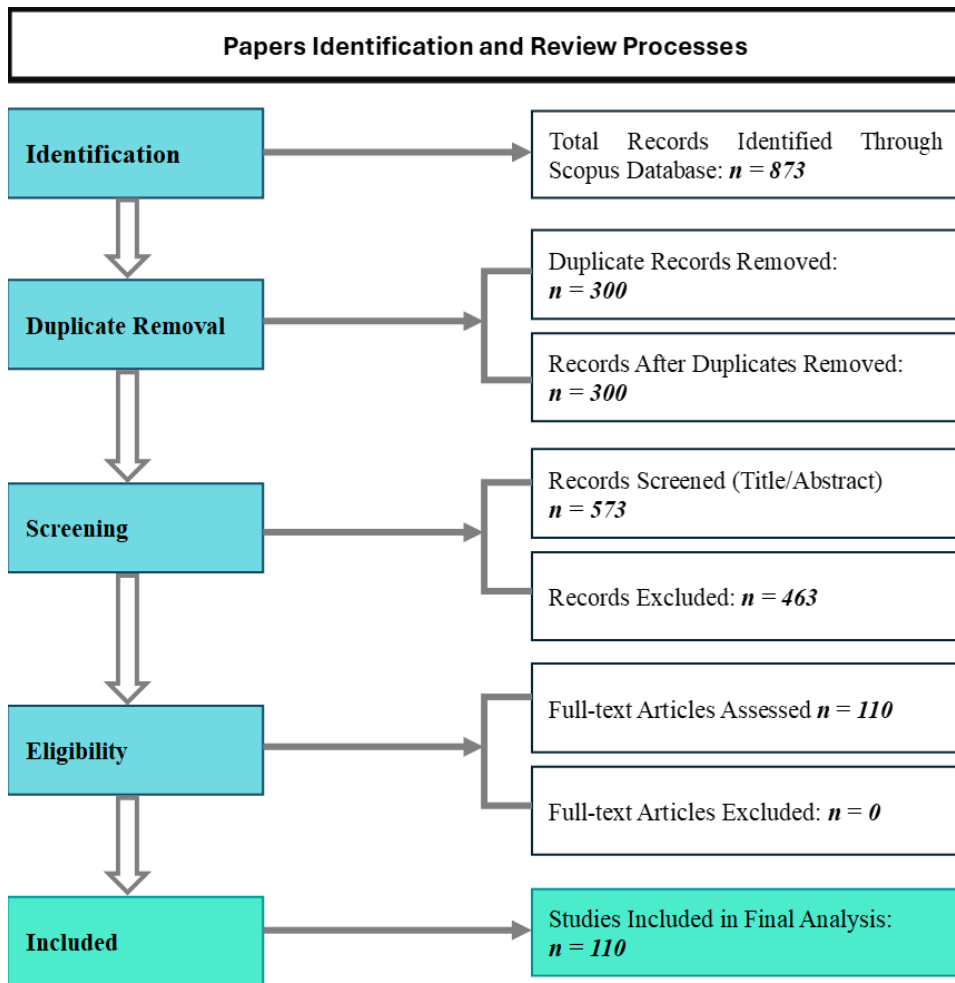


Figure 1 PRISMA Screening and Study Selection Processes
Source: Author's adaptation from (Moher et al., 2010)

Results

Bibliometric Overview and Publication Trends

The rapid increase in the number of publications on Environmental Sustainability and Green Finance from 2023 onwards is evident in the Bibliometric Analysis of the 110 reviewed articles. The increase indicates growing international concern for Climate Change, Green Financing, Sustainable Development of the Environment, and the role of Financial Systems in responding to environmental issues. At the same time, the rapidly expanding body of literature can be attributed to the implementation of internationally agreed frameworks, notably the SDGs and the

Paris Agreement, which have led to increased interest among researchers and policymakers in Green Finance mechanisms. Despite the worldwide growth in literature, these findings indicate a large regional research gap in East Africa (EA), where most Green Finance research is concentrated in Asia, particularly in China and other developed countries.

