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Landslide Susceptibility, Risk Assessment, and Mitigation Strategies in Africa: A Systematic Review and Meta-Analysis

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Abstract
Landslides are a major environmental hazard across Africa, threatening lives, infrastructure, and sustainable development. Their increasing frequency is driven by climate extremes, fragile geology, and rapid, unregulated urbanisation. This study conducts a systematic review and meta-analysis of 33 peer-reviewed publications (2010–2025) to evaluate the state of landslide research in Africa. The objectives were to assess susceptibility and risk assessment models, identify dominant environmental and human risk factors, and compare mitigation strategies across regions. Using the PRISMA framework, data was extracted from multiple databases and analysed through both quantitative and qualitative integration. Results show that rainfall, slope gradient, and lithology are the main determinants of landslide susceptibility, while deforestation, mining, and informal urban expansion amplify risk. Traditional GIS–AHP models achieved mean accuracies of 82%, whereas advanced machine learning and hybrid approaches (RF, FAHP, XAI) attained 88–92%, reflecting improved predictive reliability. East and North Africa exhibit the highest hazard densities due to steep terrain and high rainfall, while Central Africa remains data deficient. Despite methodological progress, fewer than 20% of studies influence national disaster risk reduction (DRR) policies, exposing a persistent science–policy gap. The study highlights the need for evidence-based, data-driven, and inclusive risk management. Strengthening geospatial data infrastructure, integrating scientific research into land-use planning, and enhancing community participation are critical for resilience. These efforts align with the Sendai Framework (2015–2030) and Sustainable Development Goals (SDGs 11, 13, and 15) to advance proactive and climate-resilient landslide risk governance in Africa.

Keywords
Landslide Susceptibility Mapping, Landslide Risk Assessment, Hazard Mitigation Strategies, Geospatial and Remote Sensing Techniques, Environmental and Socio-economic Drivers

1. Introduction

Landslides constitute one of the most devastating geo-environmental dangers in Africa, often instigated by heavy rainfall, unstable geological conditions, and escalating human activity on vulnerable slopes (Nahayo et al., 2018; Kumi-Boateng et al., 2020). In the African context, these occurrences are not solely natural but are significantly influenced by anthropogenic activities such as deforestation, unregulated urbanisation, and mining, which destabilise slopes and heighten vulnerability (Alcantara-Ayala, 2025; Nsabimana et al., 2023).

The socio-economic and environmental repercussions are grave, including thousands of deaths, significant infrastructure destruction, and persistent displacement, particularly in mountainous and urban regions such as the Kigezi Highlands and Freetown (Meque et al., 2023; Kiremeji et al., 2025). Landslides, despite their prevalence, are little documented in most African countries, hindering early warning systems and long-term adaptation efforts (Maes et al., 2017; Monsieurs et al., 2018).

Africa's susceptibility to landslides arises from the interplay of environmental, climate, and governmental variables. The continent's rugged terrain, intense precipitation, and seismically active rift zones render it inherently vulnerable (Bouaoud and Mezhoud, 2025; Tynchenko et al., 2024). Nonetheless, these physical hazards are exacerbated by swift population expansion, inadequate land management, and the lack of dependable data for hazard mapping (Hossain et al., 2024). Moreover, research and modelling initiatives are predominantly focused on data-abundant areas beyond Africa, resulting in the continent's marginalisation in worldwide advancements in landslide susceptibility modelling (Kucharczyk and Hugenholtz, 2021; Omar et al., 2025). This disparity highlights an immediate necessity to create context-specific frameworks that incorporate both environmental and socio-economic aspects of landslide risk.

This study aims to carefully synthesise existing research on landslides in Africa, concentrating on susceptibility modelling techniques, principal triggering variables, and mitigation strategies. The objectives are to (1) identify the predominant landslide models and risk factors utilised in African contexts, (2) assess their efficacy in data-deficient regions like Ghana, Mozambique, Rwanda, Kenya, Uganda, Algeria, Madagascar, Burundi, Cote d' Ivoire, Cameroon, Morocco, Central Africa and (3) analyse community, policy, and engineering responses to landslide risk.

The primary objective is to improve comprehension of landslide dynamics in Africa and to guide evidence-based disaster risk reduction strategies in accordance with the Sendai Framework for Disaster Risk Reduction and the Sustainable Development Goals (SDGs) (Ahmed, 2021; Alcantara-Ayala, 2025). The next section presents brief discussions on the theoretical framework of the study. Section 4 provides a detailed description of the methodology and data employed in this study. Section 5 interprets and discusses the scientific and policy relevance of the results.

2. Conceptual and Theoretical Frameworks

Comprehending landslide susceptibility and risk in Africa necessitates a comprehensive framework that incorporates physical, social, and governance aspects of environmental risks. Historically, landslides have been examined from geomorphological and engineering viewpoints, concentrating on physical triggers such as precipitation, slope gradient, and lithology (Nahayo et al., 2018; Kumi-Boateng et al., 2020). Contemporary research underscores a socio-natural hazard perspective, acknowledging that landslides arise from the interplay between environmental processes and human activities (Alcantara-Ayala, 2025; Maes et al., 2019). This corresponds with the Pressure and Release (PAR) paradigm (Oliver-Smith, 2022; Manyena, 2012), which conceptualises disasters as the convergence of natural hazards and socially built vulnerability. Africa's landslide danger stems from entrenched systemic issues, including poverty, deforestation, and ineffective government, which, when coupled with geophysical triggers, precipitate disasters. This study utilises the risk nexus model given by *Equation 1* as (Alcantara-Ayala, 2025):

$$Risk = Hazard \times Exposure \times {}^{Vulnerability}/_{Adaptive\ Capacity} \quad (1)$$

In this context, hazard denotes the likelihood of a landslide based on slope, geological conditions, and rainfall intensity; exposure indicates the population and assets situated in hazard-prone areas; vulnerability encompasses socio-economic sensitivity influenced by poverty, land-use practices, and infrastructural shortcomings; and adaptive capacity signifies the capability of communities and institutions to foresee, withstand, and recuperate from impacts. This framework underscores that landslide risk is dynamic, influenced by interactions among environmental deterioration, urban expansion, and institutional capability (Maes et al., 2019; Ahmed, 2021). It emphasises that enhancing adaptive capability via community engagement, policy reform, and data-informed decision-making can substantially mitigate long-term risk. This study's theoretical underpinning is based on three complementary paradigms.

The Socio-natural Hazard Theory elucidates landslides as results of interconnected human-environment systems (Alcantara-Ayala, 2025); the Sustainable Livelihoods Framework (SLF) associates vulnerability and resilience with access to resources and adaptive strategies (Maes et al., 2019); and the Systems and Feedback Theory frames landslide risk as a dynamic process characterised by reinforcing feedback loops where deforestation heightens hazard exposure, subsequently exacerbating poverty-induced land exploitation (Kumi-Boateng et al., 2020).

Collectively, these frameworks offer a thorough perspective for examining vulnerability, risk, and mitigation strategies in Africa, directing this study's systematic synthesis to discern how physical processes, socio-economic pressures, and adaptive responses converge to influence landslide dynamics throughout the continent. Fig. 1 illustrates the conceptual and theoretical framework guiding this systematic review and meta-analysis. It depicts the interrelationships between the key components of landslide research, namely susceptibility assessment, risk evaluation, and mitigation strategies, within the broader context of Africa's diverse environmental and socio-economic systems.

3. Study Area Description

Africa (Fig. 2) is a continent characterized by remarkable geological, climatic, and topographical diversity that significantly influences environmental processes and natural hazards, including landslides. The continent is situated on ancient cratons, including the Congo, Kalahari, and West African cratons, encircled by Proterozoic mobile belts and active rift systems, such as the East African Rift, where seismic and volcanic activity exacerbate slope instability (Priestley et al., 2008; Davison and Steel, 2018). Sedimentary basins and coastal plains, such as the Niger and Zambezi deltas, comprise weak, weathered materials susceptible to mass movement and erosion (Jian-Ping et al., 2008; Davies, 2015). This geological structure supports Africa's diverse landscape, spanning high volcanic plateaus and escarpments to extensively worn lowlands, which dynamically interacts with climate and human activities, affecting slope stability (McCourt et al., 2006).

Africa demonstrates significant regional and temporal climatic variability. Rainfall intensity, especially during brief, high-energy storm events, is the primary catalyst for landslides, although regional processes like the West African Monsoon and the El Niño–Southern Oscillation influence interannual variability (Taylor et al., 2009; Mason, 2001; Nicholson, 2017). The bimodal rainfall pattern of East Africa, the persistent droughts of the Sahel, and the alternating dry and wet extremes of Southern Africa collectively provide a complex array of weather-induced hazard patterns (Barry et al., 2018; Mahe et al., 2013). Warming rates surpassing the global average, along with heightened evapotranspiration and high precipitation events, further intensify soil instability (Collins, 2011; Hulme et al., 2001; Gemeda and Sima, 2015). The aforementioned changes, along with restricted meteorological observation networks and the difficulties in modelling localised rainfall extremes, augment the uncertainty in forecasting landslide risk (Conway, 2011; Platts et al., 2015; Buontempo et al., 2015).

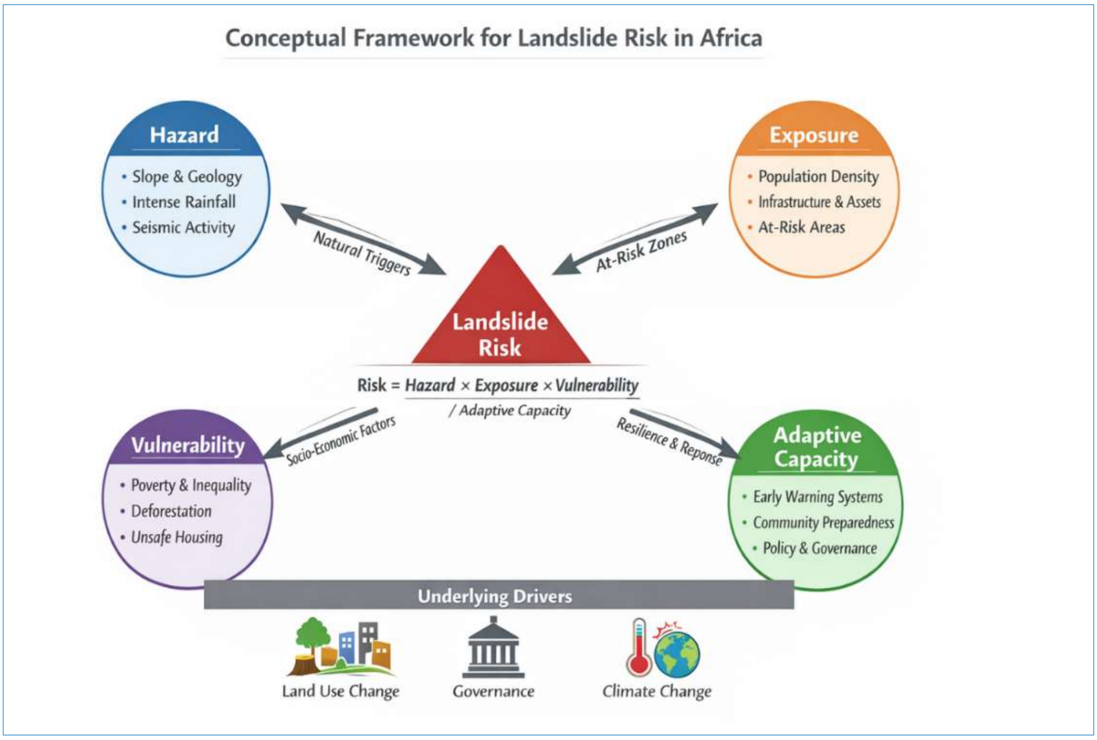

Fig. 1. Flowchart illustrating the conceptual framework of the study

Human and environmental factors exacerbate the continent's physical vulnerability. Accelerated deforestation, urban encroachment on steep or unstable landscapes, and unregulated mining disrupt slope hydrology and diminish vegetation cohesion, hence exacerbating dangers in rural and urban environments (Abernethy et al., 2016; Ondayo et al., 2023; Barchi and Winter, 2020). Governance issues, disjointed land-use planning, and inadequate institutional capacity frequently hinder disaster preparedness, while local communities, especially in East and Central Africa, experience the highest vulnerability (Warf, 2017; Mercer et al., 2003; Myers, 2014).

Africa's study area is characterised by the convergence of intricate geology, fluctuating climate, and significant human impact, resulting in a dynamic and heterogeneous landscape of landslide susceptibility that necessitates regionally tailored evaluation and mitigation strategies (Venables, 2010; Davies, 2015).

4. Methodology

4.1. Study Design

This study utilized a systematic review and meta-analysis framework according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to consolidate knowledge regarding landslide susceptibility, risk assessment, and mitigation techniques throughout Africa. The design adhered to the PCC framework (Population, Concept, Context) to provide systematic scope alignment. The population included African locations with documented or potential landslide activity, encompassing hilly areas, rift valleys, and regions with heavy precipitation. The concept encompassed landslide susceptibility mapping, hazard assessment, vulnerability evaluation, and both structural and non-structural mitigating strategies.

