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Climate change, soil health, and governance challenges in Ghana: A review

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A R T I C L E I N F O

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A B S T R A C T

Climate change poses significant challenges to soil health and agricultural productivity in Ghana, with implications for similar contexts worldwide. This review synthesises existing knowledge on the impacts of climate change on soil properties across Ghana's diverse agro-ecological zones, examines the effectiveness of current governance responses through an adaptive governance lens, and identifies critical research and policy gaps. Ghana provides an instructive case study because of its diverse agroecological zones, agriculture-dependent economy, and dual governance systems that combine formal institutions with traditional authorities. The study employs a comprehensive literature search across multiple databases, qualitative synthesis methods, and conceptual frameworks to analyse the complex interactions between climate factors, soil health parameters, and governance structures. Key findings reveal that increasing temperatures and erratic rainfall patterns contribute to soil moisture depletion, organic matter loss, and reduced fertility. Ghana's soil health governance faces limitations due to policy fragmentation, resource constraints, and insufficient stakeholder collaboration. Successful case studies highlight the potential of integrating traditional knowledge with modern soil conservation practices and emphasize the importance of community-driven approaches. From the review, it is recommended that a comprehensive national soil health policy aligned with climate adaptation strategies be developed, institutional capacity be strengthened, and participatory governance mechanisms be promoted. The findings contribute to a broader understanding of environmental governance under climate change, with relevance to international frameworks including the Sustainable Development Goals and the Global Soil Partnership. Addressing identified research gaps and implementing the proposed adaptive governance framework are crucial for enhancing resilience to climate change impacts on soil health in Ghana and other regions facing similar challenges.

1. Introduction

Climate change poses one of the most significant threats to global soil resources and agricultural systems in the 21st century. Rising temperatures, changing precipitation patterns, and increasing frequency of extreme weather events are altering fundamental soil properties and functions worldwide. Global assessments indicate that climate change is accelerating soil degradation through increased erosion, reduced organic matter content, altered microbial communities, and disrupted nutrient cycling (FAO, 2023). These impacts vary regionally but collectively threaten agricultural productivity, food security, and ecosystem services across diverse landscapes. The Intergovernmental Panel on Climate Change estimates that 25–30 % of global land areas are already affected by soil degradation, with climate change expected to exacerbate these trends (Singh, 2023). Maintaining soil health under changing climate conditions has therefore emerged as a critical challenge requiring integrated governance approaches that span multiple sectors and scales.

In this review, soil health is defined as "the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals, and

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humans" (USDA-NRCS, 2025), characterized by parameters including organic matter content, nutrient cycling capacity, biodiversity, structure, and water management properties. It encompasses physical (e.g., structure, porosity), chemical (e.g., organic matter, pH), and biological (e.g., microbial activity, biodiversity) properties. While edaphoclimatic conditions like soil texture and climate set the baseline, land use (e.g., agriculture, forestry, urban development) and management practices (e.g., tillage, crop rotation) significantly influence soil health outcomes (Guo, 2021; Shahane and Shivay, 2021). Governance refers to the formal and informal rules, mechanisms, and processes through which decisions affecting soil resources are made and implemented, and through which decision-makers are held accountable (Armitage et al., 2012). Adaptive governance, characterized by flexibility, multi-stakeholder collaboration, and learning processes (Manevska-Tasevska et al., 2021), has been identified as particularly relevant to the management of dynamic soil-climate interactions. Therefore, this review applies an adaptive governance theoretical framework to analyse soil health management under climate change. This approach is particularly suitable because it acknowledges the complex, dynamic nature of social-ecological systems and emphasizes flexibility, multi-level interactions, and knowledge integration (Manevska-Tasevska et al., 2021). Adaptive governance theory recognises that environmental challenges, such as climate-induced soil degradation, require governance systems capable of learning, adjusting, and responding to changing conditions and new information. Within this framework, the interactions between formal institutions (policies, regulations), informal institutions (traditional practices, social norms), and stakeholder networks are analysed in terms of their roles in addressing climate impacts on soil resources. Governance challenges are examined across multiple scales from local farming practices to national policies and mechanisms for enhancing resilience through increasing adaptive capacity, knowledge co-production, and institutional learning are identified.

This review focuses on the Ghanaian context, as the country represents a particularly relevant and instructive case of soil health governance under climate change. Ghana possesses several characteristics that make it an ideal case study for understanding climate, soil, and governance interactions. The country encompasses diverse agro-ecological zones, from Guinea Savannah in the north to Coastal Savannah in the south, which experience differential climate impacts and require varied governance responses. This spatial heterogeneity provides opportunities to examine how governance systems adapt to diverse environmental conditions in different regions. Ghana's economy remains heavily dependent on agriculture, with approximately 60 % of its population engaged in agricultural activities (Awunyo-Vitor and Sackey, 2018). This dependence means that soil health directly impacts national food security, rural livelihoods, and economic development, creating strong incentives for effective governance and highlighting the consequences of governance failures. Third, Ghana has dual governance systems that combine formal institutions with traditional authorities (Adotey, 2019), providing insights into how different institutional arrangements can be integrated into environmental management. Ghana has experienced significant climate variability in recent decades (Gyimah et al., 2020), offering opportunities to examine governance responses to actual climate impacts rather than projected scenarios. The country's policy landscape includes various initiatives related to soil health and climate adaptation, providing a rich context for evaluating governance effectiveness. Finally, Ghana's status as a stable democracy with functioning institutions (Ackah, 2024) but limited resources represents the conditions found in many developing countries, making the lessons learned broadly applicable. Ghana's experience with climate, soil, and governance challenges reflects the broader patterns observed across sub-Saharan Africa and other developing regions. Soil degradation affects approximately 65 % of agricultural land in Africa, with climate change accelerating this trend (Lal, 2020). However, governance responses vary significantly across countries, offering opportunities for comparative learning and policy transfers. The international policy context provides additional impetus for examining soil-health governance. The United Nations Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land), emphasise the interconnections between soil health, climate resilience, and sustainable development. The FAO's Global Soil Partnership and the UN Convention to Combat Desertification provide frameworks for international cooperation in soil health governance. The African Union's Comprehensive Africa Agriculture Development Programme specifically targets soil health as a priority for agricultural transformation in Africa (Phiri et al., 2020).

Despite the growing recognition of climate-soil governance linkages, several critical knowledge gaps persist. First, most research on the impact of climate change on soil health focuses on biophysical processes while inadequately examining governance responses and their effectiveness (Guo et al., 2023). Second, studies on environmental governance often treat soil health as a secondary concern rather than a primary focus, limiting insights into soil-specific governance challenges (Bodle, 2022). In the case of Ghana's relevance as a case study, significant knowledge gaps persist about the country's specific climate-soil-governance interactions. No comprehensive analysis exists of how Ghana's particular dual governance systems (formal government agencies alongside traditional authorities) coordinate or conflict in addressing soil health under climate change. While studies examine either formal institutions or traditional practices separately, the interactions between these systems remain poorly understood. Insufficient research has examined how Ghana's diverse agro-ecological zones—-from Guinea Savannah to Coastal zones, require differentiated governance approaches, with most studies focusing on single zones rather than comparative analysis. Inadequate evaluation exists of Ghana's specific policy instruments, particularly the Fertilizer Subsidy Programme's effectiveness for soil health outcomes rather than just productivity measures, and how these policies interact with climate adaptation strategies. Limited understanding exists of power dynamics between traditional authorities, government agencies, farmer organizations, and NGOs in Ghana's soil health governance landscape. While stakeholder roles are individually documented, the power relations and influence patterns that determine policy outcomes remain underexplored. Fifth, insufficient analysis exists of how Ghana's particular institutional landscape—with MoFA, EPA, and CSIR-SRI having overlapping mandates—coordinates or fails to coordinate on soil health issues, and what these reveals about institutional design for environmental governance.

Thus, this appraisal addresses these gaps by providing a comprehensive analysis of climate-soil governance interactions in Ghana, yielding insights applicable to broader international efforts. This analysis connects local experiences with global frameworks, offering actionable insights for improving soil governance in comparable settings worldwide. This review synthesises existing knowledge on the impact of climate change on soil health in Ghana, evaluates governance responses through an adaptive governance lens, and identifies critical research and policy gaps that constrain effective soil health management. The analysis spans multiple scales, from local farming practices to national policies, and examines how different governance arrangements respond to climate-induced soil health challenges. This review also contributes to the global discourse on environmental governance by examining how climate-soil-governance interactions manifest in Ghana, yielding insights applicable to broader international efforts. Specific actionable insights for improving soil governance in comparable settings worldwide are offered by identifying distinct challenges and promising approaches in the context of Ghana. These findings support the formulation of climate-resilient soil management strategies that can benefit Ghana and regions facing similar challenges in balancing agricultural productivity, environmental sustainability, and climate adaptation.