Citation Analysis

Publications by Year

There is evidence in the publication trend of an increasing production level, with accelerating rates over time. As illustrated in Figure 4, prior to 2021, there were relatively few publications (between 2 and 7) from 2013 through 2020, with some fluctuation each year. It appears that the body of knowledge in this subject began to gain momentum in research; the largest increase in research activity occurred in 2021 or later. After the initial large increase, we see a slight decrease in research activity, followed by another rapid growth spurt in both 2024 and 2025. In 2024 and 2025, the total number of publications peaked at 20 and 28, respectively. This large increase in scholarly work on "green" financing and climate change mitigation reflects a great deal of global attention to climate change. Additionally, the availability of many new tools and platforms for investing in "green" ways, and the urgent need to make developing country economies sustainable, would be major contributors to this large increase in scholarly research. Overall, this data set shows a continuous upward trend and demonstrates that this body of knowledge has evolved from a few peripheral academics conducting research on fringe issues into a mainstream area of scholarship using multi-disciplinary approaches and methods such as Environmental Science, Finance, and Geospatial Analytics.

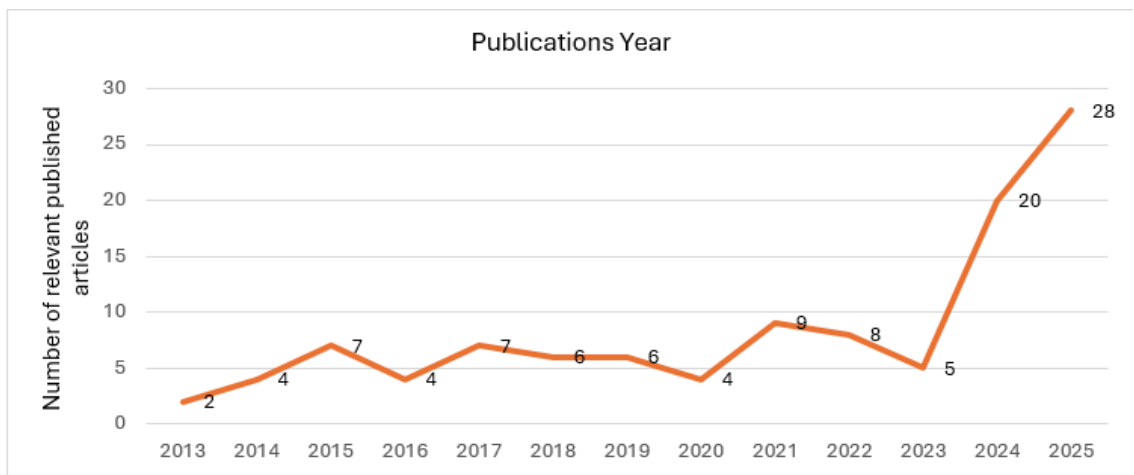


Figure 2 Publications by Year

Citations by Year

The number of citations appears to trend upward over the years. This suggests an increasing use of the academic's research on green finance and environmental sustainability, as also explained in Figure 5 below. Early year citation totals are very low (2013-2016). We see signs that the research field is gathering pace in 2018-2019, as citation numbers have accelerated significantly. There was a very large increase in citations from 2021 to 2023; most strikingly, a huge increase

in 2023 (743), indicating that many important and high-impact studies and works were being published and recognized at that point. The rapid rise in these total citation numbers from 2021 to 2023 could signal a greatly increased global focus on climate finance and sustainability in light of international policy agreements, e.g., the Paris Agreement and the SDGs. While there is also evidence of a decline in these citation numbers after 2023, this very likely reflects lag time, since newer publications (2024-2026) have had very little time to accrue citations. In general, there is an apparent trend in the number of citations that suggests the research area has matured into one of increasing influence, and the highest level of scholarly impact has been achieved in recent years.