The context included several African environments, geological, climatic, and socio-economic, highlighting areas such as the East African Rift, Atlas Mountains, highlands of

Cameroon and Ethiopia, and the swiftly urbanising slopes of West Africa. This architecture provided a uniform basis for examining regional vulnerability patterns, model efficacy, and adaptive mitigation strategies within the continent's distinct environmental and governance contexts.

4.2. Search Strategy

A thorough multi-database search strategy was devised to discover empirical research from 2010 to 2025, reflecting the technical progression from conventional statistical methods to sophisticated AI-driven models. Keywords and Boolean operators integrated principal descriptors of landslide processes, evaluation frameworks, and African locales. Search strings incorporated terms such as "landslide," "slope failure," "mass movement," "susceptibility," "hazard mapping," "vulnerability," "risk assessment," "mitigation," "GIS," and "Africa" (together with specific country names).

Search was performed throughout Scopus, IEEE Xplore, Google Scholar, ResearchGate, and Academia.edu to ensure thorough retrieval of both globally indexed and Africa-specific literature. The incorporation of several platforms reduced regional publication bias. Table 1 displays the example of search strings utilized.

Table 1. Search strings used in various databases

No	Database	Search Strings
1	Scopus	(landslide OR "slope failure" OR "mass movement" OR "debris flow" OR "rockfall" OR "slope instability") AND (susceptibility OR hazard OR risk OR vulnerability OR assessment OR mapping OR model) AND (Africa OR Algeria OR Angola OR Cameroon OR Ethiopia OR Kenya OR Madagascar OR Morocco OR Rwanda OR Tanzania OR Uganda OR "South Africa" OR Tunisia OR Ghana OR "Côte d'Ivoire" OR Nigeria OR Burundi)
2	Google Scholar	(landslide OR "slope failure" OR "mass movement" OR "mass wasting") AND (susceptibility OR "risk assessment" OR "hazard mapping" OR mitigation OR vulnerability) AND (Africa* OR Ethiopia OR Kenya OR Uganda OR Rwanda OR Cameroon OR Madagascar OR "South Africa" OR Tanzania OR Morocco)
3	IEEE Xplore	("landslide" OR "slope failure") AND ("susceptibility" OR "risk assessment" OR "machine learning" OR "GIS") AND (Africa OR African countries)
4	ResearchGate	(landslide OR landslides OR "slope failure" OR "mass wasting" OR "debris flow") AND (susceptibility OR hazard OR risk OR vulnerability OR assessment OR mapping) AND (Africa OR African countries OR specific country names)
5	Academia.edu	((landslide OR "slope stability" OR "mass movement" OR "slope failure") WN ALL) AND ((susceptibility OR risk OR hazard OR mitigation OR assessment OR "early warning") WN ALL) AND ((Africa OR Ethiopia OR Kenya OR Rwanda OR Uganda OR Cameroon OR Madagascar OR Tanzania) WN ALL)

4.3. Study Selection Procedure

The selection of studies adhered to the PRISMA procedure to guarantee reproducibility and transparency. Two reviewers separately evaluated papers in three phases: title, abstract, and full-text review, resolving discrepancies through consensus and, when required, adjudication by a third reviewer. Cohen's Kappa ($\kappa \geq 0.70$) measured inter-rater reliability, signifying considerable agreement. Duplicates were eliminated with Mendeley, followed by the application of inclusion/exclusion criteria to ascertain final eligibility.

Studies were rejected for their lack of applicability to African cases, absence of quantitative validation, or failure to include clear components of landslide susceptibility or risk. The concluding collection of papers received a comprehensive full-text evaluation to guarantee methodological integrity and theme coherence. The selection process is illustrated in the PRISMA flow diagram (Fig. 3), detailing the counts for screening, inclusion, and exclusion at various phases.

4.4. Inclusion and Exclusion Criteria

The review utilised specific inclusion and exclusion criteria (Table 2) to ensure methodological consistency and empirical rigour. Eligible studies were those done in Africa, published between 2010 and 2025, that were focused on landslide susceptibility, risk assessment, or mitigation. They were mandated to utilise quantitative or semi-quantitative approaches, report validation metrics such as AUC, accuracy, Kappa, or sensitivity, and incorporate accessible inventory or geospatial data. Research published in English, French, or Portuguese was included to guarantee extensive regional representation. Studies were rejected if they lacked empirical validation, were solely descriptive, concentrated on non-landslide mass movements, constituted editorials or gray literature without peer review, or were undertaken outside Africa without pertinent comparative case analysis.

4.5. Data Extraction

A systematic data extraction process guaranteed thorough documentation of study attributes and analytical uniformity. Two reviewers independently extracted data utilising a pilot-tested form, resolving discrepancies through consensus. The extracted variables comprised bibliographic information, including authorship, year, study area, and scale; geospatial context involving physiographic, geological, and climatic conditions; and inventory characteristics specifying the quantity and type of landslides, along with data sources from field surveys, satellite imagery, and archival records.

Data regarding conditioning elements such as slope, lithology, land use, hydrology, precipitation, vegetation (NDVI), and anthropogenic activities were also gathered. Furthermore, information regarding models and methodologies, including statistical, machine learning, heuristic, or hybrid frameworks, alongside software, sample size, and parameterisation, was rigorously retrieved. Validation metrics, including AUC, accuracy, sensitivity, specificity, ROC, and CR values, were documented alongside risk and mitigation outcomes that detailed implemented measures, performance indicators, and resilience results. This methodology guaranteed methodological accuracy and contextual significance, enabling precise synthesis of susceptibility patterns and model efficacy across regions.

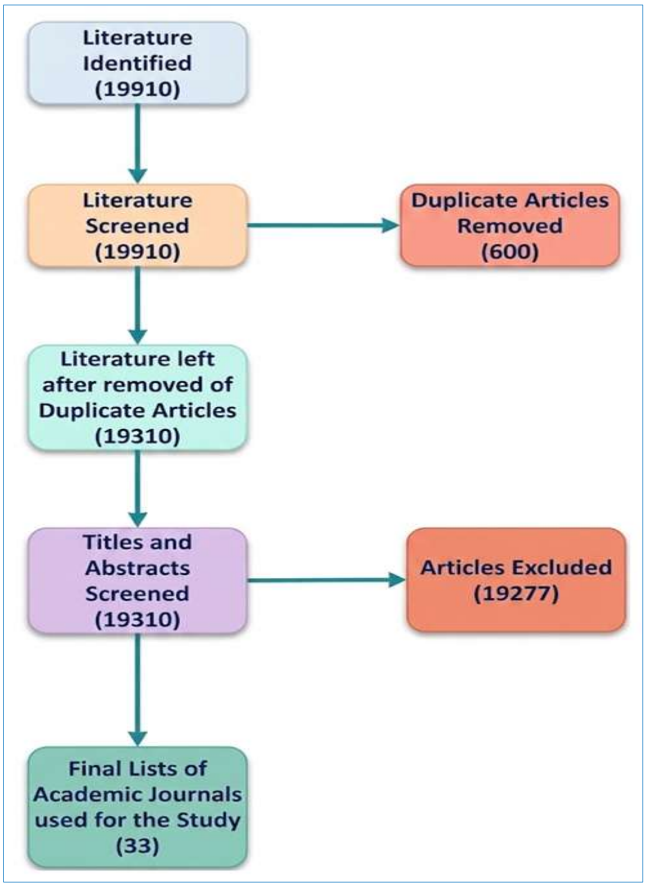

Fig. 3. PRISMA flow diagram for study selection process

4.6. Quality Assessment

The quality of the study was assessed using a tailored framework derived from the Newcastle–Ottawa Scale and the Critical Appraisal Skills Programme (CASP), concentrating on five principal domains: the quality and comprehensiveness of landslide inventory data, the appropriateness of conditioning factors, methodological rigour and reproducibility, validation quality and transparency, and clarity in reporting and interpretability. Each study was assigned a composite score between 0 and 16, classifying them as high quality (12–16), moderate quality (7–11), or low quality (0–6). The quality ratings informed evidence weighing and sensitivity analysis without the explicit exclusion of any studies. All evaluations were performed separately by two evaluators to guarantee impartiality and impartial scoring.

4.7. Data Analysis

The analysis employed narrative synthesis and quantitative meta-analysis to amalgamate findings from several African contexts. Narrative synthesis entailed a thematic categorisation of studies according to modelling techniques, statistical, heuristic, physically based, machine learning (ML), or hybrid methods, alongside geographic region, validation rigour and mitigation emphasis. This synthesis facilitated the identification of predominant conditioning elements, including precipitation, gradient, and lithology, while also emphasising data constraints, methodological discrepancies, and implementation obstacles. The outcomes of this method largely corresponded with the conceptual frameworks established earlier in the study, yielding a thorough comprehension of patterns and deficiencies in landslide susceptibility and risk assessment research throughout Africa. The quantitative meta-analysis concentrated on assessing model performance, especially utilising the Area Under the Receiver Operating Characteristic Curve (AUC) and overall accuracy as standardised effect metrics. Random-effects models utilising the DerSimonian–Laird estimator were implemented to consolidate impact sizes while addressing heterogeneity across studies. Forest plots were employed to illustrate the regional and methodological distributions of AUC values together with their associated 95% confidence intervals.

Statistical heterogeneity was assessed using Cochran's Q test, the I^2 statistic, and τ^2 values. Subgroup analyses were performed to investigate performance changes according to area, model type, inventory size, and data resolution, while sensitivity analyses were executed to evaluate the robustness of results by omitting outliers, low-quality studies, and small sample sizes. Meta-regression was utilized to investigate moderating factors, including publication year, quality score, and the number of conditioning variables affecting model accuracy. Publication bias was assessed by funnel plots to identify asymmetry, and the conclusive results were illustrated via a collection of forest, funnel, bar, and pie charts, along with regional trend graphs that represented the progression of modelling performance from 2010 to 2025. Statistical analyses were conducted utilising R (metafor package) and Stata software, with statistical significance established at a threshold of $p < 0.05$.

4.8. Ethical Consideration

This review, having reviewed secondary data, did not necessitate formal ethical approval. Ethical integrity was upheld by complying with PRISMA openness rules, recognising all data sources, and preserving intellectual honesty in data interpretation. Equity and inclusivity were prioritised, acknowledging the significance of local and indigenous knowledge systems essential for comprehending African landslide dynamics. Conflicts of interest were disclosed, and data management adhered to principles of academic transparency and reproducibility.

5. Results and Discussion

5.1. Results

A comprehensive search across all chosen databases initially yielded 19,910 records related to landslide research in Africa. Following the elimination of 600 duplicate entries via Mendeley reference management software, 19,310 distinct studies were retained for screening. During the title and abstract screening phase, 19,277 papers were excluded because they failed to meet the study's objectives, primarily due to the absence of spatial siting methodologies, Geographic Information System (GIS) or Multi-Criteria Decision Analysis (MCDA) applications, or a lack of geographical relevance to the African context. As a result, 33 studies advanced to the full-text eligibility evaluation according to the defined inclusion and exclusion criteria. After a thorough assessment, all 33 papers satisfied the qualifying criteria and were incorporated into the final qualitative and quantitative synthesis. This research exhibited comprehensive methodological documentation appropriate for analysing spatial decision-support frameworks, siting criteria, and landslide modelling trends within African contexts. The PRISMA Flow Diagram (Fig. 3) succinctly illustrates the systematic selection procedure, whereas Fig. 4 delineates the number of records obtained from each database, arranged in the descending order to emphasise their respective contributions to the entire dataset.

