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Harnessing digital technologies for food security in developing countries: A focus on conflict-affected regions (literature review)

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Abstract. Food insecurity has become an increasingly urgent global challenge, particularly in conflict-affected developing countries where armed violence, climate-related shocks, institutional fragility, and market disruptions undermine the resilience of food systems and threaten sustainable development. The aim of this study was to examine how digital technologies can contribute to strengthening food security governance in conflict-affected regions, with particular emphasis on Sub-Saharan Africa, and to develop an integrated framework supporting monitoring and decision-making processes. The research adopted a qualitative approach based on an integrative literature review, comparative case analysis, and conceptual framework development. The findings demonstrated that digital technologies can significantly enhance the monitoring and management of food security by improving information availability, supply chain transparency, risk assessment, and early warning capabilities. Mobile-based advisory systems facilitate communication with vulnerable populations and support agricultural decision-making. Remote sensing and GIS technologies enable the continuous observation of environmental and agricultural conditions, while blockchain-based solutions can improve transparency and accountability within food supply chains. Furthermore, predictive analytics and artificial intelligence offer new opportunities for anticipating food security risks and supporting evidence-based humanitarian interventions. Based on these findings, the study proposed an integrated digital food security monitoring framework that combines household-level monitoring, environmental observation, supply chain transparency, and predictive decision-support functions within a unified socio-technical system. An illustrative pilot implementation scenario was also presented to demonstrate the practical applicability of the proposed framework. The results may support policymakers, humanitarian organisations, development agencies, and food security practitioners in designing more effective, data-driven, and resilience-oriented monitoring systems for conflict-affected environments

Keywords: remote sensing; predictive analytics; humanitarian logistics; blockchain applications; resilience governance; early warning systems

Introduction

Food security has become one of the most pressing challenges of the twenty-first century. In many developing countries, particularly those affected by armed conflict, food systems are simultaneously exposed to violence,

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climate-related shocks, institutional fragility, market disruptions, and demographic pressures. These interconnected challenges weaken agricultural production, disrupt supply chains, and limit access to food. At the same time, rapid advances in digital technologies create new opportunities for monitoring risks, supporting decision-making, and strengthening food security governance. Understanding how these technologies can contribute to food security management in fragile environments has therefore become an increasingly important scientific and practical challenge.

Studies have increasingly examined the relationship between food security, humanitarian governance, and digital transformation. B. Faith *et al.* (2022) investigated the opportunities and risks associated with digital technologies in humanitarian operations. Their findings indicated that digital tools can improve accountability and information management, but may also create challenges related to privacy and data governance. The authors concluded that technological innovation requires appropriate institutional safeguards. FAO (2023) analysed global food security and nutrition trends and found that food insecurity remains particularly severe in conflict-affected and economically vulnerable regions. The report identified conflict, economic shocks, climate extremes, and structural vulnerabilities as major drivers of food insecurity and emphasised the need for integrated, data-driven approaches, strengthened food system resilience, and targeted investments to address both immediate needs and long-term challenges. The GNAFC (2023) examined the principal drivers of contemporary food crises. The analysis identified armed conflict as one of the most significant contributors to acute food insecurity and highlighted the importance of effective monitoring and early-warning systems. P.G. Juhász & C. Szeremley (2024) examined the role of local organisations in conflict-affected communities in the Democratic Republic of Congo. Their findings demonstrated that community participation and local ownership are essential factors in successful development and humanitarian interventions. From a technological perspective, P. Paillé *et al.* (2024) investigated the use of artificial intelligence, remote sensing, digital platforms, and advanced analytics in humanitarian contexts. The authors concluded that these technologies can significantly improve decision support but require interoperability and appropriate governance arrangements.

P. Devidal (2024) focused on the ethical implications of digital transformation in humanitarian operations. The study highlighted concerns regarding data ownership, surveillance, and accountability, concluding that technological innovation must be accompanied by strong ethical oversight. J. Besenyő & A.H. Sólyomfi (2024) analysed governance instability and security challenges in the Sahel region. Their findings demonstrated that prolonged conflict weakens institutional capacity and undermines food system resilience, emphasising the importance of improved coordination and information systems.

Although these studies provided valuable insights into digital technologies, humanitarian governance, and food security, important research gaps remain. Existing research has primarily focused on individual technologies or specific operational challenges. Comparatively limited attention has been devoted to integrated frameworks that combine technological, institutional, governance, and community-level dimensions within a unified food security monitoring architecture. Furthermore, relatively few studies have examined how such solutions can be operationalised in conflict-affected environments characterised by institutional fragility and limited resources. Therefore, the aim of this study was to examine the role of digital technologies in strengthening food security governance in conflict-affected developing countries and to develop an integrated Digital Food Security Monitoring Framework tailored to fragile environments.

The study addressed three interrelated research questions. The first question examined which digital technologies can be effectively applied in conflict-affected food systems. The second question explored the technological, institutional, governance-related, and ethical challenges influencing their implementation. The third question investigated how these technologies can be integrated into a coherent monitoring framework that supports food security governance, resilience-building, and evidence-based decision-making in conflict-affected regions.