2. Methodology

2.1. Literature search strategy

This write-up employed a systematic literature search methodology to search targeted peer-reviewed articles, policy documents, and grey literature related to climate change impacts on soil health and governance in Ghana. The search utilized five databases: Web of Science, Scopus, Google Scholar, AGRIS, and CAB Abstracts. A structured search string employed Boolean operators combining key terms: ("soil health" OR "soil fertility" OR "soil degradation") AND ("climate change" OR "climate variability") AND ("Ghana" OR "West Africa") AND ("governance" OR "policy" OR "institution" OR "management" OR "adaptation"). Additional searches included ("adaptive governance" AND "soil") and ("traditional knowledge" AND "soil management" AND "Ghana"). Studies were eligible if published between 1997 and 2024 (emphasizing 2018–2024), focused on Ghana, addressed climate impacts on soil properties or soil health governance, and presented empirical data, theoretical frameworks, or policy analyses. The initial database searches yielded 276 records. After removing 83 duplicates, 193 articles underwent screening based on title and abstract, 89 relevant articles distributed across eight thematic categories. Climate Change & Variability studies (12) were used to examine temperature and rainfall patterns affecting Ghana's agro-ecological zones. Soil Health & Management publications (17) were used to analysed soil properties, fertility management, and degradation processes across different regions. Agricultural Systems & Practices research (15) were used to analysed farming techniques, productivity factors, and adaptation strategies implemented by farmers. Land Use & Land Cover Change studies (6) were used to tracked landscape transformations and resulting impacts on soil resources. Water Resources & Management publications (5) were used to study hydrological factors affecting soil moisture and agricultural systems. Governance & Policy documents (10) were used to study the institutional frameworks, policy implementation, and regulatory mechanisms affecting soil management. Indigenous Knowledge & Local Perspectives research (7) were used to study the traditional soil classification systems and management practices. Technology Adoption & Information Systems studies (7) were used to examined monitoring tools, digital applications, and information access for soil management. The selection process prioritized peer-reviewed journal articles (75) while incorporating relevant technical reports and policy documents (12) from institutional sources including Ghana's Ministry of Food and Agriculture, Environmental Protection Agency, CSIR-Soil Research Institute, and international organizations. Publications spanned 1997–2024, with emphasis on recent research (2018–2024) to capture current climate conditions and governance approaches. Each reference underwent assessment for methodological quality, empirical foundation, and relevance to the review objectives.

For the comparative analysis of governance frameworks (presented in 3.2), specific selection criteria were employed to identify relevant models for comparison with Ghana's approach. First, countries and regions facing similar climate-induced soil challenges but employing different governance strategies were prioritized. Second, cases with documented outcomes were selected to enable assessment of effectiveness. Third, examples spanning a range of governance approaches from centralized to participatory, and from technical to traditional knowledge-based were sought. This resulted in the selection of Ethiopia's soil health data governance initiative, the European Union's integrated framework, and the "4 per 1000" Initiative as comparative cases. These examples were systematically analysed against Ghana's governance structures using a framework that examined: (1) policy integration and coherence, (2) stakeholder engagement mechanisms, (3) resource allocation approaches, and (4) implementation effectiveness. This comparative approach directly supports the research objective of evaluating Ghana's governance response to soil health challenges by providing benchmarks and alternative models that could inform policy recommendations.

This critique employed qualitative synthesis methods to identify patterns in governance measures, climate impacts, and stakeholder roles. This included thematic analysis of key findings across studies, with particular attention to recurring themes in soil health governance, climate adaptation strategies, and institutional frameworks. The synthesis organized findings into thematic categories such as climate change impacts on soil properties, governance challenges, and stakeholder collaboration models. Analysis included the development of conceptual frameworks and casual loop diagrams to illustrate the complex interactions between climate factors, soil health parameters, and governance structures.

3. Results and discussion

3.1. Conceptual framework for understanding climate-soil-governance linkages

Fig. 1 presents the conceptual framework that guided this analysis, illustrating the complex interconnections between climate change factors, soil health parameters, and governance structures in Ghana. This framework synthesises evidence from 89 studies to demonstrate how climate variability drives soil degradation through multiple pathways, while governance responses attempt to mitigate these impacts through various institutional arrangements and stakeholder interaction. The climate-soil vulnerability loop (R1) reveals a critical finding: increasing temperatures and erratic rainfall patterns create a reinforcing feedback mechanism in which climate impacts accelerate soil degradation, which, in turn, reduces soil resilience to future climate stressors (Abbam et al., 2018; Atiah et al., 2022; Issahaku et al., 2016). Research in Ghana has demonstrated that rising temperatures accelerate organic matter decomposition rates, reducing soil organic carbon (SOC) stocks essential for soil structure and fertility (Lal, 2020; Quaye et al., 2021). Simultaneously, erratic rainfall patterns contribute to soil moisture depletion during dry periods and increased erosion during intense precipitation events (Atiah et al., 2022; Larbi et al., 2021). This creates a degradation spiral, where soils with reduced organic matter and compromised structures become increasingly vulnerable to subsequent climate stresses.

Evidence from Ghana's diverse agro-ecological zones demonstrates that this mechanism operates differently across spatial contexts. In the Northern regions, temperatures are projected to increase by 1–1.5°C combined with reduced rainfall, which will lead to severe soil moisture depletion and desiccation risks (Asante and Amuakwa-Mensah, 2015). The Upper East Region exemplifies these challenges, where high temperatures exacerbate soil evaporation, leading to reduced soil moisture, which is critical for crop growth (Lente et al., 2023). Conversely, the Vea Catchment experiences intensified rainfall events and prolonged rainy seasons, causing increased soil erosion and nutrient leaching (Larbi et al., 2021). In the Cocoa Agroecological Zone, declining SOC and pH levels demonstrate long-term degradation trends (Quaye et al., 2021), whereas urban areas, such as Kumasi, paradoxically show increased SOC owing to concentrated organic waste inputs in home gardens (Asabere et al., 2018).

This spatial heterogeneity challenges uniform policy approaches and highlights the need for adaptive governance mechanisms that respond to diverse local conditions. The feedback loops identified suggest that without intervention, soil degradation will accelerate under continued climate change, making early action critical for the long-term sustainability of soil health. The contrasting patterns between rural and urban areas indicate that land-use decisions significantly modulate climate impacts, offering potential entry points for governance interventions. The governance response loop (B1) demonstrates how institutional arrangements attempt to break the degradation cycle through policy intervention, resource allocation, and stakeholder coordination. However, the analysis reveals significant limitations in the current