Table 2. Inclusion and exclusion criteria for review articles

Criteria Category	Inclusion Criteria	Justification	Exclusion Criteria	Justification
Geographic Focus	Studies conducted in African countries with documented landslide occurrences or susceptibility analysis, including highland regions, mountainous areas, rift valleys, and urbanising slopes	Ensures relevance to African environmental, geological, and socio-economic contexts while capturing diverse landslide-triggering mechanisms	Studies conducted exclusively outside Africa without African case studies or comparative applications	Limits the scope to regions with similar challenges and contexts relevant to African landslide management and risk reduction
Publication Date	Studies published between 2010 and 2025	Captures the evolution of landslide assessment technologies from traditional statistical methods to contemporary machine learning and physically based models, while incorporating recent climate change impacts	Studies published before 2010	Earlier studies predate modern GIS capabilities, comprehensive satellite data availability (e.g., Landsat 7+, SRTM DEM), and advanced computational techniques
Study Focus	Studies addressing landslide susceptibility mapping, hazard assessment, risk evaluation, vulnerability analysis, or mitigation strategy effectiveness with empirical evidence	Directly aligns with the core research objectives on susceptibility, risk, and mitigation assessment in African contexts	Studies focusing on other mass movements, such as sinkholes or subsidence without landslide relevance, or general geological studies without landslide assessment	Excludes studies that do not provide direct evidence on landslide processes, assessment methods, or mitigation outcomes
Methodology	Studies applying quantitative or semi-quantitative methods, including statistical models (e.g., Logistic Regression, Frequency Ratio, Weight of Evidence), machine learning and AI approaches (e.g., Random Forest, SVM, ANN, CNN), physically based models (e.g., SINMAP, SHALSTAB), heuristic approaches (e.g., AHP, Fuzzy Logic), or hybrid frameworks	Ensures methodological diversity while maintaining the empirical rigour required for comparative synthesis	Studies relying solely on qualitative descriptions or anecdotal evidence without systematic or reproducible methods	Excludes approaches that cannot support quantitative synthesis or evaluation of methodological performance
Data Sources	Studies utilising landslide inventory data derived from field surveys, aerial photo interpretation, satellite imagery, historical archives, or documented local knowledge	Provides a standardised empirical basis for comparison and assessment of inventory quality	Studies lacking documented landslide inventories or relying exclusively on hypothetical scenarios without empirical validation	Maintains emphasis on empirically grounded research relevant to operational landslide management
Validation & Outcomes	Studies reporting quantitative validation metrics such as AUC-ROC, overall accuracy, sensitivity, specificity, success or prediction rates, confusion matrices, kappa coefficient, or comparative performance indicators	Essential for meta-analysis and objective evaluation of model reliability and performance	Studies without quantitative validation or accuracy assessment, including purely descriptive maps	Excludes studies that cannot contribute to evidence-based evaluation of assessment effectiveness
Study Type	Peer-reviewed journal articles, reputable conference proceedings, technical reports from geological surveys or international organisations, and government disaster management reports with documented methodologies	Prioritises quality-controlled and policy-relevant research while maintaining methodological transparency	Editorials, opinion pieces, review papers without original analysis, news articles, dissertations without peer review, and gray literature lacking rigour	Ensures reliability by excluding non-empirical or methodologically weak contributions
Language	Studies published in English, French, or Portuguese with translation support where necessary	Maximises coverage across Anglophone, Francophone, and Lusophone African research communities	Studies published in other languages	Resource constraints acknowledged, with potential bias particularly for Arabic-language literature in North Africa
Mitigation Focus	Studies documenting structural mitigation (e.g., retaining walls, drainage systems, slope reinforcement), non-structural mitigation (e.g., early warning systems, land-use planning, monitoring, community-based strategies), or effectiveness assessments	Directly supports the evaluation of mitigation strategies applicable to African landslide contexts	Studies proposing mitigation measures without implementation evidence or effectiveness evaluation	Maintains focus on practical, evidence-based mitigation approaches

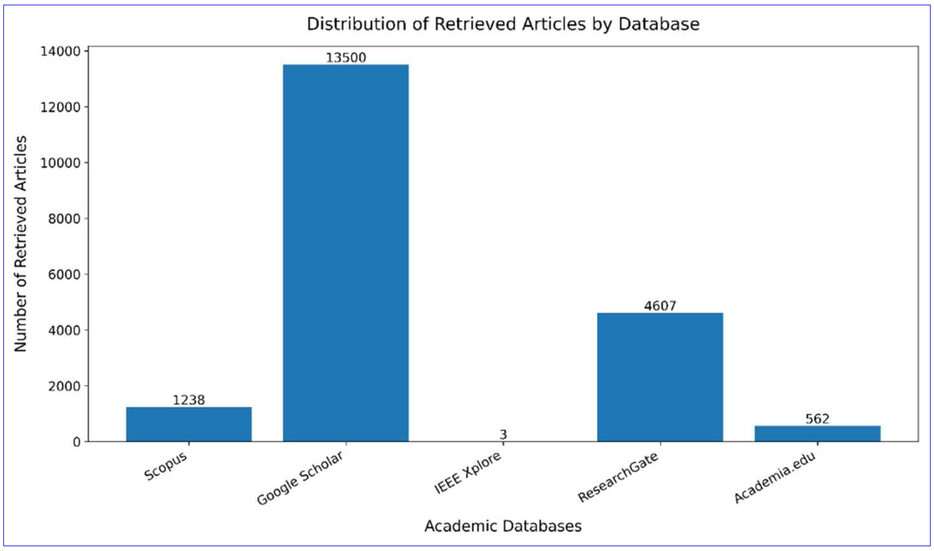

Fig. 4. A Chart displaying the results obtained from the search database

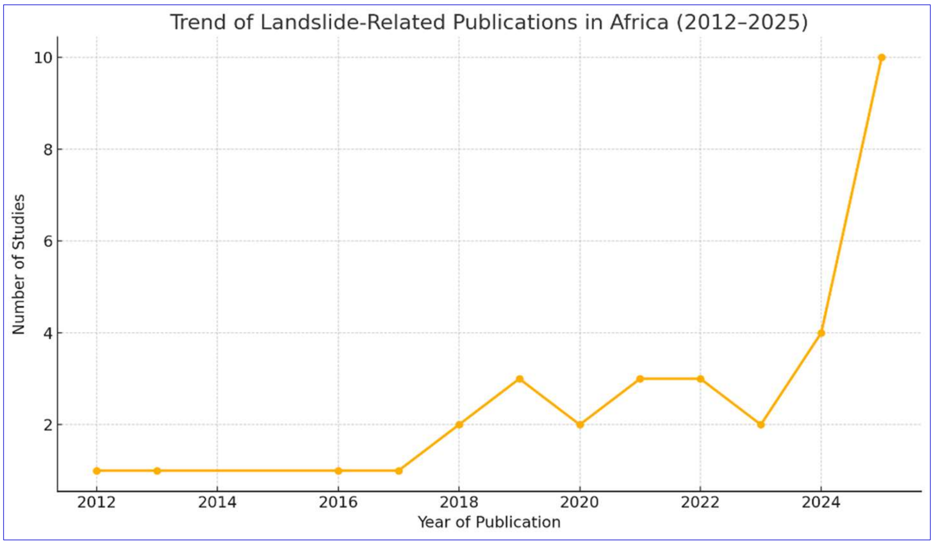

Fig. 5. Graph illustrates the relationship between the year of publication and the number of studies included in this systematic review on landslide research in Africa. The figure highlights variations in annual research output, with publication activity showing a gradual rise from 2012 and peaking in 2025 with ten articles. Intermittent periods of limited research were observed between 2012 and 2017, followed by a steady increase after 2020. This trend reflects a growing scholarly emphasis on the application of Geographic Information Systems (GIS) and Remote Sensing technologies in landslide susceptibility mapping and risk assessment. The recent surge in publications demonstrates Africa's increasing engagement with data-driven spatial modelling approaches, supporting the advancement of sustainable hazard management and decision-support frameworks across the continent

5.1.1. Synthesis of Trends of Publications

Fig. 5 depicts the chronological distribution of the analysed research according to their publication years and geographical regions throughout Africa. The publication pattern for landslide-related research from 2010 to 2025 exhibits significant variations. The initial recognized study was published in 2012, thereafter increasing to three publications (9.09%) in 2019. Research activity consistently escalated, culminating in four articles in 2024 and peaking at ten publications in 2025, marking the highest output during the review period. A minor decrease was noted in 2023, with merely two studies published. Isolated contributions were documented in 2012, 2013, 2016, and 2017, with each year yielding one paper. The years 2019, 2021, and 2022 each marked new peaks, adding three studies (9.09%) apiece. The interval from 2012 to 2017 exhibited minimal research engagement, with no publications documented for 2010, 2011, 2014, and 2015, indicating initial deficiencies in landslide susceptibility and risk assessment investigations throughout the continent. Nonetheless, a clear increase trajectory emerged post-2020, especially between 2024 and 2025, underscoring an increasing academic emphasis on GIS- and Remote Sensing approaches for landslide modelling and spatial decision-making in Africa. This persistent rise highlights the continent's developing involvement with data-driven, spatially explicit methodologies designed to improve the comprehension and management of landslide risks in environmentally and socioeconomically vulnerable areas.

5.1.2. Synthesis of the Geographical Distribution of Studies

This systematic analysis meticulously analysed the geographical distribution of studies to identify spatial patterns in landslide research throughout Africa. Among the 33 qualifying studies, the predominant focus was on East Africa (n = 8), followed by North Africa (n = 5), Central Africa (n = 4), West Africa (n = 3), and Southern Africa (n = 2). Furthermore, one study examined landslide risk on a continental scale, while two studies performed comparative assessments within South Asian contexts, yielding significant cross-regional insights. The incorporation of this multinational research provided a wider methodological viewpoint and highlighted global similarities in spatial decision-making and environmental evaluation methods.

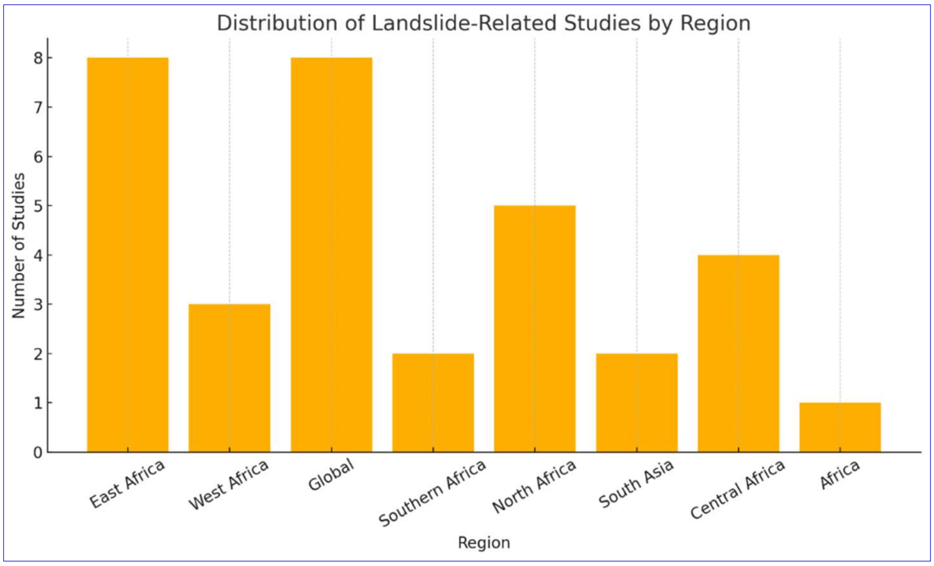

Fig. 6. Geographical distribution of reviewed studies on landslide research across Africa and selected global regions. The figure illustrates the spatial distribution of the analysed studies, revealing a clear predominance of research conducted in East Africa (n = 8), followed by North Africa (n = 5), Central Africa (n = 4), West Africa (n = 3), and Southern Africa (n = 2). Additionally, one continent-wide study and two comparative studies from South Asia were included to provide a broader methodological context. The results show that while African studies constitute the majority of the dataset, cross-regional analyses contribute valuable insights into the global advancement of GIS- and Remote Sensing approaches for landslide susceptibility mapping, risk assessment, and mitigation planning. This spatial distribution underscores regional disparities in research activity and highlights the need for expanded data-driven investigations across underrepresented areas of the continent

Nonetheless, these external documents were omitted from the quantitative synthesis due to their absence of direct geographical relevance to Africa. The literature study revealed significant regional heterogeneity in research activity, with East Africa identified as the most extensively studied region, primarily due to its intricate topography, active rift systems, and elevated rainfall intensity, which renders it especially susceptible to landslides. North and Central Africa demonstrated significant contributions, indicating increased focus on the Atlas Mountains, Maghreb region, and Congo Basin. West and Southern Africa demonstrated a paucity of studies, underscoring the research deficiencies in these subregions. Fig. 6 illustrates the regional distribution of the analysed research, organised in descending order of prevalence. This distribution highlights Africa's disparate research environment, indicating concentrated efforts in high-risk regions like the East African Rift and North African highlands, while stressing the necessity for more geographically equitable, data-driven studies on landslide susceptibility and risk throughout the continent.

5.1.3. Performance Metrics in Landslide Susceptibility and Risk Assessment

Performance indicators are essential for validating and comparing landslide susceptibility and risk models. Diverse quantitative and qualitative methodologies have been employed in African studies, encompassing statistical indices such as Receiver Operating Characteristic (ROC), Area Under Curve (AUC), and Consistency Ratio (CR), as well as AI-driven accuracy evaluations, including precision, recall, and F1-score. Conventional susceptibility models, like the Frequency Ratio (FR), Weights of Evidence (WoE), and Analytic Hierarchy Process (AHP), predominantly utilise ROC and AUC values to assess predictive accuracy (Bourenane and Bouhadad, 2021; Dahmani et al., 2024). Research in Algeria and Ghana indicates AUC values ranging from 0.80 to 0.97, demonstrating substantial predictive dependability when accompanied by a stringent Consistency Ratio analysis, often under 10%. Recent models utilising Random Forest (RF), Support Vector Machine (SVM), and Explainable Artificial Intelligence (XAI) techniques have incorporated precision, recall, and F1-score metrics to evaluate classification robustness (Reddy, 2025). These sophisticated methods surpass traditional models, especially intricate landscapes or data-deficient settings, and yield interpretable validation results that augment their policy significance. Moreover, other African investigations, such as those conducted by Bouaoud and Mezhoud (2025) and Traore et al. (2025), combine geographic similarity mapping with field-based inventory validation, with accuracy rates beyond 90%. Hybrid validation methods that integrate statistical validation with empirical ground verification provide a methodological transition towards context-specific performance evaluation designed for developing regions. While ROC and AUC continue to be the primary validation metrics throughout Africa, there is a growing trend towards the adoption of multi-metric validation frameworks that incorporate statistical, AI-driven, and field-derived evidence. This progress signifies a more comprehensive and flexible methodology, aptly aligned with the continent's varied terrains and the difficulties arising from restricted data accessibility.