To address these questions, the study adopted a qualitative research design based on an integrative literature review, comparative case analysis, and conceptual framework development, combining perspectives from food security research, humanitarian logistics, digital transformation, information systems, and development studies. The literature review was conducted between January and May 2025. The search combined keywords related to food security, digital technologies, conflict-affected regions, humanitarian logistics, remote sensing, blockchain, predictive analytics, artificial intelligence, and Sub-Saharan Africa, focusing primarily on publications from 2015 to 2025 while incorporating earlier foundational works where necessary. The retained publications were systematically examined through thematic analysis and organised into five overarching domains: mobile-based agricultural advisory systems, remote sensing and GIS-based monitoring, blockchain-enabled supply chain transparency, predictive analytics and artificial intelligence, and institutional governance and community participation. Building on this categorisation, the analysis further explored cross-cutting success factors and implementation constraints – including infrastructure availability, digital literacy, institutional capacity, data governance, and long-term sustainability – which together serve as the basis for the development of the proposed Digital Food Security Monitoring Framework.

Conceptual and regional prerequisites for food vulnerability in conflict conditions

Food security is increasingly understood as a complex socio-ecological system rather than solely an agricultural or economic issue. According to the widely accepted definition, food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food. This concept encompasses four interrelated dimensions: availability, access, utilisation, and stability (Serraj & Pingali, 2018).

Contemporary food systems are embedded within global production, trade, and logistics networks. Consequently, local disruptions may generate cascading effects across wider regional and international food systems. Geopolitical instability, market disruptions, climatic shocks, and armed conflicts can simultaneously affect agricultural production, food distribution, and household access to food. In developing countries, particularly in conflict-affected environments, these vulnerabilities often reinforce one another, creating systemic risks for food security (Kovács & Spens, 2007). Existing scholarship emphasises that food security should be analysed through a systems perspective integrating environmental, technological, institutional, and social dimensions. R. Serraj & P. Pingali (2018) argued that food security outcomes are increasingly shaped by interactions between ecological conditions, agricultural production systems, and governance mechanisms. Similarly, FAO (d23) highlighted that conflict, economic shocks, climate extremes, and structural vulnerabilities continue to undermine food system resilience across many regions, including Sub-Saharan Africa. Within this perspective, food security is not merely determined by food production levels but by the capacity of interconnected socio-ecological systems to absorb shocks and maintain essential functions.

Digital transformation has emerged as an increasingly important component of food security governance. Data-driven decision-making, remote monitoring, predictive modelling, and digital communication technologies create new opportunities for improving agricultural management, humanitarian response, and risk assessment. Remote sensing technologies, geographic information systems (GIS), artificial intelligence, and mobile-based information platforms enable the continuous observation of environmental and socio-economic conditions and support the development of early warning systems (Serraj & Pingali, 2018). At the same time, resilience has become a central concept in understanding food security in fragile environments. Resilience refers to the capacity of systems to adapt to external shocks while maintaining their core functions. In conflict-affected food systems, resilience depends not only on agricultural production but also on the quality of information flows, institutional coordination, and adaptive governance mechanisms (Kovács & Spens, 2007).

Several studies emphasised that technological innovation alone cannot ensure sustainable improvements in food security. FAO (2023) demonstrated that digital solutions are most effective when accompanied by investments in institutional and human capacities. Likewise, P.G. Juhász & C. Szeremley (2024), analysing conflict-affected communities in the Democratic Republic of Congo, conclude that local ownership and community participation are essential preconditions for successful development and humanitarian interventions. P. Paillé *et al*. (2024) similarly argued that digital technologies generate the greatest benefits when integrated into broader governance frameworks characterised by interoperability, institutional support, and stakeholder cooperation. The literature therefore suggests that digital technologies should not be regarded as stand-alone solutions. Their contribution to food security depends on their integration into institutionally supported and socially embedded systems capable of strengthening resilience and supporting evidence-based governance.

Sub-Saharan Africa remains one of the regions most exposed to food insecurity due to the combined effects of ecological vulnerability, demographic pressure, infrastructural limitations, and political instability. Existing assessments continue to identify the region as a global hotspot of hunger and food insecurity, with several conflict-affected countries experiencing particularly severe levels of food-system stress (von Grebmer *et al*., 2023). Population growth continues to increase demand for food, while agricultural productivity often remains constrained by environmental degradation, limited technological access, and insufficient investment in rural infrastructure (Serraj & Pingali, 2018).