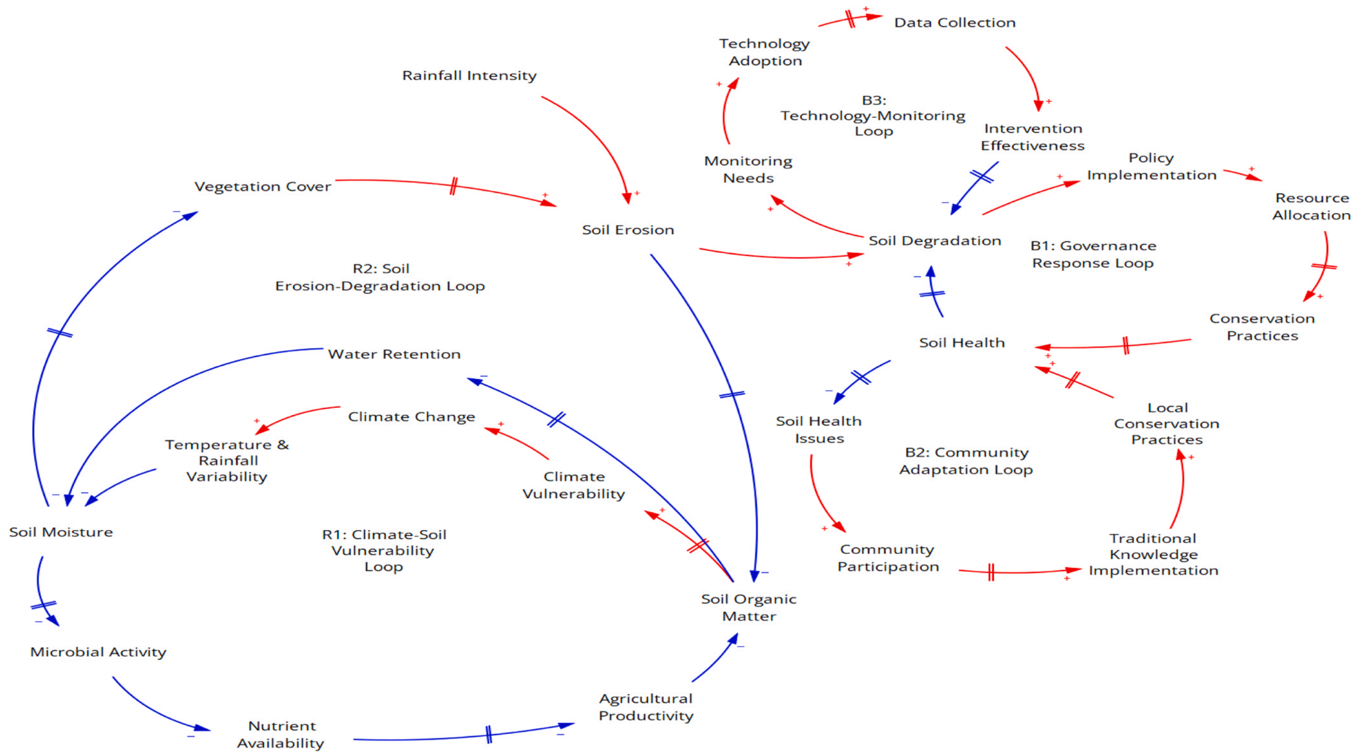

Fig. 1. Conceptual Framework of Climate-Soil-Governance Interactions using a causal loop diagram (CLD); showing the complex interconnections between climate change factors, soil health parameters, and governance structures in Ghana. Solid blue lines represent direct influences, dashed red lines indicate feedback mechanisms. Plus signs (+) indicate positive relationships (variables change in the same direction), while minus signs (-) indicate negative relationships (variables change in opposite directions). R1, R2, B1, B2, and B3 represent key feedback loops described in the text.

governance effectiveness. Ghana's soil health governance operates through a complex multi-level structure spanning national ministries to local traditional authorities, with three primary institutions anchoring the system: the Ministry of Food and Agriculture (MoFA), Environmental Protection Agency (EPA), and CSIR-Soil Research Institute (SRI) (Abdallah et al., 2014; Owusu et al., 2020). However, this institutional framework faces critical constraints, including policy fragmentation across agencies that dilute accountability and create implementation gaps (Asante et al., 2021).

The Fertilizer Subsidy Program exemplifies both the potential and limitations of current governance approaches. While aimed at improving soil fertility, evidence from other contexts suggests that fertiliser subsidies can lead to overuse and soil quality degradation when not accompanied by education on balanced nutrient management (Egyir et al., 2017). In Ghana, the program's effectiveness is further constrained by periodic funding shortages and logistical challenges that limit consistent access for smallholder farmers (FAO, 2023). Resource limitations present significant barriers to soil health governance, with the sustainability of interventions challenged by limited government ownership and engagement. The framework aligns with adaptive governance theory (Armitage et al., 2012; Manevska-Tasevska et al., 2021) but reveals that Ghana's current approach lacks the flexibility and multi-stakeholder collaboration characteristics of effective adaptive systems. This represents a critical gap between theoretical frameworks and practical implementation, where governance structures remain largely reactive rather than anticipatory in nature.

The knowledge integration loop (B2) shows promise but remains underdeveloped in formal governance systems. Traditional soil management practices demonstrate sophisticated understanding of soil-climate interactions, particularly in Northern Ghana where farmers' soil classification systems align closely with scientific taxonomies while incorporating dynamic indicators of soil health that respond to seasonal variations (Mikkelsen and Langohr, 2004). Indigenous practices, including multi-cropping and animal manure application, remain crucial for soil fertility management in the Guinea Savannah region (Tenagyei and Kanton Osumanu, 2021). However, formal governance systems inadequately incorporate this knowledge, representing a missed opportunity for enhancing governance effectiveness through knowledge co-production.

The stakeholder collaboration loop (B3) reveals the complex power dynamics that influence governance outcomes. Analysis of stakeholder interactions shows that farmers—the primary land managers—occupy a paradoxical position as both central actors in soil conservation and as marginalised participants in formal governance processes (Anderson and Larbi, 2022). Government and private sector actors typically dominate decision-making processes, often sidelining traditional knowledge and local priorities (Arko, 2019). This power asymmetry is evident in the limited influence of farmer groups on policy formulation, despite their critical role in implementation. The framework reveals that addressing the impact of climate change on soil health requires simultaneous interventions across multiple loops. Single-sector approaches, such as focusing only on agricultural inputs or climate adaptation, are insufficient. The interconnected nature of these systems demands integrated governance approaches that acknowledge the complex feedback mechanisms and power dynamics. Evidence suggests that successful interventions must strengthen not only technical capacity but also institutional coordination and stakeholder engagement mechanisms. Moving forward, this framework guides our analysis of specific climate impacts, governance structures, and adaptive management approaches, demonstrating how each component contributes to the overall system resilience or vulnerability under changing climate conditions.

3.2. *Climate change impacts on soil health across agro-ecological zones*

3.2.1. *Spatial and temporal climate variability*

The spatial and temporal heterogeneity of climate impacts across

Ghana's agro-ecological zones necessitates differentiated governance responses; however, current policy frameworks inadequately address this complexity. Table 1 reveals significant variations in soil health parameters and their temporal trends across different zones, highlighting both the challenges and opportunities for targeted interventions.

Analysis of baseline soil health data demonstrates concerning degradation trends across multiple zones but also reveals the potential for targeted interventions. The Cocoa Agroecological Zone shows declining SOC (0.39 g/100 g) and pH levels (5.35), indicating acidification and organic matter loss that threaten long-term productivity (Quaye et al., 2021). This contrasts sharply with urban Kumasi, where home gardens demonstrate significantly higher organic matter content and SOC accumulation due to concentrated organic waste inputs (Asabere et al., 2018). The Humid Savannah zone exhibits particularly concerning trends, with SOC declining to 34.56 kg/m^2 and reduced nutrient levels in croplands due to land use changes (Awoonor et al., 2022).

These spatial variations reveal that climate impacts interact with local management practices and land-use decisions to produce diverse outcomes. The success of urban home gardens in maintaining soil health suggests that intensive organic matter management can counteract climate-induced degradation; however, this approach requires adaptation to rural contexts and farmer resource constraints. Climate-induced soil degradation operates through multiple interconnected mechanisms that vary spatially across Ghana's land. Table 2 synthesises the projected climate changes and their corresponding soil health impacts, organised by region and severity level, revealing the complexity of climate-soil interactions.

Temperature increases emerged as the primary driver of soil degradation across all regions but manifested through different pathways. In Northern Ghana, temperature increases of 1–1.5°C combined with reduced rainfall create severe soil moisture stress and accelerate organic matter decomposition (Asante and Amuakwa-Mensah, 2015). Research has demonstrated that these temperature increases accelerate organic matter decomposition rates, reducing SOC stocks from approximately 51.80 Mg/ha in dense forests to just 7.00 Mg/ha in converted agricultural lands (Amissah et al., 2023). This represents a critical threshold beyond which soils lose their capacity to buffer climate extremes. Rainfall variability creates a dual challenge that differs markedly among regions. In the Vea Catchment of the Upper East Region, increased rainfall intensity and prolonged rainy seasons drive soil erosion rates that remove essential topsoil and nutrients (Larbi et al., 2021). Conversely, the Coastal Savannah Zone faces declining rainfall combined with extreme temperatures, leading to increased soil salinity and accelerated degradation (Ankrah et al., 2023). The Pra River Basin exemplifies these challenges, with erosion rates projected to increase by 20 % due to intensified precipitation (Bessah et al., 2020).