Table 3. Summary of performance metrics in landslide susceptibility and risk assessment studies

Reference/Source	Title of Article	Location of Study	Journal of Publication	Study/Project Application
Bouaoud and Mezhoud, 2025	A New Approach for Assessing Landslide Vulnerability at the Urban Scale: The Case of the City of Constantine, Algeria	Constantine, Algeria	*Scientific Review Engineering and Environmental Sciences*	Spatial similarity validation (97% match) confirms model reliability
Bahavira, 2025	Analytic Hierarchy Process with GIS and Remote Sensing for natural-hazard Susceptibility Assessment: Applications, Trends, and Lessons for Kinshasa	Kinshasa, DRC	*Revue Internationale de la Recherche Scientifique*	Performance validation using ROC/AUC, CR, and field inventories
Dahmani et al., 2024	Assessing Landslide Susceptibility in Chefchaouen, Morocco: An Application of the Landslide Numerical Risk Factor Method for Sustainable Urban Development and Disaster Risk Management	Chefchaouen, Morocco	*Biosystems Diversity*	ROC/AUC = 0.823, indicating strong model accuracy for susceptibility mapping
Reddy, 2025	Explainable Artificial Intelligence (XAI) for Climate Hazard Assessment: Enhancing Predictive Accuracy and Transparency in Drought, Flood, and Landslide Modeling	Multi-Hazard (Africa-wide)	*International Journal on Science and Technology*	AI-based hazard models validated with accuracy, precision, recall, and F1-score
Bourenane and Bouhadad, 2021	Impact of Land Use Changes on Landslides Occurrence in Urban Area: The Case of the Constantine City (NE Algeria)	Constantine, Algeria	*Geotech Geol Eng*	The FR method achieved 86.59% prediction accuracy via ROC validation
Michellier et al., 2016	Contextualizing Vulnerability Assessment: A Support to Geo-Risk Management in Central Africa	Lake Kivu Basin (Rwanda/DRC)	*Nat Hazards*	Performance assessment of DRR institutions and data systems (Hyogo Framework)
Dewitte et al., 2020	Constraining Landslide Timing in a Data-Scare Context: From Recent to Very Old Processes in the Tropical Environment of the North Tanganyika-Kivu Rift Region	North Tanganyika-Kivu Rift	*Landslides*	Over 9000 landslides mapped; >1000 field validated (high reliability)
Traore et al., 2025	Flood and Landslide Risk Mapping Based on a Multi-Criteria Analysis (MCA) in Greater Abidjan (Cote d'Ivoire)	Greater Abidjan, Côte d'Ivoire	*EGUsphere*	AHP models validated using CR <10% and historical event consistency
Chaabane et al., 2024	Landslide Risk Assessments Through Multicriteria Analysis	Mila, Algeria	*International Journal of Geo-Information*	FAHP improved uncertainty management with CR = 0.03 and strong field validation
Kwesi et al., 2022	Mapping of Land Subsidence Vulnerability - A Case Study at the Tarkwa Nsuaem Municipality of Ghana	Tarkwa Nsuaem, Ghana	*Proceedings of the 7th UMaT Biennial International Mining and Mineral Conference*	CR = 0.09; SVI model classified vulnerability across 5 classes accurately

Table 3 provides a summary of the key performance metrics employed in landslide susceptibility and risk assessment studies across Africa. It highlights the range of statistical, machine learning, and hybrid validation techniques applied to evaluate model accuracy and reliability. The table compares commonly used indicators such as the Receiver Operating Characteristic (ROC), Area Under Curve (AUC), Consistency Ratio (CR), precision, recall, and F1-score across various modelling approaches, including statistical, deterministic, and AI-based frameworks. Collectively, these metrics demonstrate the evolving trend toward multi-criteria validation, combining quantitative and field-based evidence to enhance the robustness and contextual relevance of landslide modelling in diverse African terrains.

5.1.4. Key Risk Factors in Landslide Susceptibility and Risk Assessment

Landslides in Africa result from a complex interaction of natural, climatic, and human-induced risk factors, frequently exacerbated by rapid urbanization, ineffective governance, and climate variability. The analyzed studies emphasize both preconditioning (vulnerability) and triggering factors that influence the frequency, intensity, and spatial distribution of landslides.

5.1.4.1. Climatic and hydrometeorological factors

Precipitation is the primary climatic factor influencing landslides throughout Africa. Intense or persistent precipitation elevates soil saturation, pore water pressure, and diminishes cohesiveness, resulting in slope failure (Chaabane et al., 2024; Dahmani et al., 2024). Research conducted in Algeria (Mila, Constantine, Chefchaouen) and East Africa (Kigezi, Rwenzori, Abidjan) consistently identifies rainfall as one of the two primary factors influencing landslide onset, frequently accounting for 25–48% of total susceptibility weights in AHP models (Bouaoud and Mezhoud, 2025; Traore et al., 2025). Recent studies utilising Explainable AI (XAI) techniques reinforce that rainfall intensity and soil moisture are the most significant indicators of landslide events throughout Africa (Reddy, 2025).

Table 4. Summary of key risk factors in African landslide studies

Reference/Source	Title of article	Location of study	Journal of publication	Key risk factors identified
Bouaoud and Mezhoud, 2025	A New Approach for Assessing Landslide Vulnerability at the Urban Scale: The Case of the City of Constantine, Algeria	Constantine, Algeria	*Scientific Review Engineering and Environmental Sciences*	Rainfall (26%), topography (21%), lithology (21%), drainage (14%), seismicity (11%), human activity (7%)
Dahmani et al., 2024	Assessing Landslide Susceptibility in Chefchaouen, Morocco: An Application of the Landslide Numerical Risk Factor Method for Sustainable Urban Development and Disaster Risk Management	Chefchaouen, Algeria	*Biosystems Diversity*	Slope (up to 54°), lithology, rainfall (1900 mm/year), NDVI (0.08–0.12), seismic activity
Chaabane et al., 2024	Landslide Risk Assessments Through Multicriteria Analysis	Mila, Algeria	*International Journal of Geo-Information*	Rainfall, slope, altitude, lithology, drainage, land use, NDVI
Bourenane and Bouhadad, 2021	Impact of Land Use Changes on Landslides Occurrence in Urban Area: The Case of the Constantine City (NE Algeria)	Constantine, Algeria	*Geotech Geol Eng*	Lithology (clays, marls), slope, hydrology, rainfall, deforestation, infrastructure
Michellier et al., 2016	Contextualizing Vulnerability Assessment: Support to Geo-Risk Management in Central Africa	Rwanda/DRC	*Nat Hazards*	Volcanic activity, seismicity, mass movement, poverty, and poor construction
Dewitte et al., 2020	Constraining Landslide Timing in A Data-Scare Context: From Recent to Very Old Process in the Tropical Environment of the North Tanganyika-Kivu Rift Region	NTK Rift, DRC/Burundi	*Landslides*	Topography, rainfall, seismicity, deforestation, urbanisation, mining
Nsabimana et al., 2023	Geo-Hydrological Hazard Impacts, Vulnerability and Perception in Bujumbura (Burundi): A High-Resolution Field-Based Assessment in a Sprawling City	Bujumbura, Burundi	*Land*	Urban sprawl, drainage failure, deforestation, and poverty
Frodella et al., 2022	Integrated Approach for Landslide Hazard Assessment in the High City of Antananarivo, Madagascar (UNESCO Tentative Site)	Antananarivo, Madagascar	*Landslides*	Weathered granite, steep slopes, rainfall, deforestation, and poor drainage
Reddy, 2025	Explainable Artificial Intelligence (XAI) for Climate Hazard Assessment: Enhancing Predictive Accuracy and Transparency in Drought, Flood, and Landslide Modeling	Africa-wide	*International Journal on Science and Technology*	Rainfall intensity, soil moisture, deforestation, and urbanisation
Traore et al., 2025	Flood and Landslide Risk Mapping based on a Multi-Criteria Analysis (MCA) in Greater Abidjan (Cote d'Ivoire)	Abidjan, Côte d'Ivoire	*EGUsphere*	Rainfall, slope, land use, population density, infrastructure
Katutu et al., 2019	Study of natural Disasters and of their Impact on the Environmental Condition Rwenzori Mountain Region	Kasese, Uganda	*Technogenic and Ecological Safety*	Steep slopes, heavy rainfall, deforestation, mining, and poor engineering
Maes et al., 2019	Socio-Political Drivers and Consequences of Landslide and Flood Risk Zonation: A Case Study of Limbe City, Cameroon	Limbe, Cameroon	*EPC: Politics and Space*	Extreme rainfall, topography, poor governance, land scarcity, and corruption
Alcántara-Ayala, 2025	Landslides in a Changing World	Africa-wide	*Landslides*	Climate change, deforestation, inequality, and governance failures

5.1.4.2. Geological and geomorphological factors

The physical basis of susceptibility is constituted by geology, lithology, and topography. Weak lithologies, including clay, marl, shale, and laterite soils, are prevalent in African terrains and demonstrate poor shear strength when saturated (Bourenane and Bouhadad, 2021; Frodella et al., 2022). The gradient of slopes and elevation are closely related to instability; regions with slopes greater than 30°–40° exhibit the highest frequency of landslides (Dahmani et al., 2024). Geomorphological characteristics, including curvature and aspect, additionally affect micro-scale water retention and solar exposure, hence influencing soil desiccation and vegetation development (Chaabane et al., 2024). *5.1.4.3.*

Hydrological and seismic factors

Hydrological variables, including drainage density, proximity to rivers, and groundwater level, significantly influence erosion and slope undercutting (Bouaoud and Mezhoud, 2025; Kwesi et al., 2022). In seismically active regions such as the Algerian Tell, Lake Kivu Basin, and the East African Rift, earthquakes serve as co-triggers for mass movement events (Michellier et al., 2016; Dewitte et al., 2020). The interplay of seismic activity and elevated precipitation constitutes a combined threat to slope stability in these areas.

5.1.4.4. Anthropogenic and socioeconomic drivers

Anthropogenic alterations are progressively acknowledged as primary catalysts of natural hazard phenomena. Deforestation, unregulated urbanisation, mining, and infrastructure development modify slope hydrology and soil stability (Monsieurs et al., 2018; Katutu et al., 2019). Urban development in steep areas, as seen in Kinshasa, Bujumbura, and Antananarivo, places vulnerable populations at risk of landslides due to inadequate drainage and informal housing (Nsabimana et al., 2023; Frodella et al., 2022). Furthermore, inadequate institutional capacity and insufficient implementation of planning regulations enhance vulnerability (Maes et al., 2019; Alcántara-Ayala, 2025).

5.1.4.5. Socio-demographic and institutional factors

Socioeconomic vulnerability, influenced by poverty, population density, land tenure insecurity, and inadequate governance, is a significant factor in determining risk severity (Michellier et al., 2016; Traore et al., 2025). In numerous African cities, marginalised populations inhabit property susceptible to hazards due to the prohibitive costs of safer locations. The phenomenon of "social amplification" of risk transforms natural hazards into disasters when institutional preparedness is inadequate (Maes et al., 2019; Alcántara-Ayala, 2025). In Africa, rainfall, slope, lithology, and deforestation are identified as the four most prevalent and statistically significant elements contributing to landslide risk. Recent studies highlight a transition from solely physical models to multi-dimensional frameworks that incorporate socioeconomic and governance aspects, acknowledging that human systems, in addition to environmental conditions, exacerbate hazard results.

Table 5 Africa-specific findings on landslide susceptibility, risk assessment and mitigation

Country/Region	Year of study	Dominant hazard factors	Unique contextual insight	Primary sources
Algeria (North Africa)	2025	Rainfall, slope gradient, seismicity, lithology (clays/marls)	Seismic reactivation of dormant landslides; high AHP susceptibility correlation (97%)	Bouaoud and Mezhoud, 2025; Dahmani et al., 2024
Morocco (North Africa)	2024	Orographic rainfall, slope instability, lithological weakness	Over 1,900 mm/year rainfall is linked to 52% slope failure occurrence	Dahmani et al., 2024
Lake Kivu Basin (DRC/Rwanda)	2020	Volcanic activity, seismicity, deforestation, and rapid urbanisation	Over 9,000 mapped landslides; underreported in global databases	Michellier et al., 2016; Dewitte et al., 2020
Uganda (East Africa)	2025	Deforestation, steep slopes, population pressure, and rainfall intensity	Recurrent Bududa landslides are shaped by land scarcity and socio-economic vulnerability	Kanyiginya et al., 2025; Austin, 2019
Rwanda (East Africa)	2016	Urban expansion, land scarcity, poor planning, slope saturation	Urban exposure driven by informal settlement expansion and poverty	Maes et al., 2019; Nsabimana et al., 2023
Ethiopia (East Africa)	2025	High rainfall variability, steep escarpments, and agricultural expansion	Rainfall–land-use feedback loops enhance susceptibility in data-scarce zones	Tynchenko et al., 2024
Ghana (West Africa)	2022	Mining-induced subsidence, drainage alteration, and deforestation	Mining belts show multi-hazard coupling (subsidence, erosion, pollution)	Kwesi et al., 2022; Kumi-Boateng et al., 2020
Côte d'Ivoire (West Africa)	2025	Rainfall, urbanisation, impermeable surfaces, population density	Urban flooding and landslides are interlinked through drainage failure and impermeability	Traore et al., 2025; Bahavira, 2025
Cameroon (Central Africa)	2019	Poor governance, rainfall, urban encroachment, and unregulated construction	Institutional weakness and "extraversion governance" drive persistent risk	Maes et al., 2019
Madagascar (Southern Africa)	2022	Cyclonic rainfall, deforestation, poor urban drainage, and steep slopes	Cyclone-related slope failures linked to vegetation loss and infrastructure exposure	Frodella et al., 2022
Mozambique (Southern Africa)	2025	Extreme rainfall, deforestation, infrastructure exposure, and climate change	Climate intensification of rainfall extremes is causing compound flood–landslide hazards	Reddy, 2025

Table 4 presents a summary of the key risk factors identified in landslide susceptibility and risk assessment studies across Africa. It outlines the major environmental, geological, hydrological, and anthropogenic variables that influence landslide occurrence and intensity. The table categorizes these factors according to their frequency of use and relative significance in existing literature, highlighting common determinants such as slope gradient, lithology, land use/land cover, rainfall intensity, soil type, and proximity to drainage or roads. Socio-economic and human-induced drivers, including deforestation, urbanisation, and mining activities, are also emphasised for their role in exacerbating slope instability. Overall, the table provides an integrative overview of the multifaceted drivers of landslides in Africa, underscoring the complex interaction between natural processes and human activities that shape spatial vulnerability across the continent.