The agricultural sector is dominated by smallholder farming systems that frequently operate under conditions of limited access to credit, agricultural inputs, market information, and irrigation infrastructure (FAO, 2023; von Grebmer *et al*., 2023). These structural constraints increase vulnerability to environmental stressors, including droughts, rainfall variability, soil degradation, and land-use change. Climate anomalies may significantly reduce agricultural productivity and intensify existing food security challenges, particularly in regions already affected by conflict. Infrastructure deficiencies further increase vulnerability. Damage to transportation networks, storage facilities, irrigation systems, and communication infrastructure can reduce market access, increase transaction costs, and limit the effectiveness of food distribution systems (Justino, 2012). Although mobile phone penetration has increased significantly throughout the region, substantial disparities in internet access and digital connectivity persist, particularly in rural and conflict-affected areas (von Grebmer *et al*., 2023). These ecological and infrastructural vulnerabilities create conditions in which relatively small environmental or political shocks may trigger disproportionately severe food security consequences. Consequently, effective monitoring systems must simultaneously address environmental dynamics, agricultural performance, and infrastructural constraints.

Armed conflicts affect food systems through multiple interconnected pathways, including disruptions to agricultural production, market fragmentation, population displacement, and reduced humanitarian access (Martin-Shields & Stojetz, 2019; Brück *et al*., 2019; GNAFC, 2023). Beyond conventional military violence, deliberate attacks targeting food production systems, storage facilities, transportation networks, or food supply chains may further intensify food insecurity and increase the need for robust monitoring and early-warning mechanisms (Juhaszné, 2024). Furthermore, conflicts often generate long-term environmental and economic consequences that undermine food system resilience.

Conflict conditions frequently restrict access to agricultural land, reduce labour availability, interrupt planting and harvesting activities, and damage critical infrastructure. In addition, insecurity may disrupt local and regional markets, increase food price volatility, and weaken supply chain reliability. Food price volatility may itself become a source of social instability, reinforcing existing conflict dynamics and further limiting household food access (Bellemare, 2015). Humanitarian assistance systems also face significant challenges related to coordination, information asymmetries, and logistical constraints (Faith *et al*., 2022; Sundarakani & Ghouse, 2024).

The literature further highlights the importance of digital infrastructure in conflict-affected environments. While mobile communication technologies create new opportunities for information sharing and monitoring, unstable connectivity and limited digital capacity remain significant barriers to implementation (Rajnai & Fregan, 2016). Consequently, digital interventions frequently require adaptive solutions such as offline-first architectures, SMS-based communication systems, and decentralised data management approaches. Overall, conflict-related food insecurity emerges from the interaction of environmental vulnerability, infrastructural fragility, governance constraints, and disrupted socio-economic systems. This complexity underscores the need for integrated monitoring approaches capable of capturing both ecological and human dimensions of food security and provides the rationale for examining the role of digital technologies in food security governance.

Digital technologies for monitoring and forecasting the state of agroecological and food systems

Mobile-based agricultural advisory systems reduce information asymmetries among smallholder farmers and support production-related decision-making in fragile environments. In conflict-affected regions, where physical extension services may be disrupted, SMS-, USSD-, and low-data mobile applications can provide farmers with information on weather conditions, market prices, pest risks, input use, and food security conditions. Their main advantage lies in their relatively low infrastructure requirements and their ability to reach dispersed rural populations. Such systems typically operate through three interconnected layers: data collection, data processing, and advisory output. The data collection layer may include farmer-reported information through SMS or USSD channels, while the processing layer connects these inputs with meteorological, market, and agronomic databases. The output layer then delivers simplified recommendations in text- or voice-based formats (Paillé *et al*., 2024). Machine learning models can further support yield forecasting, pest detection, and input optimisation, particularly when local calibration data are available (Jain *et al*., 2016; Wolfert *et al*., 2017; Kamilaris & Prenafeta-Boldú, 2018).

The reviewed literature agrees that mobile-based systems can improve access to agricultural information and strengthen community-level monitoring. FAO (2023) emphasised their value in reducing information gaps among smallholder farmers, while B. Faith *et al*. (2022) underlined the importance of participatory design and local ownership. However, these tools remain constrained by digital illiteracy, unstable network coverage, limited electricity access, and weak institutional support. Therefore, mobile advisory platforms are most effective when embedded within wider governance and capacity-building systems rather than introduced as isolated technological solutions.

Remote sensing and GIS-based monitoring systems are among the most relevant digital technologies for food security governance in conflict-affected regions. Their importance derives from the fact that they enable continuous observation of agricultural and environmental processes without requiring regular physical access to insecure areas. This makes them particularly suitable for monitoring vegetation stress, drought dynamics, land degradation, land-use change, soil moisture variability, and crop production risks in fragile environments. Beyond agricultural monitoring, satellite imagery combined with machine-learning techniques has also demonstrated significant potential for estimating socio-economic conditions and poverty levels in data-scarce environments, creating additional opportunities for food-security vulnerability assessment (Burke *et al*., 2016).

Satellite-derived vegetation indices, especially the Normalised Difference Vegetation Index (NDVI), remain central tools for assessing vegetation health and biomass dynamics. NDVI time series can reveal seasonal vegetation patterns and anomalies associated with drought, conflict-related abandonment of agricultural land, input shortages, or market disruption. In addition, GIS platforms allow the integration of remote sensing data with precipitation records, soil moisture indicators, conflict-event datasets such as ACLED, market price information, and population movement data (Raleigh *et al*., 2010). This creates a multivariate analytical framework for identifying spatial patterns of agroecological vulnerability.