The alternating wet-dry cycles characteristic of climate change in Ghana promote nutrient leaching, particularly of nitrogen, rendering these nutrients inaccessible to crops during critical growth periods (Atiah et al., 2022). This process disrupts microbial communities essential for nutrient cycling, creating cascading effects on soil fertility (Chatterjee and Saha, 2018). In the semi-deciduous forest zone, high soil erosion rates threaten soil fertility and crop production potential, undermining food security for smallholder farmers (Sekyi-Annan et al., 2021). These differentiated climate impacts require governance systems capable of implementing region-specific adaptation strategies to mitigate their effects. However, current institutional arrangements lack the flexibility to respond to spatial heterogeneity. The uniform application of programs, such as the Fertiliser Subsidy Program, fails to address the distinct challenges facing different agro-ecological zones, potentially exacerbating rather than alleviating soil health problems. The temporal dimension of climate impacts adds complexity to governance challenges. Long-term studies have revealed that soil degradation accelerates over time, with initial climate stress creating vulnerability to subsequent impacts. In regions such as the Upper East Region, decreasing rainfall trends combined with rising temperatures have caused sustained reductions in soil organic carbon (SOC) over multiple growing seasons (Abbam et al., 2018). This temporal persistence means that governance responses must address both immediate climate stress and long-term soil resilience.

Evidence demonstrates that effective soil health governance must move beyond generalised approaches to embrace spatial and temporal differentiation. This requires enhanced monitoring systems capable of tracking zone-specific changes, institutional mechanisms for implementing differentiated policies, and stakeholder engagement processes that incorporate local knowledge of spatial variation. The inability of the current governance framework to address this complexity represents a fundamental limitation that undermines climate adaptation efforts across Ghana's diverse landscapes.

3.3. Anthropogenic factors and governance responses: Land use, Ecosystem services, and Institutional arrangements

Land-use decisions are critical determinants of soil health resilience under climate change; however, governance systems inadequately address the complex interactions between anthropogenic pressures and climate impacts. The conversion of natural ecosystems to agricultural land represents the most significant anthropogenic driver of soil degradation, with governance implications that extend across multiple institutional levels. Evidence from Ghana's humid savannah zone demonstrates the magnitude of these impacts: forest-to-cropland conversion results in over a 50 % reduction in soil carbon and nitrogen stocks (Awoonor et al., 2022). This dramatic loss undermines the soil's buffering capacity against climate extremes, creating a governance challenge in which short-term agricultural productivity goals conflict with long-term soil sustainability. The economic implications cascade through rural livelihoods, with reduced agricultural productivity from soil degradation directly impacting food security and forcing smallholder farmers into increasingly unsustainable land use practices (Diao

Table 1
A comprehensive table showing baseline data of soil health parameters (pH, organic matter content, nutrient levels, bulk density, etc.) across different agro-ecological zones in Ghana, with temporal trends over the past decade.

Agro-Ecological Zone	pH Range	Organic Matter Content (%)	Bulk Density (g/cm^3)	Soil Organic Carbon (SOC)	Key Nutrients (e.g., N, P, K)	Temporal Trend Observed	Source
Cocoa Agroecological Zone	5.35	0.39 g/100 g	Moderate	Moderate	Moderate levels of N, P	Declining SOC and pH	(Quaye et al., 2021)
Urban Kumasi	5.0–6.5	High in home gardens	High in core areas	High in long-term urban soils	Significant increase in N and SOC	Urbanization impact on SOC and pH	(Asabere et al., 2018)
Humid Savannah	Moderate	34.56 kg/m^2 SOC	Lower	Low in croplands	Reduced in cropland	Decrease in SOC and N due to land use changes	(Awoonor et al., 2022)
Guinea Savannah	Moderate Acid	Low in croplands	Medium	Moderate	N and K slightly higher with amendments	Stable but low SOC in cropland zones	(Nketia et al., 2018)
Semi-Deciduous Forest	6.54	Moderate	Lower	High in SOC	Increased SOC with agroforestry practices	Soil conservation measures are effective	(Recha et al., 2022)

Table 2
A detailed matrix showing projected climate changes (temperature, rainfall, extreme events) and their corresponding impacts on specific soil health parameters, organized by region and severity level.

Region	Climate Projection	Soil Health Impact	Severity Level	Sources
Northern Ghana	Increase in temperature by 1–1.5°C, reduced rainfall	Reduced soil moisture, increased evapotranspiration, soil desiccation risks	High	(F. A. Asante and Amuakwa-Mensah, 2015)
Vea Catchment, Upper East	Increased rainfall intensity, prolonged rainy season	Soil erosion, nutrient leaching, and heightened flood risks	Moderate to High	(Larbi et al., 2021)
Coastal Savannah Zone	Increase in extreme temperatures, shifts in rainfall patterns	Increased soil salinity, reduced organic carbon content, accelerated soil degradation	High	(Ankrah et al., 2023)
Savannah Zone	General decline in rainfall, high temperatures	Soil degradation, nutrient loss, increased risk of desertification	High	(Incoom et al., 2023)

and Sarpong, 2011).

Agricultural management practices significantly modulate the impact of climate change on soil health; however, their adoption remains constrained by governance failures. Integrated Soil Fertility Management (ISFM) practices, which combine organic and inorganic inputs, have the potential to enhance soil microbial biomass and overall soil quality (Omari et al., 2018; Sabir et al., 2021). However, adoption remains limited due to financial constraints and inadequate technical knowledge transfer, which are governance failures that reflect deeper institutional weaknesses (Adolwa et al., 2019; Kwadzo and Quayson, 2021). The effectiveness of different management interventions varies considerably across agroecological zones, highlighting the need for adaptive governance approaches. Conservation agriculture practices show promise in moisture-limited environments in Northern Ghana, whereas agroforestry systems demonstrate superior performance in maintaining soil organic matter in forest-transition zones (Recha et al., 2022). Indigenous practices, including multi-cropping and animal manure application, remain crucial for soil fertility management in the Guinea Savannah region, yet formal governance systems provide limited support for scaling these practices (Tenagyei and Kanton Osumanu, 2021).

Soil degradation creates cascading effects through ecosystem services that amplify initial climate impacts and reveal fundamental governance limitations. Reduced soil organic matter and disrupted microbial communities impair water regulation services, thereby increasing surface runoff and reducing groundwater recharge (Awotwi et al., 2018). This hydrological disruption further exacerbates soil moisture stress during dry periods and intensifies erosion during rainfall events, creating feedback loops that current governance systems fail to address. Biodiversity loss is another critical feedback mechanism with governance implications. Degraded soils support less diverse plant and microbial communities, thereby reducing the resilience of ecosystems to climate shocks (Agbeshie et al., 2020). This decline in biodiversity compromises nutrient cycling efficiency, creating negative spirals in which poor soil health begets further degradation. The economic implications are substantial: reduced agricultural productivity limits farmers' capacity to invest in soil conservation measures, perpetuating degradation cycles that governance interventions must address (Diao and Sarpong, 2011).

Fig. 2 illustrates Ghana's multilevel governance structure for soil health management, revealing both the complexity of institutional arrangements and the coordination challenges that undermine effectiveness.