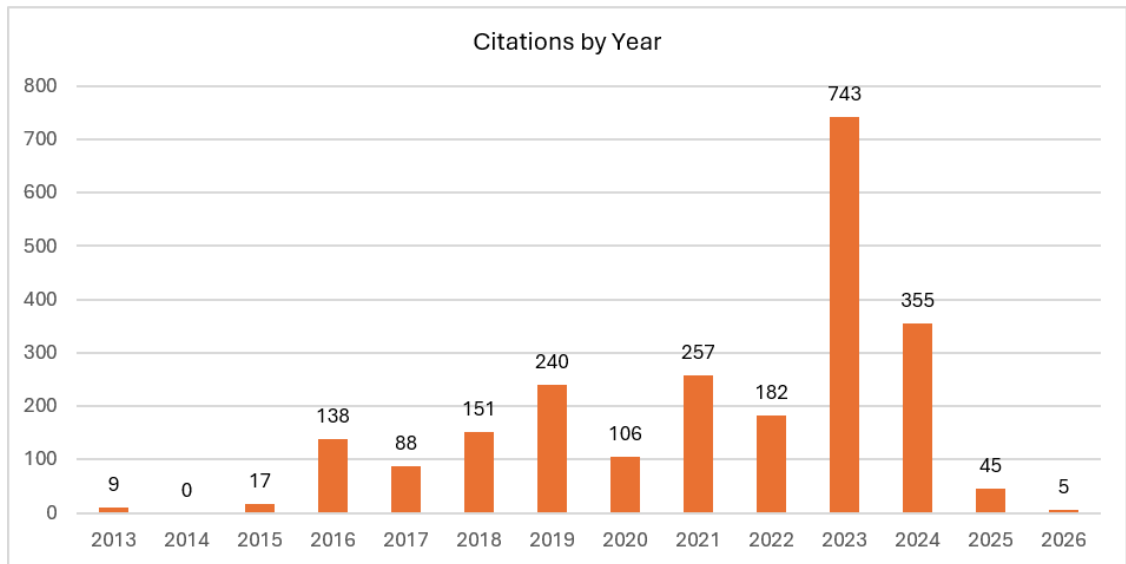


Figure 3 Citations by Year

Top-Most Frequently Cited Articles

As illustrated in **Table 2** below, a climate risk framework for climate-sensitive sectors, including agriculture, is important. According to Parker et al. (2019), subnational-level climate planning is possible with local climate data. In addition, according to Zougmore et al. (2021) climate-smart agriculture, it strengthens food systems under climate stress. Renewable energy and climate finance have both identified structural constraints, such as a lack of policy clarity and financing shortfalls, as major barriers to expanding scalable sustainable energy investment in Sub-Saharan Africa (SSA) (Mungai et al., 2022). In general, highly cited literature supports the idea that linking environmental risk, sectoral resilience, and financial options will be central to moving forward the sustainability agenda. In addition, other authors in the field of green finance and environmental sustainability research in East Africa have focused on developing theoretical models or empirical methods to assess the impact of environmental degradation on economic outcomes.

While there is growing evidence that ecosystem-based solutions and new forms of financing can contribute to climate mitigation and adaptation objectives, it is also clear that many of these initiatives have yet to be scaled up to meet the ambitions set out by governments at international conferences. For example, while the literature provides increasing evidence of the dual contributions of agroforestry and forest-based mitigation activities to both livelihoods and carbon

sequestration in regions such as East Africa (Muthuri et al., 2023; Njana et al., 2021), the literature similarly indicates a substantial gulf between the policy ambitions set by governments around private climate finance and green bonds and the actual capacity to implement them. As a result, there is little alignment between financial flows and environmental outcomes from these types of financial instruments (Michaelowa et al., 2021; Ngwenya & Simatele, 2020; Pauw et al., 2016). In addition to these empirical findings, conceptual work has shown that there remains considerable ambiguity around how climate finance should be defined and operationalized across complex governance systems (Hall, 2017). However, despite these advances, most reviewed studies lack integration of geospatial and hydrological aspects to enable spatial validation and monitoring of the environmental impacts associated with environmental projects. The absence of this type of information further supports the need for an interdisciplinary approach that links financial systems to environmental processes and to spatial analysis, as applied in this research.