Existing studies confirm the increasing value of remote sensing for environmental and agricultural monitoring in African contexts. N. Heiss *et al*. (2025) reviewed the potential of Earth observation for mapping small-scale agriculture and cropping systems in West Africa. Their study highlighted the usefulness of Sentinel-1 and Sentinel-2 data for identifying cropland patterns, crop types, and smallholder production systems. The authors concluded that Earth observation can significantly improve food security monitoring, but they also noted that fragmented field data, heterogeneous smallholder plots, and cloud contamination remain major methodological limitations.

A.W. Moomen *et al*. (2024) examined remote sensing applications for sustainable agriculture in the Northern

Savannah regions of Ghana. Their review showed that satellite-based indicators can support land-use monitoring, crop condition assessment, and detection of environmental degradation. The study emphasised that Sentinel-2-derived NDVI patterns are particularly useful for tracking vegetation changes in rainfed agricultural systems. However, the authors also stressed that remote sensing outputs need to be combined with local agronomic knowledge to avoid misinterpretation of spectral signals.

N. Mubonderi *et al.* (2025) focused specifically on optical remote sensing for monitoring soil erosion in Sub-Saharan grassland biomes. Their systematic review found that multispectral Landsat and Sentinel-2 data, combined with indices such as modified NDVI, Normalised Difference Soil Index, and tasseled cap transformation, are increasingly applied to estimate erosion risk and land degradation. The study is particularly relevant for food security because soil erosion directly reduces long-term agricultural productivity. Its limitation is that optical remote sensing may be less effective under persistent cloud cover or dense vegetation, and erosion processes often require complementary field validation. M.B. Moisa *et al.* (2025) analysed the impact of land-use and land-cover change on soil moisture variability in southwestern Ethiopia using GIS and remote sensing techniques. Their research demonstrated that agricultural expansion, vegetation loss, and land-cover transformation influence soil moisture availability, with direct implications for drought vulnerability and crop productivity. The study strengthens the argument that food security monitoring should not rely only on crop indicators but should also incorporate land-use dynamics and hydrological variables.

M. Mustapha & M. Zineddine (2024) developed an evaluative technique for analysing drought impacts on agricultural land-use and land-cover variation using remote sensing and machine learning. Their work shows that combining satellite data, soil information, NDVI, and machine learning methods can improve the identification of drought-affected agricultural areas. This approach is especially useful for early-warning systems, although its reliability depends on data quality, model calibration, and the availability of validation datasets. M.G. Alemu & F.A. Zimale (2025) integrated remote sensing and machine learning for agricultural drought early warning in the Genale Dawa river basin in Ethiopia. Their study tracked drought severity between 2003 and 2023 and demonstrated that combined geospatial and machine-learning approaches can strengthen early warning capacity. The value of this approach lies in its ability to transform environmental indicators into operational risk information. However, as with other predictive models, its practical use requires regular recalibration and institutional capacity for interpretation.

Comparing these studies reveals several common conclusions. First, remote sensing is most effective when used as a continuous monitoring tool rather than as a one-time assessment method. Second, vegetation indices such as NDVI are useful but insufficient on their own; stronger results emerge when NDVI is combined with soil moisture, precipitation, land-use, and socio-economic indicators. Third, Sentinel-based systems offer high spatial resolution and are particularly promising for smallholder agriculture, while MODIS-based systems remain useful for long-term regional drought monitoring. Fourth, remote sensing cannot fully replace local knowledge or field validation, especially in complex agroecological systems where spectral changes may result from multiple interacting causes.

From the perspective of conflict-affected food systems, the most promising approach is therefore an integrated GIS-based monitoring model that combines satellite-derived vegetation indices, land degradation indicators, soil moisture data, precipitation anomalies, conflict-event data, and market indicators. Such a model can identify not only where agricultural stress is occurring, but also whether it is primarily driven by climatic, environmental, infrastructural, or conflict-related factors. This distinction is essential for designing appropriate humanitarian and development interventions. Predictive analytics and artificial intelligence enable food security monitoring systems to move beyond descriptive assessment toward anticipatory decision support. In conflict-affected regions, where risks evolve rapidly and nonlinearly, predictive models can integrate meteorological data, vegetation indices, market prices, conflict events, and population movement patterns to estimate the probability of food shortages or humanitarian crises (Funk *et al.*, 2019).

Machine learning approaches, including random forests, gradient boosting models, and time-series neural networks, can identify nonlinear relationships between climate stress, agricultural productivity, market volatility, and conflict intensity. These models may support early warning, vulnerability mapping, and intervention prioritisation. However, their effectiveness depends heavily on data completeness, contextual calibration, and institutional capacity for interpretation.