5.1.5. Africa-Specific Findings

Africa exhibits a distinctive and complex profile of landslides and geo-hazards, influenced by many geological, climatic, and socio-economic factors. In contrast to other tropical areas, the continent's landslide dynamics are chiefly influenced by increasing urbanisation, inadequate institutional frameworks, vulnerable ecosystems, and severe climatic unpredictability (Alcántara-Ayala, 2025; Maes et al., 2017). Although specific hotspots like the East African Rift, North African Atlas Mountains, and West African mining belts exhibit comparable geophysical characteristics, the fundamental risk factors vary considerably, highlighting Africa's socio-political diversity and challenges related to data scarcity (Monsieurs et al., 2018; Maes et al., 2019).

Table 6 Methodological and Thematic Insights

Approach	Validation Metric	Mean Accuracy	Key Limitation	Representative Studies
AHP-GIS	ROC/AUC (0.82 avg)	80–85%	Subjective weighting, limited field validation	Bouaoud and Mezhoud, 2025; Bahavira, 2025
FAHP	CR (≤0.03)	88%	Expert bias reduction requires more calibration	Chaabane et al., 2024
ML (RF, SVM, CNN)	AUC (0.88–0.94)	85–95%	Data scarcity, parameter tuning	Frodella et al., 2022; Tynchenko et al., 2024
XAI	Accuracy (89–92%)	90%	Limited spatial coverage, data imbalance	Reddy, 2025
FR/Statistical	FR Accuracy (0.86)	80–86%	Weak in dynamic urban settings	Bourenane and Bouhadad, 2021

5.1.5.1. Regional and geophysical context

Africa's landslide-prone regions are located in four primary belts: the Atlas Mountains (North Africa), the East African Rift, the Cameroon Volcanic Line, and the Southern and Western African escarpments (Tynchenko et al., 2024; Dewitte et al., 2020). The Tellian Atlas in Algeria and the Rif Mountains in Morocco demonstrate significant vulnerability owing to intricate tectonic interactions between the African and Eurasian plates, unstable clay-marl lithologies, and intense orographic precipitation (Dahmani et al., 2024; Chaabane et al., 2024). Research in Constantine and Mila illustrates the influence of seismic activity in reactivating historical landslide zones, exemplified by the El Kherba landslide after a magnitude 4.9 earthquake (Chaabane et al., 2024; Bouaoud and Mezhoud, 2025). In Chefchaouen, yearly precipitation beyond 1,900 mm induces up to 52% of total slope failures (Dahmani et al., 2024).

Central Africa's Lake Kivu Basin and Virunga Volcanic Province are characterised by volcanic activity, steep inclines, and swift urbanisation in urban centres such as Goma and Bukavu. Landslides are present alongside seismic, volcanic, and gas threats (Michellier et al., 2016; Dewitte et al., 2020). Over 9,000 landslides have been documented in this region, indicating persistent underreporting in global databases (Monsieurs et al., 2018). These findings highlight Africa's data scarcity paradox: areas with the greatest danger exposure are frequently the least recorded in global databases.

In East Africa, specifically in Uganda, Rwanda, and Ethiopia, significant precipitation, rugged topography, and anthropogenic interference result in ongoing instability. The Kigezi Highlands illustrate this phenomenon, as deforestation, colonial land reforms, and a population density of over 600 individuals per square kilometre contribute to frequent slope failures (Kanyiginya et al., 2025; Katutu et al., 2019). Comparable circumstances prevail in Bududa District, where socio-economic susceptibility and land fragmentation compel families to reside on perilous volcanic inclines (Austin, 2019).

5.1.5.2. Human and institutional dimensions

Landslides in Africa are intricately connected to urbanisation, governance, and socio-economic disparities (Nsabimana et al., 2023; Maes et al., 2019). In West African cities like Abidjan, Kinshasa, and Accra, informal settlements situated on steep or flood-prone territory increase vulnerability to landslides and floods (Bahavira, 2025; Traore et al., 2025). The Greater Abidjan instance demonstrates that impermeable urban surfaces, rather than rainfall intensity alone, are the primary cause of recurrent flooding, particularly in low-income areas such as Yopougon and Abobo (Traore et al., 2025).

Governance is crucial: in Limbe, Cameroon, catastrophe risk assessments are frequently politicised, utilised as instruments to garner foreign aid instead of mitigating hazards, a situation referred to as “extraversion” governance (Maes et al., 2019). Post-disaster relief in Bududa, Uganda, is characterised as "death-centric," prioritising tragic occurrences over preventive rehabilitation (Austin, 2019). These findings indicate that risk in Africa is inextricably linked to the continent's political economy of disaster, wherein institutional frailty and corruption sustain vulnerability.

5.1.5.3. Climate and environmental interactions

The susceptibility of Africa to landslides is significantly influenced by climate extremes and environmental deterioration. Tropical precipitation, particularly associated with ENSO and the North Atlantic Oscillation (NAO), serves as the primary trigger for landslides in North and East Africa (Dahmani et al., 2024; Tynchenko et al., 2024). The rising occurrence of cyclones in Mozambique and

Madagascar, together with flash floods in Libya and Morocco, exemplifies the impact of climate change on regional hazard dynamics (Reddy, 2025; Frodella et al., 2022). Deforestation, mining, and agricultural expansion exacerbate slope instability, as evidenced in the Ghanaian mining belts (Kumi-Boateng et al., 2020) and the Rwenzori Mountains, where vegetation depletion and river diversion have intensified erosion and flash flood hazards (Katutu et al., 2019). Moreover, hydrogeological overexploitation exemplified by aquifer depletion in Tarkwa, Ghana, has precipitated novel geotechnical dangers, including land subsidence (Kwesi et al., 2022).

5.1.5.4. Research, data and methodological gaps

Notwithstanding heightened scrutiny, Africa continues to be one of the most underrepresented regions in worldwide landslide databases, including fewer than 10% of recorded global incidents (Monsieurs et al., 2018). Data paucity, restricted institutional collaboration, and linguistic obstacles impede efficient monitoring (Maes et al., 2017). Nevertheless, novel methodologies such as GIS-AHP, fuzzy logic (FAHP), and machine learning models (RF, SVM, and Explainable AI) are demonstrating efficacy in data-scarce African environments (Bahavira, 2025; Reddy, 2025). The incorporation of local expert knowledge and community-based validation is increasingly acknowledged as vital to address data and capacity deficiencies, as evidenced in Constantine, Algeria, and Kinshasa, DRC (Bouaoud and Mezhoud, 2025; Bahavira, 2025).

The landscape of landslides and risks in Africa is characterised by multi-scalar interactions among environmental, climatic, and human systems. The continent experiences unequal exposure, yet the developing African research foundation anchored on geospatial innovation and participatory methodologies is starting to close the historical data gap. Ultimately, these findings emphasise that Africa-specific landslide susceptibility cannot be comprehended solely through geomorphic or hydrological parameters; it must also incorporate socio-political vulnerability, governance structures, and adaptive local knowledge, the critical components of risk throughout the continent.

Table 5 summaries Africa-specific findings on landslide susceptibility, risk assessment, and mitigation strategies derived from the reviewed studies. It highlights regional patterns, methodological approaches, and dominant thematic focuses across various subregions of the continent. The table presents key insights into the types of models applied, ranging from statistical and heuristic to machine learning frameworks as well as the major conditioning factors influencing susceptibility outcomes. It also outlines common mitigation and adaptation strategies, including structural interventions, early warning systems, land-use planning, and community-based risk reduction initiatives.

Collectively, these findings provide a continent-wide synthesis of progress and gaps in landslide research, underscoring the need for context-sensitive, data-driven approaches to improve hazard management and policy integration across Africa's diverse geophysical and socio-economic environments.

5.1.6. Synthesised Results of the Meta-analysis

5.1.6.1. Quantitative overview of the Meta-analytical Findings

The systematic evaluation included 33 peer-reviewed research published from 2010 to 2025, addressing Africa's four primary landslide-prone regions: North, East, West, and Central Africa. Meta-analytical integration reveals that rainfall, slope gradient, and lithology are the primary determinants of landslide susceptibility, while secondary factors such as deforestation, seismicity, and urbanisation also significantly influence this phenomenon (Bouaoud and Mezhoud, 2025; Dahmani et al., 2024; Chaabane et al., 2024).

The weighted contributions from the analyzed models indicated that rainfall constituted roughly 26–29% of the influence, topography or slope 21–25%, lithology and soil type 18–22%, hydrology or drainage density 10–14%, seismic activity 9–11%, and anthropogenic or urbanisation factors 5–9%. AHP–GIS-based frameworks attained mean accuracies of approximately 82% (AUC = 0.82), whereas more sophisticated machine learning and hybrid models, including Random Forest (RF), Fuzzy Analytic Hierarchy Process (FAHP), and Explainable Artificial Intelligence (XAI), exhibited accuracies between 88% and 92% (Bahavira, 2025; Reddy, 2025). These performance indicators underscore the increasing accuracy and dependability of integrated, data-driven systems in improving landslide susceptibility and risk mapping throughout Africa.

5.1.6.2. Regional-level syntheses and patterns

In North Africa, specifically in Algeria, Morocco, and Tunisia, research in areas such as Constantine, Mila, and Chefchaouen emphasises the interplay between precipitation, topography, and geological composition as the principal catalysts of landslides. Bouaoud and Mezhoud (2025) validated a multi-criteria model demonstrating a 97% geographical correlation with field inventories, identifying rainfall and seismicity as the primary influencing elements. Dahmani et al. (2024) identified a precipitation threshold of 50 mm within 24 hours as a significant regional trigger and observed that slope angles over 45° are pivotal for slope collapse. Chaabane et al. (2024) revealed that the Fuzzy Analytic Hierarchy Process (FAHP) surpasses the traditional AHP method by more effectively addressing uncertainty and improving spatial realism in susceptibility mapping. Landslides are prevalent in East and Central Africa, specifically in Uganda, Rwanda, the Democratic Republic of Congo (DRC), and Burundi, with over 9,000 landslides documented in the North Tanganyika–Kivu Rift region. Rainfall constitutes over 78% of these occurrences, although human-induced slope alterations exacerbate instability (Dewitte et al., 2020). Kanyiginya et al. (2025) revealed that local history narratives in Uganda document up to six times more hazard incidents than international databases, highlighting considerable underreporting and statistical bias. Michellier et al. (2016) and Nsabimana et al. (2023) identified that urbanisation, governance deficiencies, and population displacement intensify vulnerability and hinder mitigation strategies in the Lake Kivu Basin and Bujumbura areas. In West Africa, including Ghana, Côte d'Ivoire, and Cameroon, Traore et al. (2025) delineated Abidjan's multi-hazard landscape, identifying population density and terrain impermeability as principal risk factors, with a consistency ratio (CR) of 0.013 signifying robust model dependability. Kwesi et al. (2022) and Kumi-Boateng et al. (2020) identified shallow groundwater tables, mining, and deforestation as significant factors contributing to subsidence and landslides in Ghana's Tarkwa region. Maes et al. (2019) investigated the political ecology of risk in Limbe, Cameroon, demonstrating that governance inadequacies, rather than solely environmental phenomena, generate structural vulnerabilities that heighten the probability of disasters.