Table 2 Top-Most Frequently Cited Articles

#	Title	Journal	Citations	Year	References
1	Vulnerability of the agricultural sector to climate change: The development of a pan-tropical Climate Risk Vulnerability Assessment to inform sub-national decision making	PLoS ONE	162	2019	Parker L., et al., 2019
2	What constrains renewable energy investment in Sub-Saharan Africa? A comparison of Kenya and Ghana	World Development	128	2018	Pueyo A., et al., 2018
3	Transforming food systems in africa under climate change pressure: Role of climate-smart agriculture	Sustainability (Switzerland)	102	2021	Zougmore R.B., et al., 2021
4	Unlocking climate finance potential and policy barriers - A case of renewable energy and energy efficiency in Sub-Saharan Africa	Resources, Environment and Sustainability	101	2022	Mungai E.M., et al., 2022
5	Agroforestry's contribution to livelihoods and carbon sequestration in East Africa: A systematic review	Trees, Forests and People	87	2023	Muthuri C.W., et al., 2023
6	Private finance for adaptation: do private realities meet public ambitions?	Climatic Change	58	2016	Pauw W.P., et al., 2016
7	Mobilizing private climate finance for sustainable energy access and climate change mitigation in Sub-Saharan Africa	Climate Policy	57	2021	Michaelowa A., et al., 2021
8	The role of forests in the mitigation of global climate change: Empirical evidence from Tanzania	Environmental Challenges	51	2021	Njana M.A., et al., 2021
9	Unbundling of the green bond market in the economic hubs of Africa: Case study of Kenya, Nigeria and South Africa	Development Southern Africa	47	2020	Ngwenya N., et al., 2020

10	What is adaptation to climate change? Epistemic ambiguity in the climate finance system	International Environmental Agreements: Politics, Law and Economics	46	2017	Hall N., et al., 2017
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Influential Countries

The network of co-authors, which represents countries that significantly influence others, demonstrates how heavily many countries are influenced globally in producing new information on green finance and sustainable development. These countries are mainly located in developed economies, whereas African countries have an important role within developing or regional research collaborations. The UK, the USA, and Germany stand out as major players in this network because they produce the highest amount of scientific literature, have the largest amounts of funds available, and also lead the world in terms of climate finance discussions, as reflected in highly cited research on climate finance, adaptation framework and policy systems (Hall, 2017; Michaelowa et al., 2021; Pauw et al., 2016), and also show large numbers of collaborative relationships with Europe (e.g., Switzerland, Netherlands, and Sweden) and the emerging research locations in Africa.

By comparison, Kenya is the single most influential country from Africa and acts as a bridge to connect global research collaboration with the local context and issues of Sub-Saharan Africa (SSA), especially in relation to renewable energy investment, climate-smart agriculture, and agroforestry (Muthuri et al., 2023; Pueyo, 2018; Zougmore et al., 2021). Although there are some signs of growth, for example, in Ethiopia and Somalia, they seem to be at a periphery level within this global research community. Finally, it can be seen that China and the Netherlands contribute to methodological and financial innovation in areas such as green finance and location-based applications, as **Figure 6** below shows. As a whole, the network shows a clear one-periphery structure with global northern countries dominating knowledge production, while the East African countries remain significantly under-represented, although they represent one of the regions that will be most affected by climate change, therefore increasing the importance of furthering inclusion and creating research collaborations that are regionally focused.