The governance landscape encompasses national ministries (MoFA,

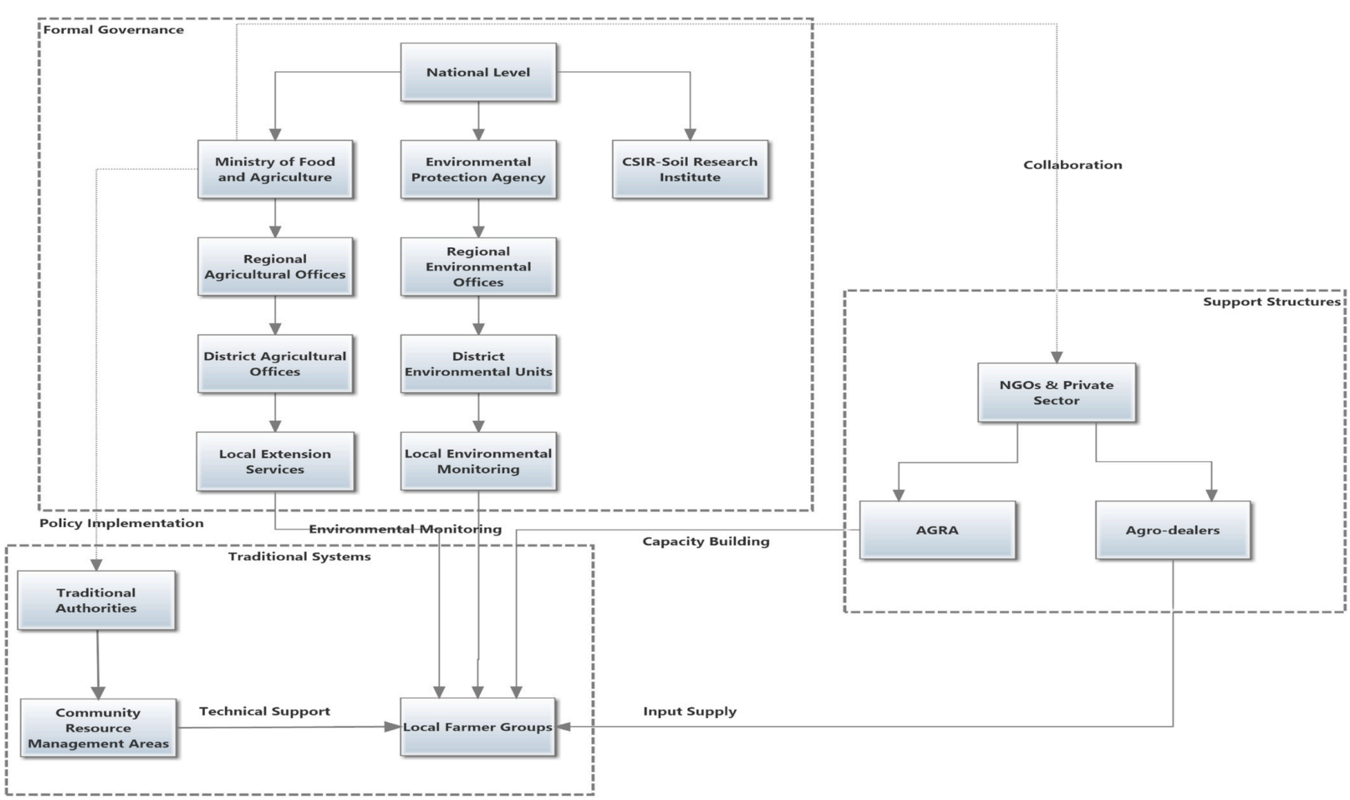

Fig. 2. Multi-level Governance Structure for Soil Health Management.

EPA), research institutions (CSIR-SRI), regional coordination bodies, district assemblies, traditional authorities, and local farmer groups. However, this apparent comprehensiveness masks significant coordination failures and power imbalances that constrain effective governance. At the national level, policy fragmentation across agencies dilutes accountability and creates implementation gaps. The Ministry of Food and Agriculture oversees the Fertilizer Subsidy Programme and broader agricultural policy, while the Environmental Protection Agency manages environmental regulations, and CSIR-Soil Research Institute conducts research and soil surveys (Abdallah et al., 2014; Owusu et al., 2020). Yet these institutions operate with limited coordination, leading to duplicated efforts and missed synergies in addressing soil health challenges (Ahmed et al., 2022).

The governance structure reveals critical power asymmetries that undermine effective soil health management. Table 3 provides comprehensive stakeholder mapping, demonstrating the complex web of actors whose interactions determine governance outcomes.

Farmers occupy a paradoxical position as both central actors in soil conservation and as marginalised participants in formal governance processes. Despite managing the majority of Ghana's agricultural land, farmers have limited influence on policy formulation and resource allocation decisions (Abdul-Rahaman and Abdulai, 2018). Traditional authorities play crucial roles in mediating land access and enforcing customary conservation practices; however, their knowledge and institutional capacity remain underutilised in formal governance structures (Anderson and Larbi, 2022).

NGOs and private sector actors increasingly bridge gaps between government services and farming communities through capacity building and technical support (Aniah et al., 2019). However, these relationships often perpetuate dependency rather than building local institutional capacity. Research institutions generate important knowledge about soil health and climate impacts; however, this knowledge inadequately informs policy decisions because of weak science-policy interfaces (MacCarthy et al., 2021).

International experiences offer insights for strengthening Ghana's approach, but reveal the limitations of transplanting governance models without addressing underlying institutional weaknesses. Table 4 synthesizes governance approaches from multiple contexts, highlighting both successful innovations and implementation challenges. Ethiopia's Supporting Soil Health Interventions (SSHIiE) project demonstrates the value of robust data governance frameworks that enable evidence-based decision-making (Whittard et al., 2022). This contrasts sharply with Ghana's limited monitoring infrastructure and fragmented data systems, which constrain its adaptive management capacity. The European Union's EJP SOIL initiative offers a model for interdisciplinary, stakeholder-co-constructed research that positions soil health as central to climate resilience (Keesstra et al., 2024). However, this approach requires institutional capacity and coordination mechanisms that are currently lacking in Ghana.

The "4 per 1000" Initiative's focus on soil carbon sequestration provides a framework for aligning soil health with climate mitigation goals, potentially unlocking climate finance for soil conservation in Brazil. Ghana's limited engagement with carbon markets represents a missed opportunity for incentivising sustainable soil management practices, but also reflects broader governance limitations in accessing international climate finance mechanisms. Evidence reveals that anthropogenic factors and governance responses are inextricably linked through feedback mechanisms that either amplify or mitigate climate impacts on soil health. Successful interventions require addressing power imbalances that marginalise key stakeholders, investing in institutional coordination mechanisms, and developing adaptive capacity to respond to spatial and temporal variations in climate impacts. Current governance approaches remain largely sectoral and reactive, failing to address the integrated nature of climate-soil-society interactions. Moving toward adaptive governance requires fundamental reforms in institutional arrangements, stakeholder engagement processes, and knowledge integration mechanisms—challenges that the following section addresses through analysis of emerging innovations and adaptive management approaches.

3.4. Adaptive governance innovations and technological solutions: Bridging knowledge systems and institutional gaps

Despite institutional limitations identified in previous sections, emerging innovations in Ghana demonstrate the potential for transformative governance approaches. However, critical analysis reveals that many celebrated "adaptive" initiatives remain constrained by the same structural problems that limit conventional governance effectiveness.

3.4.1. Community-driven approaches: promise and limitations of knowledge integration

Community Resource Management Areas (CREMAs) are frequently cited as exemplars of adaptive governance that integrate traditional knowledge with scientific approaches (Foli et al., 2018). These initiatives incorporate practices like fire belt creation and taboo observance while co-managing natural resources alongside formal conservation strategies. However, critical examination reveals significant limitations in their application to soil health governance.

While CREMAs demonstrate institutional innovation, their soil

Table 3
A comprehensive mapping of key stakeholders (government agencies, NGOs, traditional authorities, farmer groups) involved in soil health governance, their specific roles, responsibilities, and interactions.

Stakeholder	Roles	Responsibilities	Interactions	Sources
Government Agencies	Formulating policies, enforcing regulations	Oversee soil health policies, provide funding for soil conservation, issue guidelines for sustainable practices	Collaborate with NGOs for project funding, interact with farmer groups for implementation feedback	(Egyir et al., 2017; Yeleliere et al., 2022)
NGOs	Capacity building, advocacy, project management	Provide training for sustainable practices, promote awareness, assist in research	Work with government for funding, partner with farmer groups for community engagement	(Aniah et al., 2019; Weston et al., 2015)
Traditional Authorities	Cultural authority, community organization	Oversee customary land usage rights, mediate conflicts related to land and resource use	Collaborate with farmer groups and NGOs, provide guidance on customary practices	(Anderson and Larbi, 2022)
Farmer Groups	Implement soil conservation techniques, advocate for farmer needs	Adopt sustainable practices, share resources, participate in training programs	Interact closely with NGOs and government, provide feedback on policies	(Abdul-Rahaman and Abdulai, 2018; Abdul Hanan, 2017)
Private Sector (Agro-dealers)	Supply soil health products (fertilizers, tools), promote sustainable agricultural products	Provide resources and technologies to farmers, offer credit options for inputs	Collaborate with NGOs and government to provide access to farmers, interact with farmer groups for product feedback	(Sones et al., 2015)
Research Institutions	Conduct soil health research, evaluate impacts of agricultural practices	Provide data on soil health status, recommend best practices, monitor environmental impacts	Work with government for policy insights, collaborate with NGOs for field implementation, engage with farmer groups	(MacCarthy et al., 2021)

Table 4
A comparative analyses of soil health policies, regulations, and institutional frameworks in Ghana versus other West African countries, highlighting strengths, weaknesses, and gaps in implementation.