The reviewed literature consistently emphasises that predictive analytics should complement rather than replace expert judgement. C. Funk *et al.* (2019) demonstrated the value of integrated predictive models for famine forecasting, while P. Paillé *et al.* (2024) highlighted the increasing role of AI-supported decision tools in humanitarian operations. At the same time, concerns remain regarding data gaps, algorithmic bias, explainability, and accountability. Existing advances in explainable artificial intelligence, including SHAP-based interpretation techniques, may improve the transparency of predictive food-security models and facilitate their adoption by humanitarian decision-makers (Lundberg & Lee, 2017). In conflict settings, where data may be incomplete, manipulated, or politically sensitive, predictive models must be transparent, regularly validated, and interpreted through local contextual knowledge.

Blockchain technology can contribute to food security governance by improving transparency, traceability, and accountability in food supply chains and humanitarian logistics. Similar blockchain-based architectures have recently been proposed for refugee management and humanitarian resource allocation, demonstrating their potential to improve transparency and accountability in fragile governance environments (Abraha, 2025). Its decentralised and immutable structure can reduce opportunities for data manipulation, fraud, and resource diversion, particularly in environments where institutional trust is weak (Sundarakani & Ghouse, 2024). In conflict-affected regions, permissioned blockchain systems are more appropriate than open public blockchain architectures because they allow controlled access, stakeholder-specific permissions, and more energy-efficient operation. Blockchain can be strengthened through geo-tagging, digital signatures, and IoT-based monitoring of storage or transport conditions. However, the technology does not solve the problem of unreliable source data. If incorrect or manipulated data are entered into the system, blockchain merely preserves inaccurate information.

The literature therefore suggests that blockchain should not be treated as a universal solution. B. Sundarakani & A. Ghouse (2024) emphasised its potential for improving transaction visibility and traceability, while B. Faith *et al.* (2022) cautioned that technological transparency cannot replace institutional accountability. Blockchain-based systems are most useful when combined with independent audits, community oversight, clear governance rules, and reliable data validation mechanisms. The reviewed technologies differ in their primary functions, strengths, and limitations. Mobile advisory systems are relatively accessible and useful for household-level communication but depend on mobile coverage and digital literacy. Remote sensing and GIS provide the strongest environmental monitoring capacity, especially in inaccessible areas, but require technical expertise and analytical infrastructure. Predictive analytics can strengthen early warning and resource allocation, but its reliability depends on data quality and model transparency. Blockchain can improve supply chain accountability, but only when supported by institutional oversight and valid source data, as summarised in Tables 1 and 2.

Table 1. Comparative assessment matrix of digital technologies for food security monitoring in conflict-affected regions

Technology	Primary function	Main advantages	Key limitations	Relevance for conflict-affected regions
Mobile-based advisory systems	Dissemination of agricultural, market, and weather information	Low implementation cost; direct communication with vulnerable populations; supports local participation	Dependence on mobile coverage, electricity access, and digital literacy	High
Remote sensing and GIS	Environmental and agricultural monitoring; detection of droughts, land degradation, and crop stress	Large spatial coverage; continuous monitoring; suitable for inaccessible and insecure areas	Requires technical expertise, satellite data processing capacity, and field validation	Very High
Predictive analytics and artificial intelligence	Risk forecasting and decision support	Early warning capability; identification of complex risk patterns; supports resource prioritisation	Dependence on data quality; model uncertainty; explainability challenges	High
Blockchain-based systems	Supply chain transparency and traceability	Improved accountability; tamper-resistant records; enhanced transparency	Governance requirements; interoperability issues; does not guarantee data accuracy at input stage	Medium

Source: compiled by authors

Table 2. Comparative assessment of digital technologies supporting food security monitoring

Technology	Main data sources	Spatial scale	Temporal scale	Typical outputs
Mobile-based advisory systems	Farmer reports, SMS surveys, local extension data, market information	Household and community level	Daily to weekly	Advisory messages, vulnerability profiles, market alerts
Remote sensing and GIS	Satellite imagery (Sentinel, Landsat, MODIS), weather data, soil moisture indicators	Local, regional, national	Near real-time to seasonal	Vegetation maps, drought indicators, land-use change analysis, risk maps
Predictive analytics and AI	Multi-source databases, conflict-event datasets, climate data, market data	Community to national level	Short- and medium-term forecasting	Early warning alerts, food security forecasts, intervention prioritisation

Table 2. Continued

Technology	Main data sources	Spatial scale	Temporal scale	Typical outputs
Blockchain-based systems	Supply chain records, logistics data, digital transactions, IoT sensors	Local to international supply chains	Continuous	Traceability records, audit trails, transparency dashboards

Source: compiled by authors

Overall, the literature indicates that no single technology can address the multidimensional nature of food insecurity in conflict-affected regions. The highest strategic value emerges when these tools are integrated into an interoperable digital ecosystem. In such a system, mobile platforms provide local data, remote sensing captures regional environmental dynamics, predictive analytics generates risk forecasts, and blockchain strengthens transparency in supply chains. This integrated approach provides the strongest basis for proactive, evidence-based food security governance.

Building on the comparative assessment of digital technologies, an integrated Digital Food Security Monitoring Framework is proposed. The framework combines household-level monitoring, environmental observation, supply-chain information, and contextual conflict-related data within a unified governance-oriented architecture. Figure 1 presents food security monitoring as a multi-layered socio-technical system operating under conditions of conflict, climatic uncertainty, market volatility, and population displacement.