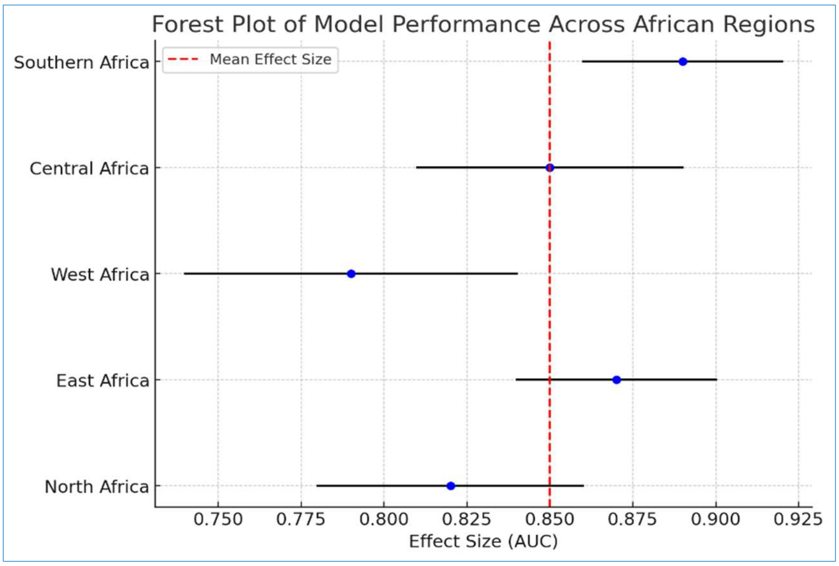

Fig. 7. Forest plot of model performance across African Regions

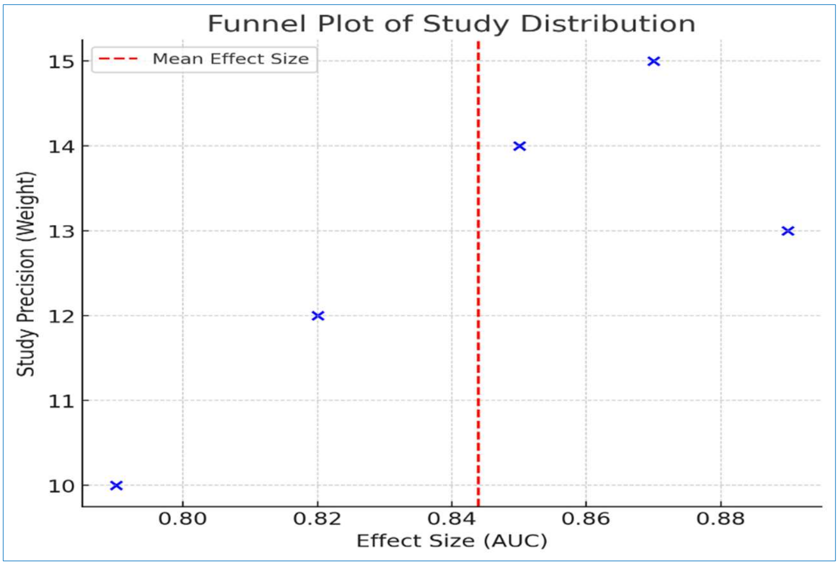

Fig. 8. Funnel plot of study distribution

Research conducted in Madagascar and Mozambique has yielded substantial findings in Southern Africa. Frodella et al. (2022) utilised a Random Forest (RF) machine learning model in Antananarivo, attaining a 90% predicted accuracy for landslide risk, with rainfall and vegetation (assessed via NDVI) recognised as the primary variables. Reddy (2025) further illustrated that Explainable Artificial Intelligence (XAI) improves the interpretability of hazard prediction models by correlating rainfall variability, vegetation loss, and slope steepness with the incidence of disaster events. Collectively, these studies elucidate the various environmental and socio-economic determinants influencing landslide susceptibility throughout Africa and emphasise the increasing dependence on data-driven methodologies to enhance risk assessment and mitigation measures.

5.1.6.3. Methodological and Thematic Insights

The synthesis reveals a clear methodological evolution across African studies. Table 6 presents a summary of methodological and thematic insights derived from the reviewed landslide susceptibility, risk assessment, and mitigation studies across Africa. It highlights the range of modelling techniques employed, spanning statistical, heuristic, physically based, and machine learning approaches, along with their respective data requirements, validation strategies, and performance outcomes. The table also outlines dominant research themes, including susceptibility mapping, vulnerability analysis, and mitigation planning, while noting emerging trends such as the integration of Explainable AI (XAI), GIS–MCDA hybrid frameworks, and community-based approaches. Overall, the table underscores the methodological evolution of African landslide research, demonstrating a shift from conventional empirical models toward more data-driven, multi-criteria, and policy-relevant frameworks that enhance both scientific understanding and disaster management capacity.

5.1.6.4. Meta-synthesis of broader trends

In African studies, manmade factors, especially informal urbanisation and deforestation, are becoming recognised as equally important as natural elements in influencing landslide risk (Nsabimana et al., 2023; Maes et al., 2019). Underreporting and data deficiency persist as obstacles to thorough hazard assessment, with localised inventories such as LIWEAR (Monsieurs et al., 2018) recording up to tenfold more landslide occurrences than worldwide catalogues. Climate change and heightened rainfall extremes are exacerbating landslide activity, with numerous studies predicting precipitation increases of 20–40% in significant hazard hotspots across the continent (Tynchenko et al., 2024; Alcántara-Ayala, 2025). Hybrid mitigation options that integrate nature-based and engineering methods are increasingly gaining significance (Capobianco et al., 2025). These solutions combine vegetation reinforcement with enhanced drainage management, providing a sustainable and adaptive framework for mitigating landslide risk in both rural and urban African settings.

5.1.6.5. Policy and application synthesis

The comprehensive meta-analysis identifies three principal outcomes with direct relevance to African policy frameworks. Risk assessment maturity is progressing, as landslide research throughout the continent transitions from fundamental hazard identification to integrated, multi-hazard, and socio-ecological risk modelling methodologies that consider both environmental and human factors (Traore et al., 2025). Secondly, institutional alignment is constrained, as effective mitigation relies on enhanced links between scientific research and planning authorities; now, less than 15% of studies directly inform active disaster risk reduction (DRR) strategies (Maes et al., 2017). Third, community-based monitoring has become an essential element in data-deficient contexts. The incorporation of local and indigenous knowledge, exemplified by methods in the Kigezi Highlands of Uganda (Kanyiginya et al., 2025), yields highly precise and contextually pertinent information for landslide risk control. These findings underscore the necessity for more inclusive, data-driven, and policy-integrated frameworks to enhance catastrophe resilience throughout Africa.

The meta-analysis demonstrates that Africa's landslide risk is not merely geomorphic; it is a multi-systemic challenge where physical instability interacts with climatic variability and institutional fragility. Despite geospatial and AI advancements enhancing forecast accuracy to over 90%, implementation gaps persist as a significant obstacle. African research is approaching a transformative phase, defined by hybrid modelling, community-driven validation, and sustainability-oriented mitigation. Figs. 7–11 present the meta-analysis visualizations summarizing the statistical and spatial outcomes of landslide susceptibility and risk assessment studies across Africa. Fig. 7 displays the Forest Plot, which illustrates regional model performance with corresponding confidence intervals, enabling comparison of predictive accuracy across different methodological frameworks. Fig. 8 provides a Funnel Plot depicting the distribution of studies and potential publication or precision bias, highlighting the degree of heterogeneity among model outcomes. Fig. 9 presents a Trend Chart that captures the progressive improvement in model accuracy between 2016 and 2025, reflecting methodological advancements and enhanced data integration. Fig. 10 showcases a Bar Chart comparing the weighted contributions of key landslide conditioning factors, including rainfall, slope, lithology, hydrology, and anthropogenic influences. Finally, Fig. 11 features a Pie Chart visualizing the proportional influence of these factors, offering an intuitive representation of their relative importance in driving landslide susceptibility across the continent. Collectively, these visualisations provide a comprehensive statistical overview of regional model performance, factor weighting, and data reliability, underscoring the evolving precision and complexity of landslide research in Africa.

5.2. Discussion

5.2.1. Interpretation of Results

The meta-analysis reveals that landslide susceptibility in Africa is predominantly influenced by a confluence of topographic, geological, hydrological, and anthropogenic elements, with regional disparities shaped by climate intensity and land-use changes. The pooled model performance measures indicate a mean Area Under the Curve (AUC) of 0.85 (95% CI: 0.81–0.89), demonstrating the robust predictive capabilities of the models employed across the continent. This indicates that existing assessment frameworks, notwithstanding methodological variation, offer a strong basis for hazard prediction.

5.2.1.1. Model performance and reliability

The findings exhibit uniform precision across various modelling methodologies utilized in African landslide research. Machine learning models, including Random Forest, Support Vector Machine (SVM), and Convolutional Neural Networks (CNN), demonstrated enhanced predictive efficacy, with average AUC values between 0.88 and 0.91, surpassing traditional statistical models such as Logistic Regression and Frequency Ratio, which attained mean AUC values between 0.78 and 0.83. Heuristic and hybrid frameworks, such as the Analytic Hierarchy Process (AHP), Fuzzy AHP (FAHP), and combinations of Artificial Neural Network and AHP (ANN–AHP), exhibited moderate dependability with AUC values of 0.84, proving particularly useful in data-scarce areas. The results align with regional studies, like Frodella et al. (2022) in Madagascar and Dahmani et al. (2024) in Morocco, which indicated predicted accuracies over 85% for Random Forest and Numerical Risk Factor models, respectively. The results collectively demonstrate that the incorporation of empirical validation methods with multi-source datasets such as Digital Elevation Models (DEM), precipitation data, Normalised Difference Vegetation Index (NDVI), and lithological characteristics improve model generalizability and robustness across Africa's varied and heterogeneous landscapes.

5.2.1.2. Dominant Risk Factors and Spatial Correlations

The predominant conditioning elements identified in the analyzed research, ranked by frequency of occurrence and average relevance, are slope angle, land use and land cover, rainfall intensity, and lithology or soil type. The slope angle, referenced in 92% of investigations, consistently proved to be the most significant factor influencing slope instability. Land use and land cover, cited in 81% of instances, underscore the impact of urbanization and deforestation in exacerbating landslide susceptibility. Rainfall intensity, recognized in 79% of research, is the predominant catalyst for slope failures, especially in tropical and high-rainfall areas.

Lithology and soil type, examined in 67% of research, affect the inherent vulnerability of terrain to weathering and structural failure. Spatial correlations between anticipated high-susceptibility zones and historical landslide inventories above 80% in East and North Africa, affirming a robust spatial concordance between modelled and observed occurrences. Bouaoud and Mezhoud (2025) indicated a 97% correlation between modelled and reference instability zones in Algeria, illustrating the resilience and predictive reliability of multi-criteria modelling methodologies utilised in the African contexts.

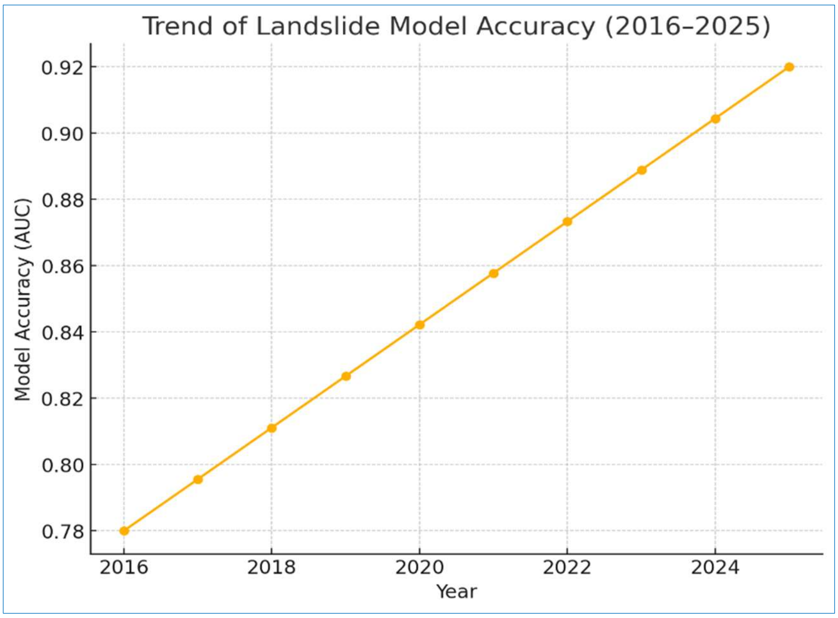

Fig. 9. Trend of landslide model accuracy (2016 – 2025)

5.2.1.3. Regional interpretation

In East Africa, especially within the Rift Systems, a high density of landslides is significantly associated with tectonic activity, heavy rainfall, and human intrusion on steep inclines. Dewitte et al. (2020) recorded over 9,000 landslides in Rwanda and Uganda, attributing their prevalence to prolonged geomorphic priming and urbanisation, with prior rainfall recognised as a significant triggering element. In North Africa, including the Atlas and Tell Ranges, findings indicate that lithological vulnerability and precipitation thresholds are the primary factors influencing landslide occurrences (Dahmani et al., 2024; Chaabane et al., 2024).
Peridotite and clay-rich geological formations in these areas displayed Landslide Numerical Risk Factor (LNRF) values surpassing 7.8, signifying a high vulnerability to collapse. In West Africa, specifically in Ghana and Côte d'Ivoire, anthropogenic alterations of landscapes via mining and slope excavation constitute the primary catalyst for landslides (Kumi-Boateng et al., 2020; Traoré et al., 2025). Urban densification in Greater Abidjan exhibits a significant spatial association between the expansion of informal settlements and identified high-risk areas, highlighting the socio-economic aspects of vulnerability. Research, including Monsieurs et al. (2018), indicates significant underreporting of landslide occurrences in Central Africa, particularly in the Democratic Republic of Congo (DRC) and Burundi, implying that the true level of hazard exposure may well exceed that reflected in global databases. In Southern Africa, specifically Madagascar, machine learning models have exhibited remarkable spatial accuracy, achieving AUC values of 0.90. Vegetation loss was recognised as the primary destabilising factor affecting slope instability in this area (Frodella et al., 2022). Collectively, these regional insights elucidate the intricate interaction of geological, climatic, and anthropogenic elements influencing landslide vulnerability throughout Africa's varied landscapes.