Aspect	Ghana	Other West African Countries	Strengths	Weaknesses	Gaps	Sources
Regulatory Frameworks	Fertilizer Subsidy Program for soil health	Limited implementation in some countries	Well-defined regulatory intent to support soil health, and specific subsidies for fertilizers.	Lack of comprehensive policies addressing all facets of soil health, such as organic content or erosion control.	No robust, enforceable framework for soil health standards across the region.	(Egyir et al., 2017)
Implementation and Compliance	Inconsistent	Limited across countries	Ghana's structured subsidy programs demonstrate commitment to implementation	Limited enforcement of standards across borders, reliance on external funding, political will varies.	Monitoring frameworks and capacity for enforcement are weak regionally.	(Egyir et al., 2017)
Policy Gaps and Needs	Focus on economic support rather than ecosystem health	Limited policies in soil health	Policy attention given to addressing food security through soil fertility improvement, seen in fertilizer subsidy policy.	Policies often lack environmental considerations, and there is minimal emphasis on long-term soil sustainability.	Need for integration of soil health policies into broader environmental and agricultural frameworks; coordination with WAHO or ECOWAS is limited.	(Aidam and Sombié, 2016; Egyir et al., 2017)
Regional Collaboration and Governance	Limited but expanding through WAHO	Some nations collaborate with WAHO	Regional organizations like WAHO aim to facilitate collaborative health frameworks that could extend to soil health.	Uneven collaboration due to varying national capacities, lack of standardized protocols across the region.	Weak frameworks for collaboration on soil health, despite environmental links to health (e.g., food security).	(Aidam and Sombié, 2016; Ojomo, 2017)

health impacts remain poorly documented and unevenly distributed. The initiatives often focus on forest conservation rather than agricultural soil management, limiting their relevance to the 60 % of Ghana's population dependent on agriculture. Moreover, CREMA governance structures frequently reproduce existing power asymmetries, with traditional authorities and educated elites dominating decision-making while marginalized farmers remain passive participants (Nastar et al., 2018). Indigenous soil classification systems offer more substantive examples of knowledge integration. In Northern Ghana, farmers' soil classification systems align closely with scientific taxonomies while incorporating dynamic indicators of soil health that respond to seasonal variations (Mikkelsen and Langohr, 2004). These systems demonstrate sophisticated understanding of soil-climate interactions that formal governance structures fail to utilize effectively. However, the romanticization of traditional knowledge often obscures its limitations and the need for integration with scientific monitoring approaches.

3.4.2. *Technological innovations: promise versus Implementation reality*

Table 5 evaluates emerging technologies for soil health governance, revealing significant gaps between technological potential and practical implementation in resource-constrained settings.

Digital innovations theoretically offer pathways to democratize data access and enhance participatory decision-making. Remote sensing technologies using open-source platforms like SNAP Toolbox enable cost-effective monitoring of soil conditions and land use changes (Kpienbaareh et al., 2019). Mobile applications further promise to democratize soil health monitoring by enabling real-time data collection on parameters like soil moisture and pH (Ngongo et al., 2019). However, technology adoption faces structural barriers that governance reforms inadequately address. Rural areas experience limited connectivity and technical capacity, while the high upfront costs of advanced monitoring systems restrict access to well-resourced institutions. More fundamentally, technological solutions often bypass rather than strengthen local institutional capacity, creating dependency relationships that undermine long-term sustainability.

The promotion of Integrated Soil Fertility Management (ISFM) technologies exemplifies these challenges. While ISFM demonstrates significant productivity improvements, adoption remains low due to high initial costs and limited access to credit (Adolwa et al., 2019; Kwadzo and Quayson, 2021). Small-scale irrigation technologies show promise for enhancing soil health and food security, but their high upfront costs and financing constraints limit adoption to better-resourced farmers (Balana et al., 2020). This technological bias toward resource-rich adopters may exacerbate rather than reduce inequalities in soil health outcomes.

3.4.3. *Proposed adaptive governance framework: innovation or Institutional wishful thinking*

Fig. 3 synthesizes insights from successful interventions into a proposed adaptive governance framework for climate-resilient soil management. While conceptually appealing, critical analysis reveals potential implementation challenges that must be addressed. The

Table 5
An evaluation of current and emerging technologies for soil health monitoring in Ghana, including costs, accessibility, effectiveness, and adoption rates.

Technology	Cost	Accessibility	Effectiveness	Adoption Rates	Sources
Soil and Water Conservation Practices (SWCP)	Moderate	Moderate, limited by market access	Increases yield, reduces soil erosion	Variable; impacted by access to credit, education	(Darkwah et al., 2019)
Integrated Soil Fertility Management (ISFM)	High initial cost	Limited due to resource constraints	Improves productivity significantly	Low adoption due to costs and access barriers	(Adolwa et al., 2019; Kwadzo and Quayson, 2021)
Mobile Soil Health Apps	Low to moderate	High in urban areas, low in rural	Useful for data collection, real-time feedback	Growing in urban areas, low in rural	(Ngongo et al., 2019)
Small-Scale Irrigation Technologies	High upfront cost	Limited, especially for solar-powered options	Effective for yield increase, food security impact	Low; constrained by financing availability	(Balana et al., 2020)
Zai Pits	Low	Highly accessible for smallholders	Enhances soil fertility, water retention	Moderate in drier regions	(Danso-Abbeam et al., 2019)
Digital Soil Health Mapping	High	Limited; requires technical resources	Provides comprehensive soil quality data	Low, mainly used in research settings	(Hollingworth et al., 2020)

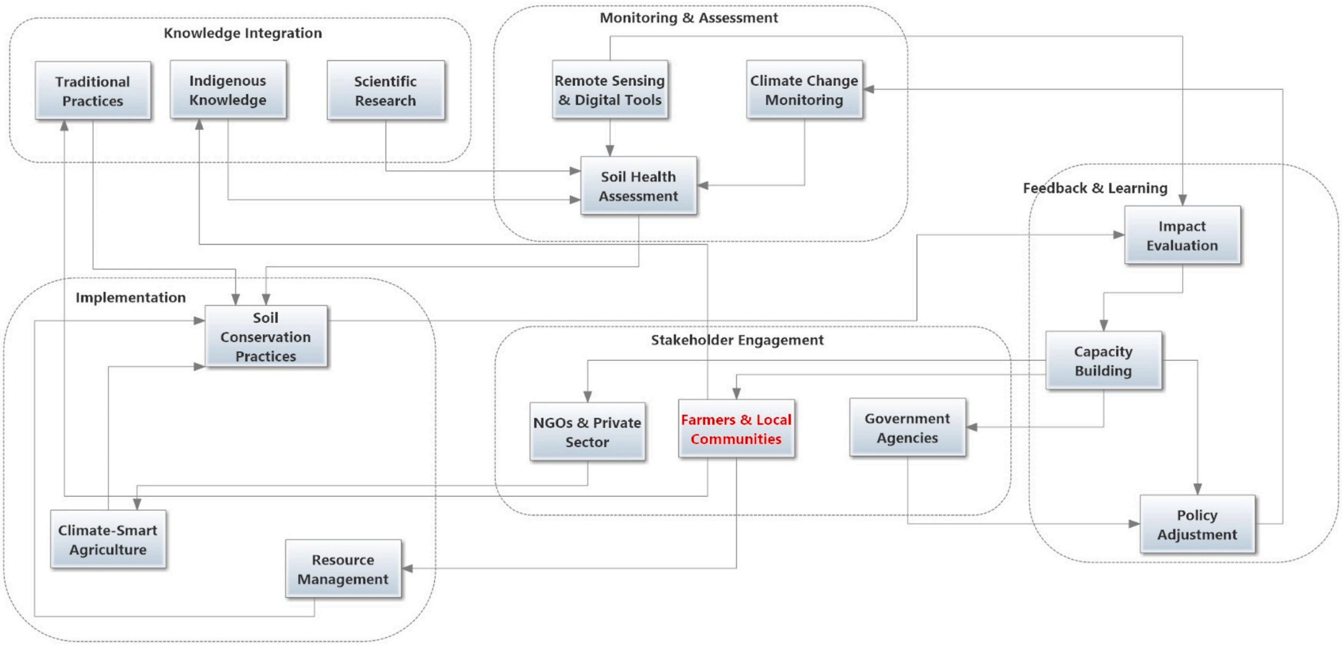

Fig. 3. A proposed adaptive governance framework for climate-resilient soil management.

framework positions farmers as primary governors of soil conservation, acknowledging their daily management decisions as the foundation of soil health outcomes. It incorporates feedback mechanisms, learning processes, and stakeholder engagement pathways designed to ensure effective governance under climate change uncertainty. Critical elements include: (1) Knowledge Integration Hub synthesizing traditional practices, scientific research, and real-time monitoring data; (2) Multi-stakeholder Platforms facilitating genuine participation across power gradients; (3) Adaptive Policy Mechanisms enabling rapid adjustments based on emerging evidence; (4) Capacity Building Networks strengthening technical and institutional capabilities; and (5) Feedback and Learning Systems institutionalizing processes for scaling innovations (Guodaar et al., 2021).