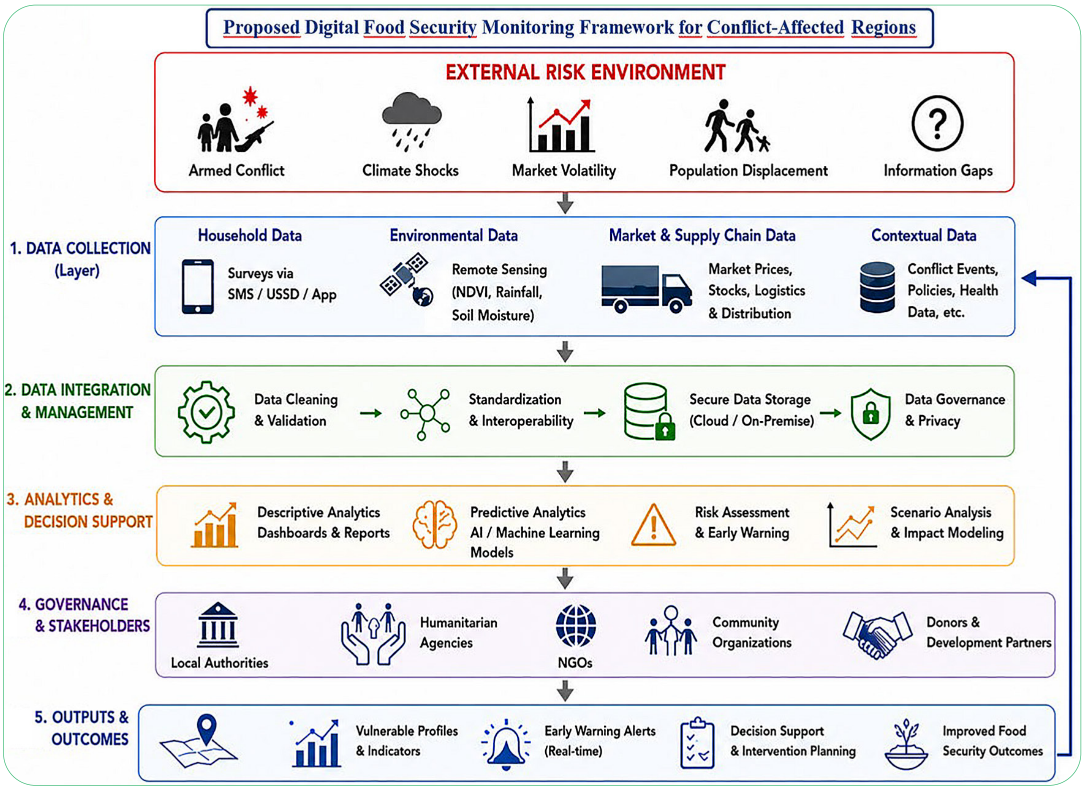

Figure 1. Proposed digital food security monitoring framework for conflict-affected regions
Source: compiled by authors

The framework consists of five interconnected layers. The first layer focuses on data collection from household, environmental, market, and contextual sources. The second layer ensures data integration, validation, storage, and governance. The third layer transforms raw information into decision-support outputs through descriptive and predictive analytics. The fourth layer highlights the role of institutional stakeholders, while the fifth layer translates analytical results into operational outputs such as vulnerability assessments, early-warning alerts, and intervention planning. While Figure 1 presents the conceptual logic of the proposed monitoring system, Figure 2 illustrates its operational data architecture. The architecture specifies how data flows from multiple sources through processing and analytical layers before reaching decision-makers and humanitarian actors. The architecture emphasises interoperability, continuous feedback, and adaptive learning. By integrating household surveys, Earth observation data, market information, and contextual conflict indicators, the system can generate near real-time assessments of food security conditions and support evidence-based interventions in fragile environments.