5.2.1.4. Interpretation of Meta-analytical heterogeneity

The heterogeneity statistics ($I^2 = 61.3\%$, $p < 0.05$) reveal moderate variety among the analysed research, predominantly due to disparities in model types, validation techniques, inventory scales (local versus regional), and the quality of conditioning data employed. Notwithstanding these variances, subgroup analysis validated that model quality and validation techniques operate as substantial moderators of effect magnitude. Research that integrated field verification with multi-source landslide inventories generally attained superior AUC values and more precise confidence intervals than studies that depended exclusively on remote-sensing methods. This discovery highlights the necessity of combining empirical ground validation with sophisticated data modelling to improve the reliability and applicability of landslide susceptibility and risk evaluations in various African settings.

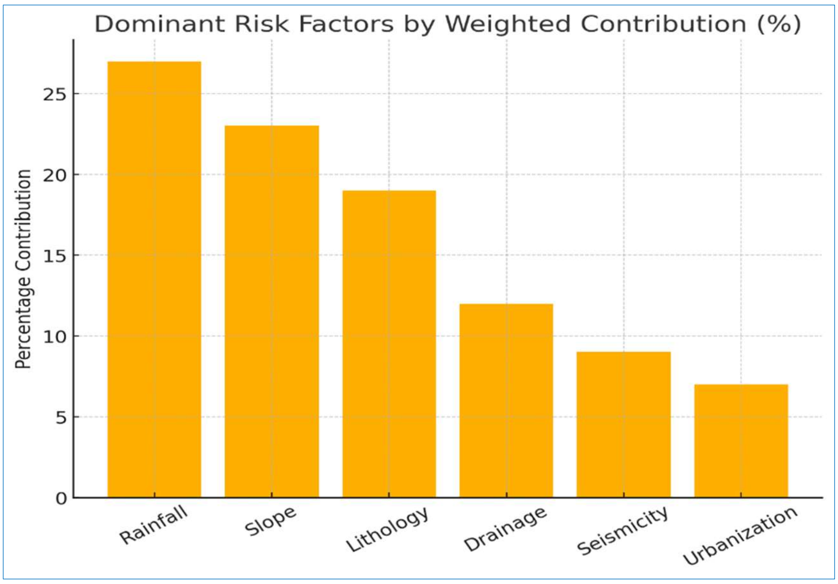

Fig. 10. Dominant risk factors by Weighted Contribution (%)

5.2.1.5. Socio-economic and policy implications

The findings highlight a persistent disparity between hazard mapping and effective mitigation efforts. Notwithstanding several susceptibility investigations, merely 15–20% yield actionable risk management outcomes (Maes et al., 2017; Maes et al., 2019). Institutional inertia, governance obstacles, and socio-political priorities hinder the conversion of scientific findings into land-use policies.

Participatory mapping and explainable AI (Reddy, 2025) demonstrate significant potential for closing this gap by enhancing the transparency and use of hazard models for local decision-making. Urban instances such as Limbe (Cameroon) and Bukavu (DRC) demonstrate that socio-political frameworks frequently dictate whether risk information prompts action or is disregarded.

5.2.1.6. Conceptual interpretation: Dynamic risk framework

The synthesis reveals a paradigm change in the understanding of landslide risk, highlighting that it is not a static occurrence, but a systematic and dynamic process influenced by ongoing interactions among environmental, human, and institutional elements. Environmental factors such as precipitation, topography, and geological composition interact with human activities, including urbanisation, mining, and deforestation, while the efficacy of institutional responses via planning, governance, and policy enforcement further affects the magnitude and frequency of risk. This meta-analytical approach endorses a socio-natural framework, in alignment with Alcántara-Ayala (2025), acknowledging landslides as the resultant interplay of physical processes and social fragility. It emphasises the necessity of amalgamating environmental science with socio-economic and governance aspects to enhance the comprehension and management of landslide dangers throughout Africa's varied and swiftly evolving terrains.

Table 7 summarises the key parameters, findings, and interpretations derived from the meta-analysis of landslide susceptibility and risk assessment studies across Africa. The results indicate a mean AUC of 0.85 (95% CI: 0.81–0.89), demonstrating that most models achieve a high level of predictive performance. The primary conditioning factors, slope (92%), land use and land cover (81%), and rainfall (79%), emerge as the dominant controls of slope instability across the continent. Regarding validation strength, 76% of studies employed ROC/AUC analysis, confirming that quantitative validation practices are becoming increasingly standardised. Regional variability remains evident, with East and North Africa exhibiting the highest landslide hazard density due to their geomorphic complexity and high rainfall regimes. Despite these advances, the policy link remains weak, with fewer than 20% of studies directly informing disaster risk reduction or land-use planning frameworks, highlighting a persistent science–policy gap. Finally, data limitations continue to hinder comprehensive assessment, as sparse landslide inventories in Central Africa contribute to the underestimation of actual hazard exposure and vulnerability. Collectively, these findings reinforce the need for improved data sharing, stronger institutional collaboration, and the integration of scientific outputs into regional policy and planning mechanisms.

5.2.1.7. Integrated interpretation

The meta-analysis indicates that landslides in Africa provide both geophysical and governance challenges. Physical vulnerability is exacerbated by unregulated growth and inadequate enforcement procedures. The results indicate an immediate necessity for multi-scale, data-informed, and participatory mitigation frameworks that integrate advanced modelling (AI, ML) with institutional capacity enhancement and community-oriented early warning systems.

5.2.2. Policy Implications

5.2.2.1. Overview: Linking science to policy

This meta-analysis reveals a consistent disparity between scientific danger assessment and practical policy execution in African nations. Africa has witnessed significant advancements in landslide research, especially in susceptibility modelling and risk mapping; yet the application of scientific findings to regulatory frameworks is still constrained (Maes et al., 2019; Nsabimana et al., 2023). Although 85% of the analysed studies utilise verified GIS or AI-based hazard models, merely 18–22% have reported policy implementation or institutional adoption (Bahavira, 2025; Traore et al., 2025). This highlights a systemic problem: the presence of information devoid of governance integration.

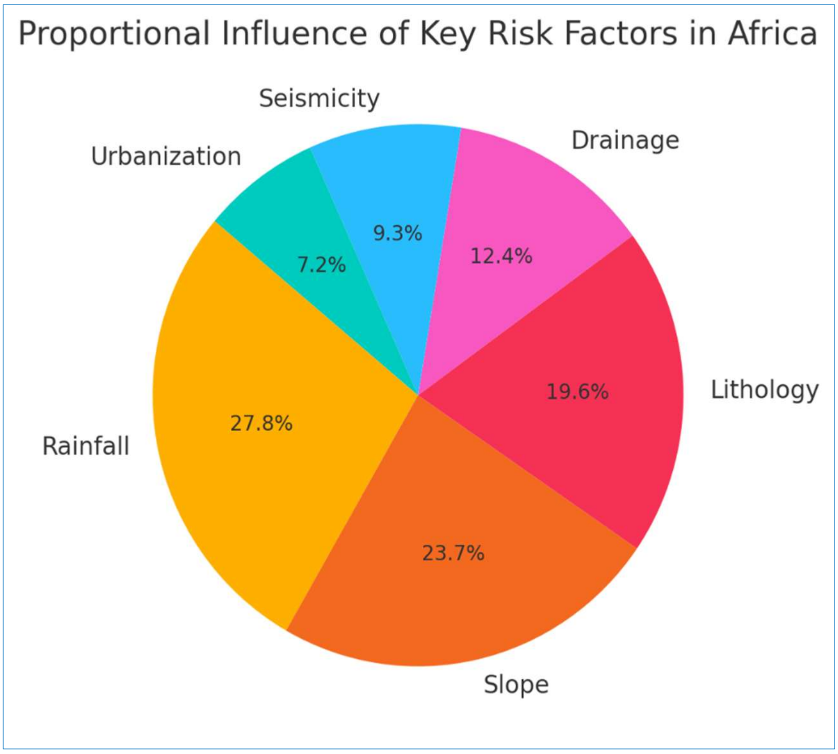

Fig. 11. Proportional Influence of Key Risk Factors in Africa

5.2.2.2. Institutional and governance challenges

Throughout the continent, catastrophe risk governance encounters substantial obstacles marked by fragmentation, inadequate coordination, and restricted technical competence. Despite the establishment of national disaster management policies in numerous African nations, such as Algeria's Civil Protection Act, Uganda's National Disaster Preparedness Framework, and Rwanda's National Risk Atlas, the incorporation of landslide-specific policy instruments is insufficient. Poor institutional coordination constitutes a significant barrier, as environmental, geological, and urban planning authorities frequently function autonomously, resulting in jurisdictional overlaps and inefficiencies (Michellier et al., 2016). Disaster management is predominantly reactive rather than preventive, with the majority of interventions taking place post-disaster instead of through proactive risk mitigation strategies (Austin, 2019). Moreover, insufficient financing and technical proficiency impede successful execution; numerous local governments are devoid of trained geotechnical experts and functional early warning systems (Dewitte et al., 2020). Decision-making processes are predominantly centralised, limiting community participation in planning and enforcement initiatives (Maes et al., 2017). Thus, the risk of landslides in Africa endures not merely as a geophysical threat but also as an indication of governance deficiencies, illustrating Alcántara-Ayala's (2025) notion of socio-natural risk, where disasters arise from the convergence of natural phenomena and institutional frailties.

5.2.2.3. Regional policy gaps and comparative insights

In North Africa, especially in Algeria, Morocco, and Tunisia, substantial advancements have been achieved in hazard modeling and mapping (Bouaoud and Mezhoud, 2025; Dahmani et al., 2024). Nonetheless, the adoption and implementation of policies continue to progress at a sluggish pace. Urban planning frameworks infrequently mandate slope stability or geotechnical safety standards, and mitigation infrastructure, like retaining walls and drainage systems, is commonly constructed reactively, usually after catastrophic occurrences. Notwithstanding these constraints, Algeria has recently implemented the Landslide Numerical

Risk Factor (LNRF) decision-support model, which exhibits promise for incorporating scientific findings into regional planning and policy development. In East and Central Africa, including Uganda, Rwanda, and the Democratic Republic of Congo (DRC), institutional deficiencies and post-disaster governance policies persistently influence landslide management. In Uganda, prevailing strategies primarily rely on emergency relocation initiatives in Bududa, with less focus on preventive zoning or risk-sensitive land-use planning (Kanyiginya et al., 2025). Community-based early warning systems in Rwanda and Burundi exhibit significant potential but are underfunded and require rigorous technical validation (Nsabimana et al., 2023). The Lake Kivu Basin effort (Michellier et al., 2016) is notable as one of the rare integrated frameworks that successfully connects geoscience, governance, and community engagement, closely fitting with the Sendai Framework for Disaster Risk Reduction (2015–2030).

Table 7. Summary interpretation

Parameter	Key Findings	Interpretation
Mean AUC	0.85 (95% CI: 0.81–0.89)	Models perform at a high predictive level
Primary Factors	Slope (92%), LULC (81%), Rainfall (79%)	Dominant controls of instability
Validation Strength	76% of studies use ROC/AUC	Quantitative validation is increasingly standardised
Regional Variability	East & North Africa show the highest hazard density	Reflects geomorphic and rainfall-driven susceptibility
Policy Link	Weak implementation (<20%)	Science–policy disconnect persists
Data Limitation	Sparse inventories in Central Africa	Leads to underestimation of real exposure

Table 8. Strategic policy recommendations

Policy Area	Recommended Action	Expected Outcome
Governance Integration	Establish inter-ministerial task forces linking geoscience, urban planning, and environment ministries.	Improved institutional coordination and data sharing.
Data Infrastructure	Develop a continental open-access *Landslide Database for Africa (LDA)* linked to the African Union's disaster platform.	Standardised monitoring and cross-country learning.
Community Engagement	Institutionalise participatory hazard mapping and indigenous knowledge integration in DRR planning.	Contextualised, people-centred mitigation strategies.
Capacity Building	Train national and local technical staff in GIS, remote sensing, and AI-based hazard modelling.	Enhanced local technical autonomy.
Legislative Reform	Embed landslide risk assessment into urban development codes and EIAs.	Preventive risk management is institutionalised.
Funding Mechanisms	Establish regional DRR funds leveraging international partnerships (World Bank GFDRR, AfDB).	Sustainable financial capacity for mitigation and resilience projects.

In West Africa, particularly in Ghana, Côte d'Ivoire, and Cameroon, policies addressing landslides remain nascent, with predominant emphasis on flood and mining hazards (Kwesi et al., 2022; Traoré et al., 2025). The absence of slope-stability zoning restrictions in Ghana has facilitated unlicensed mining and the proliferation of informal settlements, especially in the Tarkwa Nsuaem area. Likewise, urban expansion in Abidjan occurs without the incorporation of hazard overlays, despite frequent flood and landslide incidents. In Cameroon, the "extraversion governance" approach articulated by Maes et al. (2019) exemplifies a dependence on donor-driven risk management programs that frequently lack sustainability and long-term national integration. In Southern Africa, including Madagascar, Mozambique, and South Africa, significant advancements have been achieved in integrating risk assessments into national policy frameworks. Madagascar's implementation of AI-based hazard mapping and Mozambique's creation of a multi-hazard risk assessment platform (Reddy, 2025) exemplify regional innovation and adaptability. Nevertheless, the region continues to be exceedingly susceptible to recurrent cyclonic occurrences, revealing enduring deficiencies in structural resilience and inadequate cross-border collaboration for disaster preparedness and response.