However, the framework risks replicating the participatory rhetoric that has characterized failed governance reforms in Ghana and across sub-Saharan Africa. Multi-stakeholder platforms often become venues for elite capture rather than genuine participation, particularly when they lack mechanisms for addressing structural power imbalances (Arko, 2019). Knowledge integration hubs require substantial institutional capacity and sustained funding that Ghana's resource-constrained context may not support. The emphasis on adaptive policy mechanisms assumes institutional flexibility that Ghana's bureaucratic structures currently lack. Policy adjustment requires administrative capacity, political will, and coordination mechanisms that remain underdeveloped. The framework's success depends on addressing fundamental institutional weaknesses—including policy fragmentation, resource constraints, and weak enforcement capacity—that previous governance reforms have failed to resolve (Mensah et al., 2023).

3.4.4. Financing and sustainability challenges

Financial constraints represent perhaps the most binding limitation to adaptive governance implementation. Current soil health initiatives rely heavily on external funding, compromising program sustainability and local ownership (FAO, 2023). The frameworks proposed innovations require substantial upfront investments in institutional capacity, monitoring systems, and stakeholder engagement processes that exceed current government budgets. International development experience suggests that externally funded adaptive governance initiatives often collapse when donor support ends, leaving behind institutional dependencies rather than enhanced local capacity. Ghana's limited fiscal space and competing development priorities make sustained investment in soil health governance unlikely without innovative financing mechanisms that align soil conservation with immediate economic returns.

3.4.5. Research and implementation gaps

Despite technological advances, critical knowledge gaps persist that limit evidence-based governance. Long-term, spatially explicit data on soil health trajectories under different climate scenarios remains scarce, impeding adaptive management (Abdulai et al., 2020). Institutional research on governance effectiveness remains limited, with most studies focusing on technical interventions rather than institutional arrangements and their outcomes. The evidence suggests that successful adaptive governance must begin with incremental institutional improvements rather than comprehensive system transformation. This includes strengthening coordination mechanisms between existing agencies, improving data collection and sharing systems, and piloting participatory approaches in contexts where they can demonstrate concrete benefits. Only through addressing fundamental institutional weaknesses can Ghana build the foundation for more ambitious adaptive governance innovations.

3.5. Critical gaps and future directions: Systemic limitations and research priorities

Despite advances in understanding climate-soil-governance interactions demonstrated in the preceding analysis, significant knowledge and implementation gaps persist that fundamentally constrain Ghana's capacity to achieve climate-resilient soil management. These gaps span technical, institutional, and financial dimensions, requiring coordinated interventions across multiple scales and sectors.

3.5.1. Data and monitoring infrastructure deficits

Long-term, spatially explicit data on soil health trajectories under different climate scenarios remains critically scarce, representing perhaps the most binding constraint on evidence-based governance (Abdulai et al., 2020). This data deficit impedes adaptive management by preventing early detection of degradation trends and limiting evaluation of intervention effectiveness. Current monitoring systems lack standardization across agro-ecological zones, with the CSIR-Soil Research Institute conducting limited surveys that inadequately capture spatial and temporal variations in soil health parameters (Owusu et al., 2020). The absence of integrated data systems compounds these limitations. Agricultural, meteorological, and soil health data remain fragmented across different agencies, preventing holistic analysis of climate-soil-governance interactions (Whittard et al., 2022). Ghana's limited engagement with emerging technologies like remote sensing and digital soil mapping constrains real-time monitoring capacity, particularly in remote areas where soil degradation risks are highest (Hollingworth et al., 2020; Kpienbaareh et al., 2019).

International experiences demonstrate that robust monitoring infrastructure requires sustained investment over decades, not short-term project funding. Ethiopia's Supporting Soil Health Interventions project illustrates how data governance frameworks can enable evidence-based decision-making, but implementation requires institutional capacity that Ghana currently lacks (Whittard et al., 2022). The European Union's investment in soil monitoring through the EJP SOIL initiative demonstrates the resources required for effective data systems—resources that exceed Ghana's current capacity without substantial external support (Keesstra et al., 2024).

3.5.2. Institutional coordination and governance architecture failures

Weak coordination mechanisms between agencies result in duplicated efforts, missed synergies, and conflicting policy signals that undermine soil health governance effectiveness (Ahmed et al., 2022). The Ministry of Food and Agriculture, Environmental Protection Agency, and CSIR-Soil Research Institute operate with limited coordination despite overlapping mandates for soil health management (Asante et al., 2021). This institutional fragmentation reflects broader governance challenges in Ghana's public sector, where sectoral approaches predominate over integrated environmental management. The absence of dedicated soil health legislation creates regulatory ambiguity that allows unsustainable practices to persist despite existing environmental regulations (Mensah et al., 2023). Current agricultural policies embed soil health considerations within broader productivity goals, diluting focus and accountability for soil conservation outcomes (FAO, 2023). Limited enforcement capacity further allows unsustainable practices to continue, with insufficient oversight of fertilizer use, land conversion, and soil conservation compliance (Mensah et al., 2023).

3.5.3. Power dynamics and stakeholder marginalization

Despite rhetoric about participatory governance, power imbalances continue to marginalize key stakeholders, particularly smallholder farmers who manage the majority of Ghana's agricultural land (Arko, 2019). Farmer groups have limited influence on policy formulation and resource allocation decisions, despite their critical role in implementing soil conservation practices (Abdul-Rahaman and Abdulai, 2018). Traditional authorities possess important knowledge about local soil management practices and land governance systems, but formal institutions inadequately incorporate this knowledge into policy processes (Anderson and Larbi, 2022).

Women farmers face particular marginalization in soil health governance, despite their significant roles in soil management and agricultural production. Gender-differentiated impacts of soil degradation remain poorly understood, with limited research on how governance systems can address women's specific knowledge and needs (Antwi-Agyei and Nyantakyi-Frimpong, 2021). Youth engagement in soil health governance also remains limited, despite young people's potential roles in technology adoption and long-term land stewardship.

3.5.4. Financial resource constraints and sustainability challenges

Insufficient government funding for soil health initiatives necessitates heavy reliance on external support, compromising program sustainability and local ownership (FAO, 2023). The Fertilizer Subsidy Programme illustrates these challenges, with periodic funding shortages limiting consistent access for smallholder farmers who most need support (Egyir et al., 2017). Resource scarcity particularly affects monitoring and evaluation systems, creating information feedback loops where limited data justifies continued underinvestment in soil health governance. International development experience reveals that externally funded soil health programs often collapse when donor support ends, leaving behind institutional dependencies rather than enhanced local capacity. Ghana's limited fiscal space and competing development priorities make sustained investment in soil health governance unlikely without innovative financing mechanisms that demonstrate immediate economic returns (Diao and Sarpong, 2011).

Climate finance represents an underutilized opportunity for supporting soil health governance, but accessing these resources requires institutional capacity for project development and implementation that Ghana currently lacks. The "4 per 1000" Initiative demonstrates how soil carbon sequestration can align with climate mitigation goals, potentially unlocking international funding for soil conservation (Keesstra et al., 2024). However, Ghana's limited engagement with carbon markets reflects broader governance limitations in accessing and managing climate finance mechanisms.

3.5.5. Knowledge integration and science-policy interface weaknesses

Despite rich traditional knowledge about soil management practices, formal governance systems inadequately incorporate this knowledge into policy development and implementation (Mikkelsen and Langohr, 2004; Omari et al., 2018). The disconnect between research institutions and policy-making bodies limits evidence-based governance, with soil health research inadequately informing agricultural and environmental policies (MacCarthy et al., 2021). Extension services lack capacity for translating research findings into practical guidance for farmers, creating knowledge gaps that constrain adoption of improved soil management practices (Adolwa et al., 2019).

University-based research on soil health remains disconnected from policy processes, with limited mechanisms for knowledge translation and uptake by government agencies (Chemura et al., 2020). International research collaborations focus predominantly on technical aspects of soil health rather than governance innovations, missing opportunities for institutional learning and capacity building.