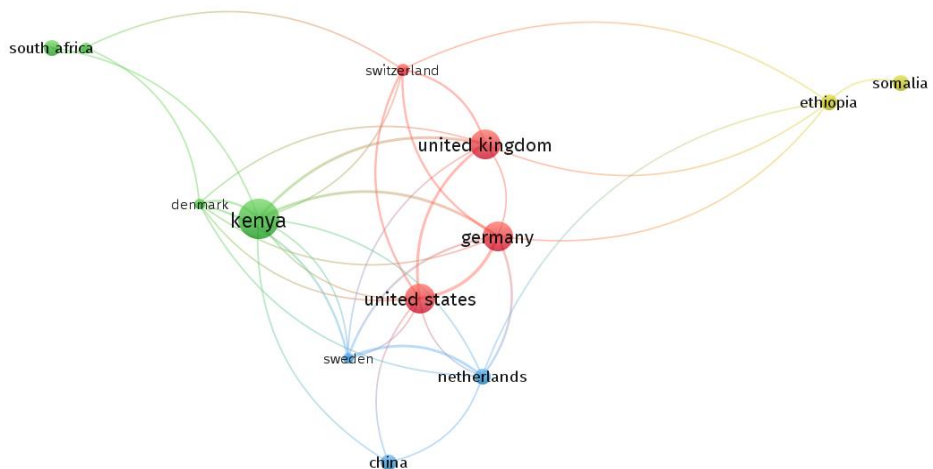


Figure 6 *Influential Countries*

green finance is developing into an important tool for enhancing environmental sustainability, it still lacks empirical evidence and conceptual development in East Africa. The bibliographic data indicate that there has been a large increase in published works on green finance since 2025, primarily as a result of international policies, specifically the SDG's and the Paris Agreement (Michaelowa et al., 2021; Pauw et al., 2016) that highlight the potential of financial systems to contribute to action against climate change (Flammer, 2021; Tolliver et al., 2020). Although this trend is evident in the results, it also aligns with what was discussed previously in the literature review regarding the institutionalization of green finance within global sustainable frameworks (Ngwenya & Simatele, 2020; Zhou & Zhou, 2024). Even though we see growth in terms of research production on green finance globally, our analysis demonstrates that there is a significant spatial inequality in the geographical distribution of research productivity, i.e., much of the research is conducted in Asia or developed countries and does not provide sufficient representation of the East Africa region, specifically, the environmental and institutional context (Ngwenya & Simatele, 2020; Zhou & Zhou, 2024).

The thematic cluster analysis also shows that current research on green finance focuses on three core categories: financial tools, climate-reduction strategies, and government policies. However, it appears that these areas do not focus on interactions with the environment. As previously mentioned, many of the studies referenced have shown that green financing has a high possibility of supporting transitions to low-carbon economies and reducing greenhouse gas emissions (for example, through application of the EKC); however, there are constraints limiting its use in vulnerable climate communities (Nabi et al., 2025; Rady et al., 2025; Stern, 2014). Similarly, previous reviews identified that most models used in studies on green finance fail to take into account environmental variability at local levels and therefore cannot reflect changes due to climate that can vary from one region to another (including droughts, ecosystem vulnerability, land-use, etc.), which are very common in East Africa (Dai, 2013; Zougmore et al., 2021). Therefore, the results show that although climate-related topics were dominant within the keyword network, hydrology and environmental risks remained poorly represented, and because they are central to several key economic sectors (such as agriculture and energy), they need to be included in future research (Kundzewicz et al., 2008; Parker et al., 2019; Sibandze et al., 2025). A significant result of integrating the findings with the conceptual model is a separation of the domains of finance, environmental, and space. As outlined in the methods section, the structured keywords included multiple themes related to **“green finance”, “environmental”, “hydrology”, and “geographic information”**; yet, as indicated by the bibliometric research, there are relatively few references across the domains. The lack of interdomain reference precludes an understanding of how green finance operates at the interface of the climate-hydrology-land nexus where environmental processes have direct effects on both risk and value creation of green financing activities (IPCC, 2007; Ludwig et al., 2011) e.g. climate variability creates uncertainty about investments, hydrologic cycles create variability in water resources and productivity and land use change affects carbon sequestration and ecosystem services.

In addition, the study emphasizes that although geospatial technology is increasingly being applied to environmental monitoring, it has yet to be fully utilized in green finance research. The authors illustrate how the use of geospatial technologies, including geographic information systems (GIS) and remote sensing, to evaluate changes in land use, forest loss, and climate-related risks has become more common (Chen et al., 2023; Pandey et al., 2026). Nonetheless, most applications of geospatial technology remain unconnected to financial analyses, thereby constraining its ability to demonstrate whether the environmental impacts resulting from green

investment have occurred. Therefore, this finding provides direct support for the conceptual model presented in this study, which identifies geospatial monitoring as an important analytical layer connecting the input parameters of green investments with their resultant environmental outputs. Geospatial data may provide additional transparency, accountability, and evidence-based decision-making capabilities when integrated into green finance frameworks, especially in areas such as East Africa, where traditional data collection systems are generally lacking (Muthuri et al., 2023; Parker et al., 2019).