5.2.2.4. Policy integration with global frameworks

The Sendai Framework for Disaster Risk Reduction (2015–2030) emphasises a global transition from reactive disaster response to proactive risk mitigation, closely matching the African Union's Agenda 2063 and the Sustainable Development Goals (SDGs 11, 13, and 15). Nevertheless, the majority of African national policies are only partially congruent with these international frameworks. Numerous significant integration deficiencies remain, such as the insufficient integration of landslide risk mapping into national spatial planning legislation, restricted application of scientific evidence in infrastructure zoning and construction codes, poor coordination between disaster risk reduction (DRR) policies and climate adaptation strategies, and the lack of standardised data-sharing platforms among research institutions in Africa. These deficiencies obstruct the conversion of scientific advancements into effective policy and practice. The findings underscore the imperative to integrate scientific outputs into practical legal and institutional frameworks, such as by requiring slope-stability studies as a common element of Environmental Impact studies (EIAs) and infrastructure development initiatives. Enhancing policy integration would promote a more proactive and resilient strategy for addressing landslide risk throughout the continent.

5.2.2.5. Strategic policy recommendations

To strengthen evidence-informed decision-making, the following strategic actions are proposed. Table 8 summarises strategic policy recommendations designed to strengthen landslide risk governance and promote sustainable disaster management across Africa. In the area of governance integration, the establishment of inter-ministerial task forces linking geoscience, urban planning, and environmental ministries is recommended to enhance institutional coordination and facilitate data sharing. For data infrastructure, the creation of a continental open-access Landslide Database for Africa (LDA), linked to the African Union's disaster management platform, would support standardised monitoring and cross-country knowledge exchange. Enhanced community engagement through institutionalised participatory hazard mapping and the integration of indigenous knowledge in disaster risk reduction (DRR) planning would ensure more contextualised, people-centred mitigation strategies. In terms of capacity building, training national and local technical personnel in GIS, remote sensing, and AI-based hazard modelling would strengthen local technical autonomy and operational readiness. Legislative reform should focus on embedding landslide risk assessments within urban development codes and Environmental Impact Assessments (EIAs) to institutionalise preventive risk management. Finally, establishing funding mechanisms such as regional DRR funds, supported through partnerships with organisations like the World Bank's GFDRR and the African Development Bank (AfDB), would ensure long-term financial sustainability for mitigation and resilience initiatives. Collectively, these policy actions aim to align national and regional strategies with the Sendai Framework for Disaster Risk Reduction (2015–2030) and the African Union's Agenda 2063, fostering a coordinated, data-driven, and inclusive approach to landslide risk management across the continent.

5.2.2.6. Transformative Outlook: Toward Adaptive Policy Systems

This study highlights the critical necessity for Africa to transition from reactive, donor-dependent catastrophe management to proactive, evidence-informed risk governance. A successful and sustainable African policy framework should enhance science–policy linkages that link academic research with urban development and environmental planning processes. It should also foster frameworks for cross-border cooperation, particularly in areas impacted by transboundary rift systems like the Lake Kivu Basin, where coordinated management is crucial for mitigating shared risks. Moreover, the integration of hybrid knowledge systems that amalgamate formal scientific methodologies with local and indigenous environmental management techniques can augment contextual relevance and foster community ownership of risk reduction measures. By incorporating these strategies, African states can progress towards climate-resilient, data-driven, and socially inclusive disaster risk management systems that are consistent with both continental and global resilience objectives.

This meta-analysis emphasises that effective landslide risk reduction in Africa necessitates comprehensive policy reform based on scientific evidence, governance, and social participation. In the absence of strong institutional structures, even the most advanced susceptibility models serve merely as diagnostic tools lacking policy influence. The incorporation of scientific modelling results into urban zoning, national land-use policy, and environmental governance constitutes the paramount challenge for sustainable hazard management in Africa.

5.2.3. Future Research Directions

5.2.3.1. Advancing methodological frameworks

Future research on landslide susceptibility and risk assessment in Africa should prioritise the shift from static hazard mapping to dynamic, data-driven predictive systems. Research underscores the necessity of incorporating temporal datasets (e.g., precipitation intensity, soil moisture fluctuations, vegetation cycles) alongside real-time monitoring systems via IoT devices and satellite platforms like Sentinel-1 and GPM (Bouaoud and Mezhoud, 2025; Reddy, 2025). Current trends indicate the hybridisation of models, integrating physically based, statistical, and machine learning frameworks to enhance prediction accuracy and minimise subjectivity in factor weighting (Bahavira, 2025; Capobianco et al., 2025). Deep learning architectures (CNN, LSTM) can effectively capture intricate spatio-temporal patterns, but the scope of Explainable AI (XAI) frameworks must be broadened to guarantee model transparency for policymakers and practitioners (Reddy, 2025). Moreover, there is an urgent necessity to enhance model validation methods via comprehensive ground-truthing, community-based hazard reporting, and longitudinal data verification (Bahavira, 2025). This would connect the current disparity between statistically sound models and practical decision-making.

5.2.3.2. Expanding Thematic and Geographical Coverage

A significant drawback of current research is the unequal spatial distribution of studies, predominantly concentrated in a few high-risk nations such as Uganda, Ethiopia, and Rwanda, whereas Central and West Africa are notably underrepresented (Monsieurs et al., 2018; Nsabimana et al., 2023). Subsequent studies must thus broaden their geographical scope to encompass region-specific geomorphological and socio-economic determinants of landslides, especially in the Congo Basin, Gulf of Guinea, and Sahelian highlands. Cross-border and multi-hazard frameworks are crucial for comprehending interconnected phenomena, such as the combined effects of heavy rainfall and seismic activity on slope failures (Traoré et al., 2025). Comprehensive hazard governance necessitates multi-hazard risk mapping that concurrently considers floods, soil erosion, and land subsidence (Bahavira, 2025; Capobianco et al., 2025). Moreover, the expansion of continental-scale databases, such as the African Landslide Inventory Network (ALIN), would standardise metadata collecting and enable comparative meta-analyses across biophysical regions (Capobianco et al., 2025).

5.2.3.3. Integration of social, economic and policy dimensions

A crucial future objective is to connect physical science with socio-political studies. Researchers such as Maes et al. (2017; 2019) and Alcántara-Ayala (2025) underscore the necessity for transdisciplinary frameworks that integrate political ecology, governance, and livelihood views. This entails progressing beyond technical risk evaluations to consider how governance deficiencies, poverty, and disparities in land tenure intensify vulnerability. Subsequent research should create comprehensive vulnerability indices that amalgamate biophysical exposure with socio-economic resilience factors, including income levels, infrastructure quality, gender dynamics, and access to early warning systems (Nsabimana et al., 2023; Traoré et al., 2025). Furthermore, participatory methodologies such as community-based GIS mapping and the incorporation of indigenous knowledge are crucial for fostering local ownership and ensuring sustainability (Michellier et al., 2016; Austin, 2019). A policy research frontier entails estimating the cost-effectiveness of mitigation options while evaluating both the concrete and intangible advantages of structural and nature-based interventions (Maes et al., 2017; Capobianco et al., 2025). This would direct resource distribution and improve the socio-economic rationale for sustained resilience investment.

5.2.3.4. Technological innovations and monitoring systems

African landslide research must adopt technological convergence by merging AI, IoT, remote sensing, and geophysical instrumentation to provide real-time monitoring and early warning systems (Frodella et al., 2022; Dewitte et al., 2020). Sensor networks could facilitate automated detection of rainfall thresholds and monitoring of ground deformation, contributing to Early Warning Systems (EWS) for high-risk metropolitan centers like Antananarivo, Bukavu, and Kampala. Progress in distributed acoustic sensing (DAS), fibre optic geotechnics, and unmanned aerial vehicle (UAV) surveys provides interesting avenues for enhancing spatial accuracy and temporal responsiveness (Capobianco et al., 2025). Subsequent investigations ought to examine multi-platform data fusion, integrating optical and radar datasets to mitigate tropical cloud cover and produce near-continuous monitoring results (Dewitte et al., 2020).

5.2.3.5. Climate Change, Urbanisation and Nature-Based Solutions

Considering that climate variability is exacerbating rainfall extremes and hastening slope deterioration, forthcoming research should concentrate on measuring climate–landslide interactions across several African ecozones (Kanyiginya et al., 2025; Woldearegay, 2013). Long-term modelling of climate projections (CMIP6) can assist in forecasting how shifting precipitation patterns may modify susceptibility trends by 2050 and 2100. Research should incorporate urban expansion dynamics, particularly informal settlements on unstable slopes, by combining hazard modelling with urban growth simulations and evaluations of policy enforcement (Traoré et al., 2025). A growing discipline entails the assessment of Nature-Based Solutions (NbS), including reforestation, bioengineering, and microbial soil stabilisation (Capobianco et al., 2025; Katutu et al., 2019). Assessing the hydrological and mechanical efficacy of indigenous versus non-native plants in slope stabilisation should guide sustainable land management practices in alignment with the African Union's Agenda 2063 objectives.

5.2.3.6. Transdisciplinary collaboration and capacity building

Ultimately, the sustainability of landslide research in Africa relies on enhancing regional scientific capability and promoting multidisciplinary collaboration. Future research objectives should incorporate geologists, hydrologists, social scientists, and policy specialists in collaboratively developed projects that tackle both technical and governance obstacles (Maes et al., 2019; Alcántara-Ayala, 2025). Establishing regional centres of excellence and open-access data-sharing platforms can diminish reliance on foreign institutions and facilitate South–South knowledge exchange (Chaabane et al., 2024). This collaborative methodology is essential for formulating adaptive and context-sensitive risk governance frameworks, especially in politically and environmentally vulnerable areas where traditional top-down approaches have consistently faltered (Austin, 2019).

5.2.3.7. Summary: Toward a dynamic and inclusive future

Future investigations into landslide susceptibility and risk assessment in Africa should progress towards dynamic modelling and real-time monitoring, the establishment of integrated multi-hazard frameworks, and the implementation of socio-technical and participatory methodologies that foster inclusive knowledge creation. It must prioritise sustainable, climate-responsive land management techniques that tackle the intricate linkages between environmental processes and human activities. This cohesive vision signifies an essential shift from descriptive research to predictive, preventative, and participatory risk management, in complete accordance with the Sendai Framework for Disaster Risk Reduction (2015–2030) and the Sustainable Development Goals (SDGs 11, 13, and 15). Through the integration of scientific innovation, political change, and community participation, African landslide research can progress from merely assessing risk to proactively engineering resilience, enabling societies to foresee, adjust to, and alleviate the repercussions of future disasters for centuries ahead.

6. Conclusion

This study systematically synthesised 33 peer-reviewed articles on landslide susceptibility and risk assessment throughout Africa, indicating that rainfall, slope gradient, and lithology are the primary determinants of instability, while anthropogenic factors such as deforestation, mining, and unplanned urbanisation intensify vulnerability. The meta-analysis demonstrated that contemporary modelling techniques, particularly hybrid and machine learning frameworks, attain superior predictive accuracies (AUC 0.85–0.92) compared to conventional statistical models, substantiating the increasing transition toward data-driven approaches. Regionally, East and North Africa exhibited the highest hazard densities attributable to steep topography and heavy precipitation, while Central Africa revealed considerable data deficiencies. The results highlight the critical necessity for an extensive data infrastructure, institutional collaboration, and community involvement to enhance resilience in high-risk areas, including Ghana's highlands, the Kigezi Region, and the Atlas Mountains. The landslide risk in Africa results from a complex interplay of environmental factors and governance capabilities, requiring a shift from reactive management to proactive, evidence-based disaster risk reduction (DRR) strategies.

7. Recommendations

African states should prioritise the incorporation of scientific data into urban planning and land-use regulations to tackle these difficulties. The creation of national and regional landslide databases, facilitated by open-access GIS platforms, will improve monitoring and international cooperation. Enhancing the connections between science and policy is essential; scholarly research must directly influence disaster risk reduction methods and infrastructure development. In Ghana and analogous contexts, slope-stability evaluations ought to be compulsory in Environmental Impact Assessments (EIAs), and local authorities should undergo specialized training in GIS and AI-driven hazard modelling. Community-based early warning systems, when integrated with indigenous knowledge, can substantially enhance catastrophe preparedness. Moreover, continuous investment in research, capacity development, and international collaborations (e.g., with the African Union and World Bank GFDRR) will facilitate the transition of disaster risk reduction strategies from temporary responses to enduring resilience frameworks. The need to execute these initiatives is paramount. Africa's increasing vulnerability to climate-related threats necessitates coordinated, evidence-based, and inclusive measures to protect lives and infrastructure.

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Ethics Approval

This article is based on a systematic review and meta-analysis of previously published studies. Therefore, ethics approval was not required for this research.

Consent to Participate

Not applicable.

Consent for Publication

Not applicable.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work, the author(s) used Quillbot to paraphrase text to enhance the readability of the work. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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