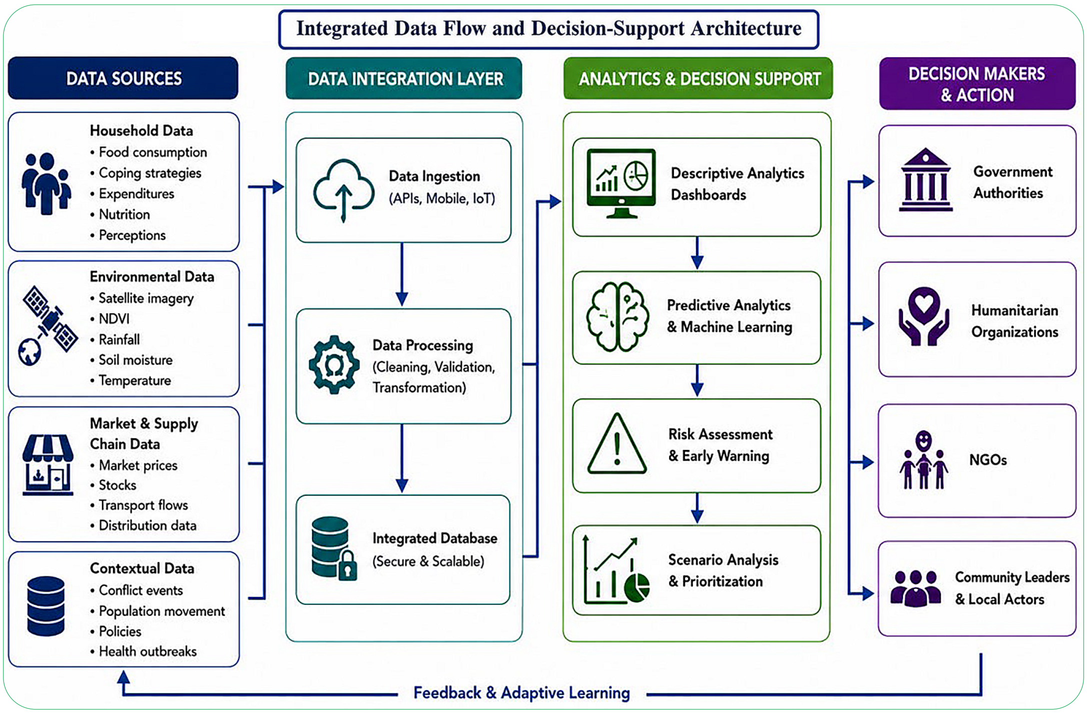

Figure 2. Integrated data flow and decision-support architecture

Source: compiled by authors

Table 3. Key risks and mitigation strategies for digital food security monitoring systems in conflict-affected regions

Risk Category	Example of Risk	Potential Consequences	Affected Technology Domains	Recommended Mitigation Measures
Technical Risks	Network outages, power interruptions, hardware failures	Data loss, delayed reporting, interrupted monitoring activities	Mobile systems, GIS platforms, AI systems, blockchain networks	Offline functionality, cloud backup, redundant communication channels, decentralised data storage
Data Quality Risks	Missing observations, inaccurate reporting, inconsistent datasets	Reduced reliability of forecasts, incorrect risk assessments, poor decision-making	Remote sensing, AI models, mobile reporting systems	Data validation procedures, triangulation of multiple data sources, periodic audits, field verification
Institutional Risks	Weak governance structures, insufficient technical expertise, fragmented responsibilities	Low sustainability, poor system adoption, ineffective coordination among stakeholders	All technology domains	Capacity-building programmes, stakeholder coordination mechanisms, institutional ownership, long-term funding strategies
Ethical Risks	Privacy violations, unauthorised access to personal information, surveillance concerns	Loss of trust, reduced participation, reputational and legal risks	Mobile systems, AI systems, blockchain databases	Data protection policies, encryption, informed consent procedures, ethical oversight mechanisms
Social Risks	Digital divide, exclusion of vulnerable populations, limited digital literacy	Unequal access to information and services, biased monitoring outcomes	Mobile systems, digital platforms, AI-supported tools	Community engagement, inclusive system design, multilingual interfaces, hybrid data collection methods
Security Risks	Cyberattacks, manipulation of datasets, conflict-related destruction of infrastructure	Operational disruption, compromised data integrity, reduced system reliability	GIS platforms, AI systems, blockchain networks	Cybersecurity protocols, access control systems, secure authentication, contingency planning
Operational Risks	Lack of interoperability between platforms and databases	Duplication of effort, information silos, delayed responses	All technology domains	Adoption of common data standards, interoperable architectures, integrated information management frameworks
Financial Risks	Insufficient long-term funding and maintenance resources	System degradation, project discontinuation, technology obsolescence	All technology domains	Multi-year financing mechanisms, public-private partnerships, phased implementation strategies

Source: compiled by authors

Ethical and privacy-related concerns represent a critical challenge for digital food security monitoring systems. Similar concerns have been identified in the application of big-data analytics within fragile and conflict-affected states, where weak governance structures may amplify risks related to data misuse and exclusion (Idris, 2019). Existing studies highlight risks associated with personal data processing, group privacy, algorithmic accountability, and the outsourcing of data governance responsibilities in humanitarian contexts (Masinde *et al.*, 2023; Diepeveen *et al.*, 2025; Kreutzer *et al.*, 2025). These challenges underline the importance of transparent governance arrangements, clear accountability mechanisms, and robust data protection measures when implementing digital monitoring systems in conflict-affected environments.

Illustrative pilot implementation scenario

To demonstrate the practical applicability of the proposed Digital Food Security Monitoring Framework, an illustrative pilot implementation scenario is presented. The scenario is not intended as empirical validation but as a conceptual operationalisation of the framework within a realistic conflict-affected environment. Nyangezi, located in South Kivu Province of the Democratic Republic of Congo (DRC), represents a suitable illustrative context due to its combination of chronic food insecurity, recurring security challenges, agricultural dependence, and infrastructural limitations. Similar conditions are observed in numerous conflict-affected regions across Sub-Saharan Africa, making the area an appropriate reference point for demonstrating the potential functionality of the proposed monitoring system.