In addition to highlighting the necessity of governance and institutional capacity for the realization of green finance outcomes, the study's results reflect the literature's emphasis on the strength of the regulatory framework and institutional alignment as critical factors for the successful implementation of green finance. By comparison, the East Africa region faces structural impediments such as weak regulatory systems, underdeveloped financial markets, and limited financial access, which impede the potential scale and impact of green finance initiatives (Ngwenya & Simatele, 2020; Michaelowa et al., 2021). As well, the results from the co-authorship and country network analyses provide additional evidence of an underpinning 'core-periphery' model of knowledge production where developed countries produce the majority of the research, whereas, due to their high vulnerability to climate change, developing countries in Africa have very little representation (Pueyo, 2018; Zougmoré et al., 2021).

Finally, synthesizing and connecting across the introduction, literature review, methodology, and results, this research demonstrates that the effectiveness of green finance cannot exist independently of both the environment and space. The results support the core hypothesis of this research that sustainability outcomes are generated through interaction among financial mechanisms, governmental frameworks, natural environment process dynamics, and geospatial data collection (Mungai et al., 2022; Tolliver et al., 2020). More specifically, this research fills important gaps in the existing literature by integrating hydrology into the analysis, utilizing available geospatial technology, and providing a representation of African countries. In addition, the development of a geospatially based analytical framework provides greater insight into how green finance may be made compatible with environmental reality. Overall, this research is timely for East Africa, which faces challenges related to climate change risk, water availability, and institutional weakness requiring context-specific, interdisciplinary, and evidence-based approaches to achieve sustainable development.

Conclusion and Policy Implications

This research examined Green Finance in East Africa from an Environmental Science and Geospatial perspective. While there have been very rapid advancements in green finance, it remains underdeveloped and lacks a unifying framework and basis for sustainable development grounded in actual environmental parameters. As such, existing studies and practices are largely based upon financing mechanisms and policy rhetoric rather than the relationships among hydrological/climate systems, which are critical to determining the sustainability of the environment in this part of Africa (IPCC, 2007; Tolliver et al., 2020).

One of the most significant findings is that there has been very little connection made between the use of geospatial technologies and their potential role in the structure for implementing green financing. GIS and Remote Sensing are widely used in environmental monitoring, but they are rarely employed to assess the impact of green financial initiatives, thereby exacerbating a lack of transparency and accountability (Chen et al., 2023; Pandey et al., 2026). Furthermore, at this time, institutional and governance constraints continue to limit the success of green finance in

East Africa, with factors such as weak regulatory structures and environmental policy fragmentation, combined with low levels of financial inclusion, continuing to impede its implementation and scaling up (Michaelowa et al., 2021; Ngwenya & Simatele, 2020). The institutional/governance-related challenges associated with successful green financing in East Africa are exacerbated by the fact that many academic models of green financing lack sufficient representation of the unique characteristics of the African context (Pueyo, 2018; Zougmore et al., 2021).

The study therefore proposes an integrated, systems-based, geospatially informed analytical framework for identifying financial mechanisms in relation to environmental processes and geospatial data collection. The Study shows that the relationship between sustainable results and the interaction among financial systems, governance structures, the environment, and geographic information systems is iterative, causal, and non-linear; therefore, this research provides additional insight into the traditional cause-and-effect approach to examining green finance by integrating environmental and geographic considerations.

Green finance in East Africa needs three focused priority areas to strengthen from a policy context: environmental system dynamics, such as water and land; developing the government's use of geo-spatial monitoring to validate green outcomes; and enhancing governance coherence, regulatory frameworks, and financial access to support green investments. Overall, advancing green finance in this region will require a shift towards integrated, data-driven approaches grounded in local conditions and needs.

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