3.5.6. Spatial and temporal scale mismatches

Current governance systems inadequately address the spatial heterogeneity of climate impacts and soil health challenges across Ghana's diverse agro-ecological zones (Asante and Amuakwa-Mensah, 2015; Larbi et al., 2021). Uniform policy approaches fail to account for the distinct challenges facing Northern regions (moisture stress and desiccation) versus Coastal areas (salinity and erosion) versus Forest zones (organic matter loss and acidification) (Ankrah et al., 2023; Quaye et al., 2021; Sekyi-Annan et al., 2021). Temporal mismatches between political cycles and soil health timescales create additional governance challenges. Soil degradation and restoration operate over decades, while political incentives focus on short-term visible outcomes (Lal, 2020). This temporal disconnect constrains long-term investment in soil health and favours interventions with immediate political payoffs rather than sustainable soil management.

3.5.7. Future research priorities and methodological innovations

Longitudinal studies tracking changes in soil properties, carbon sequestration potential, and microbial health under different climate scenarios are urgently needed to inform evidence-based policy decisions (Abdulai et al., 2020; Chemura et al., 2020). These studies should employ standardized methodologies across agro-ecological zones to enable comparative analysis and scaling of successful interventions. Research on governance effectiveness remains particularly limited, with most studies focusing on technical interventions rather than institutional arrangements and their outcomes (Ahmed et al., 2022).

Technology applications require research on appropriate designs for resource-constrained settings, moving beyond high-tech solutions toward innovations that strengthen rather than bypass local institutional capacity (Kpienbaareh et al., 2019; Ngongo et al., 2019). Digital soil mapping and remote sensing applications need adaptation to Ghana's institutional context, with research on how these tools can support rather than replace local knowledge systems (Hollingworth et al., 2020).

3.5.8. Pathways forward: realistic institutional development

Evidence suggests that successful governance reform must begin with incremental institutional improvements rather than comprehensive system transformation. Priority interventions include strengthening coordination mechanisms between existing agencies, improving data collection and sharing systems, and piloting participatory approaches in contexts where they can demonstrate concrete benefits (Guodaar et al., 2021). Only through addressing fundamental institutional weaknesses can Ghana build the foundation for more ambitious adaptive governance innovations. Moving forward requires acknowledging that soil health governance operates within broader systems of political economy, resource allocation, and institutional capacity that constrain what is possible in the short term while working toward longer-term transformational change (Manevska-Tasevska et al., 2021). The following conclusion synthesizes these insights into actionable recommendations that balance aspirational goals with institutional realities.

4. Conclusions

4.1. Summary of key findings

This review reveals the complex, interconnected nature of climate-soil-governance interactions in Ghana, demonstrating that effective soil health management under climate change requires fundamental transformation of existing governance approaches. The analysis of 89 studies across Ghana's diverse agro-ecological zones provides compelling evidence that climate variability significantly impacts soil health through multiple pathways, while current governance systems remain inadequately equipped to address these challenges. The review establishes that increasing temperatures and erratic rainfall patterns create reinforcing feedback mechanisms where climate impacts accelerate soil degradation, which in turn reduces soil resilience to future climate stresses (Abbam et al., 2018; Atiah et al., 2022; Issahaku et al., 2016). Evidence demonstrates that temperature increases of 1–1.5°C combined with altered precipitation patterns drive soil organic carbon losses from 51.80 Mg/ha in dense forests to just 7.00 Mg/ha in converted agricultural lands (Amissah et al., 2023). These impacts vary spatially from moisture stress and desiccation in Northern regions to erosion and nutrient leaching in coastal areas requiring differentiated governance responses those current institutional arrangements cannot provide. Analysis reveals that Ghana's soil health governance suffers from fundamental structural weaknesses that constrain adaptive capacity. Policy fragmentation across agencies (MoFA, EPA, CSIR-SRI) dilutes accountability and creates implementation gaps, while power asymmetries marginalize key stakeholders, particularly smallholder farmers who manage the majority of agricultural land (Arko, 2019; Asante et al., 2021). The Fertilizer Subsidy Programme exemplifies these limitations while aimed at soil fertility improvement, periodic funding shortages and logistical challenges limit effectiveness, while inadequate integration with soil conservation education risks promoting unsustainable practices (Egyir et al., 2017; FAO, 2023).

Despite rich traditional knowledge about soil management, formal governance systems inadequately incorporate this knowledge into policy development and implementation (Mikkelsen and Langohr, 2004; Omari et al., 2018). The disconnect between research institutions and policy-making bodies limits evidence-based governance, while extension services lack capacity for translating research findings into practical guidance for farmers (Adolwa et al., 2019; MacCarthy et al., 2021).

4.2. Research priorities and future directions

The write-up identifies critical needs for longitudinal studies tracking soil health trajectories under different climate scenarios and governance interventions. Priority research should employ standardized methodologies across agro-ecological zones to enable comparative analysis and scaling of successful approaches (Abdulai et al., 2020; Chemura et al., 2020). Research must also examine governance effectiveness rather than focusing exclusively on technical interventions. Future research should investigate how emerging technologies can strengthen rather than bypass local institutional capacity. This includes examining appropriate designs for remote sensing and digital soil mapping applications in resource-constrained settings, while evaluating how technological innovations can support participatory governance processes (Hollingworth et al., 2020; Ngongo et al., 2019).

Expanding comparative analysis beyond the limited cases examined in this review could provide insights for policy transfer and institutional learning. Priority comparisons should examine governance approaches across West African countries facing similar climate-soil challenges, while investigating how different institutional arrangements affect soil health outcomes (Whittard et al., 2022). Research on power dynamics in soil health governance remains limited, particularly regarding gender-differentiated impacts and youth engagement. Future studies should examine how governance systems can address women's specific knowledge and needs in soil management, while investigating mechanisms for meaningful youth participation in long-term land stewardship (Antwi-Agyei and Nyantakyi-Frimpong, 2021).

4.3. Broader implications and global relevance

This critique finding contributes directly to international efforts under the UN Sustainable Development Goals, particularly SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land). The adaptive governance framework provides insights for implementing the FAO's Global Soil Partnership and the UN Convention to Combat Desertification, while demonstrating how local governance innovations can contribute to global soil health objectives. Ghana's experience offers lessons for climate adaptation governance in other developing countries facing similar institutional constraints and resource limitations. The review demonstrates that effective adaptation requires addressing governance system limitations rather than focusing exclusively on technical interventions. This insight applies broadly across developing countries where institutional capacity constraints limit adaptive governance effectiveness. The analysis reveals that successful governance innovations often emerge at local scales but face challenges in scaling to national levels. The Community Resource Management Areas model demonstrates both the potential and limitations of local governance innovations, providing insights for scaling participatory approaches while addressing power asymmetries that constrain effectiveness (Foli et al., 2018).

4.4. Concluding remarks

Strengthening soil health governance is an urgent priority for Ghana's sustainable future, as climate change poses significant threats to agricultural productivity, food security, and rural livelihoods. This review contributes to the broader discourse on climate change and sustainable land management by highlighting the complex interactions between climate variability, soil degradation, and governance challenges in Ghana. By addressing the identified research gaps, implementing the recommended policy actions, and fostering multi-stakeholder collaboration, Ghana can enhance its resilience to climate change impacts on soil health and pave the way for a more sustainable and prosperous future.

Ethical approval and consent to participate

This review paper was designed and written in the National Nuclear Research Institute, Ghana Atomic Energy Commission, Legon-Accra All the images in this research were originally designed by the authors.

Authors' contributions

EAA conceived of the study and carried out the design of the review work. EAA and DA-W carried out the investigation and drafting of the manuscript. EAA, DA-W, AB-K, RW, ZN, CKK, IKK and CKB helped edit the manuscript. The author(s) read and approved the final manuscript.

CRediT authorship contribution statement

Zainab Ngaini: Writing – review & editing, Validation, Investigation. **Rafeah Wahi:** Writing – review & editing, Resources, Investigation. **Ibrahim Kwame Kwarteng:** Writing – review & editing, Supervision, Investigation. **Charles Kofi Klutse:** Writing – review & editing, Supervision, Methodology. **Archibold Buah-Kwofie:** Writing – review & editing, Project administration, Methodology. **Dickson Abdul-Wahab:** Writing – review & editing, Writing – original draft, Validation, Software, Data curation. **Ebenezer Aquisman Asare:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Data curation, Conceptualization. **Crentsil Kofi Bempah:** Writing – review & editing, Visualization, Project administration.

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Data availability

Data will be made available on request.

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