The local economy is predominantly based on smallholder agriculture, while households remain highly vulnerable to market disruptions, population displacement, climatic shocks, and fluctuations in security conditions. These characteristics create a complex environment in which continuous food security monitoring could provide substantial decision-support value for both local stakeholders and humanitarian actors. The illustrative monitoring system would track a set of indicators representing all four dimensions of food security. The availability dimension would be assessed through indicators related to crop production conditions, vegetation health, and the availability of agricultural inputs. Food access would be monitored using measures such as market prices, the share of household expenditure devoted to food, and transportation accessibility. The utilisation dimension would be evaluated through indicators reflecting dietary diversity, meal frequency, and nutritional status. Stability would be assessed by monitoring conflict intensity, population displacement, climatic anomalies, and market volatility.

Based on the continuous collection and analysis of these indicators, the system would generate a range of operational outputs. These would include household vulnerability profiles, community-level food security dashboards, risk maps, early-warning alerts, and intervention prioritisation reports. Such outputs could support local authorities, humanitarian organisations, and development agencies in making evidence-based decisions and allocating resources more effectively under rapidly changing and uncertain conditions.

Conclusions

This study examined the potential of digital technologies to strengthen food security governance in conflict-affected developing countries, with particular emphasis on Sub-Saharan Africa. The review demonstrated that mobile-based advisory systems, remote sensing and GIS technologies, predictive analytics, artificial intelligence, and blockchain-based solutions can significantly enhance food security monitoring, risk assessment, and decision-making processes. The analysis further revealed that technological effectiveness depends not only on technical performance but also on institutional capacity, governance quality, stakeholder cooperation, and community participation. Consequently, integrated digital ecosystems offer greater potential for strengthening resilience and supporting evidence-based interventions than isolated technological solutions.

Based on the reviewed literature, the study proposed an integrated Digital Food Security Monitoring Framework that combines household-level monitoring, environmental observation, supply-chain information, and predictive decision-support functions within a unified socio-technical architecture. The framework may support governments, humanitarian organisations, and development agencies in designing more adaptive and data-driven food security monitoring systems for fragile environments. Future research should focus on the empirical validation of the proposed framework through pilot implementation projects in conflict-affected regions and on assessing the long-term effectiveness of integrated digital monitoring systems under real-world operational conditions.

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Використання цифрових технологій для продовольчої безпеки в країнах, що розвиваються: акцент на регіонах, які постраждали від конфлікту (огляд літератури)

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Анотація. Продовольча незабезпеченість стає дедалі гострішою глобальною проблемою, особливо в країнах, що розвиваються та потерпають від конфліктів, де збройне насильство, кліматичні потрясіння, інституційна нестабільність і порушення ринкових механізмів підривають стійкість продовольчих систем і загрожують сталому розвитку. Метою цієї статті було дослідити, як цифрові технології можуть сприяти зміцненню управління продовольчою безпекою в регіонах, уражених конфліктами, з особливим акцентом на країнах Африки на південь від Сахари, а також розроблення інтегрованої системи підтримки моніторингу та процесів прийняття рішень. У дослідженні застосовано якісний підхід, що базувався на інтегративному огляді літератури, порівняльному аналізі кейсів і розробленні концептуальної моделі. Результати дослідження засвідчили, що цифрові технології можуть суттєво підвищити ефективність моніторингу та управління продовольчою безпекою завдяки покращенню доступності інформації, прозорості ланцюгів постачання, оцінювання ризиків і можливостей систем раннього попередження. Мобільні консультаційні сервіси сприяють комунікації з уразливими групами населення та підтримують прийняття рішень у сільському господарстві. Технології дистанційного зондування Землі та геоінформаційні системи забезпечують безперервне спостереження за станом довкілля й аграрного сектору, тоді як рішення на основі блокчейну можуть підвищити прозорість і підзвітність у продовольчих ланцюгах постачання. Крім того, предиктивна аналітика та штучний інтелект відкривають нові можливості для прогнозування ризиків продовольчої безпеки та підтримки гуманітарних заходів, що ґрунтуються на доказових даних. На основі отриманих результатів запропоновано інтегровану цифрову систему моніторингу продовольчої безпеки, яка поєднує моніторинг на рівні домогосподарств, екологічне спостереження, забезпечення прозорості ланцюгів постачання та функції прогнозно-аналітичної підтримки прийняття рішень у межах єдиної соціотехнічної системи. Також представлено ілюстративний сценарій пілотного впровадження для демонстрації практичної придатності запропонованої моделі. Отримані результати можуть бути корисними для політиків, гуманітарних організацій, агенцій розвитку та фахівців у сфері продовольчої безпеки під час розроблення більш ефективних, орієнтованих на дані та стійкість систем моніторингу в умовах конфліктів

Ключові слова: дистанційне зондування Землі; предиктивна аналітика; гуманітарна логістика; застосування блокчейну; управління стійкістю; системи раннього попередження