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# Digital Frontlines: Innovation for Food and Water Resilience in Humanitarian Contexts

**Authors:**

Kazeem Oyedele Lamidi (53508777@mynwu.ac.za)
School of Government Studies, Faculty of Humanities, North West University, Vanderbijlpark, South Africa
ORCiD: 0000-0002-0434-8990

Paul Oluwamoroti Adebayo (adebayopaul20@gmail.com)
Department of Local Government and Development Studies, Faculty of Administration, Obafemi Awolowo University, Ile-Ife, Nigeria

Costa Hofisi (costa.hofisi@nwu.ac.za)
Department of Public Administration and Management, School of Government Studies, Faculty of Humanities, North West University, Vanderbijlpark, South Africa
ORCiD: 0000-0002-2571-6991

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**Abstract:**

Humanitarian crises, resulting from conflicts, climate change, displacement, and environmental shocks, continue to put food and water security at risk for millions of vulnerable populations globally. Digital technologies are increasingly being used at the "digital frontlines" of humanitarian work to enhance food and water resilience. This paper explores the contributions of developing digital innovations including mobile and SMS systems, remote sensing, Internet of Things (IoT) sensors, drones, blockchain, AI, digital cash transfers, and data dashboards, to humanitarian food and water activities. An integrative review approach is employed in synthesizing evidence from humanitarian contexts and analyzing eight case studies from across Africa, Asia and global disaster settings. The research reveals significant benefits to early warning, efficiency in service delivery, aid targeting, reduction in costs, transparency, and community engagement. Key results include decreased downtime in water infrastructure, enhanced prediction in food insecurity, effective cash-transfer operations, and better water quality control. Challenges remain to implementation due to infrastructural limitations, digital exclusion, data protection issues, interoperability, low local capacity, and insufficient longer-term funding. Operational and cost-efficiency gains appear to be substantiated but there is still a lack of evidence-based assessments of

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longer-term resilience outcomes. To achieve effective institutionalization of digital humanitarian innovation, the paper suggests strengthened governance structures, ethical guidelines, participatory design, long-term investment, and enhanced partnerships among governments, humanitarian organizations, private sector actors and local communities. In conclusion, digital innovations can play a significant role in reinforcing humanitarian resilience and achieving the SDGs on food security, water and climate adaptation.

**Keywords:**

Digital Technologies, Digital Humanitarian Innovation, Food Security Resilience, Humanitarian Crisis Response, Water Sanitation and Hygiene (WASH)

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## Introduction

Digital solutions are being deployed in the 'digital frontlines' of humanitarian crises to improve food security and water resilience. Across conflicts, displacements, disasters and protracted crises, from satellite analytics to mobile phones, information and communication tools are being leveraged in tandem with traditional relief, in an effort to close the gap between short-term response and longer-term development objectives Lidn (2026). ICRC points to how, with modern conflicts having 'information dimensions' the digital frontlines of a modern war can, through quick access to good information save lives. In food and WASH (water, sanitation and hygiene) remote sensing, IoT sensors, mobile cash and blockchain have all entered the sphere to allow for better early warning, increased efficiency in aid distribution and greater community participation in building resilience.

Over the past decade, a range of digital solutions have been adopted including: mobile/SMS based systems for data collection and cash transfers; remote sensing (satellites) for crop, drought and flood monitoring; IoT sensors (smart pumps, water quality monitors); drones/UAVs for mapping and delivery; blockchain technology (coordinating agency cash and vouchers); AI/ML (predicting food needs, optimizing water treatment); digital finance (mobile money, e-vouchers); and data dashboards (real-time food security monitoring) (Crabtree & Obadi, 2024). For example, AI is used by the WFP HungerMap Live, which utilizes climate, market and conflict data to predict future food insecurity in 16 food insecure "hotspot" countries (Pizzi, Romanoff & Engelhardt, 2021; GSMA, 2023). The WFP's "Building Blocks" blockchain platform has successfully managed more than $555 million in transfers to over 1 million Syrian and Bangladeshi refugees and in doing so saved $3.5 million in transaction fees (IWMI, 2024). Novel solutions have also been piloted in the humanitarian sector; Geophysical+Satellite surveys in Madagascar employed earth observation and oil industry geophysics to find deep aquifers in a drought-affected region (Abay, Abdelfattah, Abushama, Kirui, Nigus & Siddig, 2026; Beduschi, 2022).

Digital frontlines is defined as the use of information and communication technologies at the point of crisis – such as satellite-based monitoring, sensor networks or digital markets in camps – in order to provide or improve services. This paper focusses on food and water systems in humanitarian settings. Food security is defined as people's ability at all times to have physical and economic access to sufficient, safe and nutritious food (Abay, 2026). It consists of four dimensions; availability, access, utilization and stability, all of which need to be ensured (Kreutzer, 2024; Krishnan, 2022). This can be undermined rapidly in crisis situations, for example through lack of food aid or market shocks.

WASH stands for Water, Sanitation and Hygiene and covers providing access to adequate quantities of safe drinking water and the safe disposal of human excreta and waste water, coupled with adequate hygiene facilities and practices (Beduschi, 2022). These facilities are critical in humanitarian contexts and must be quickly provided or restored to save lives, particularly during natural disasters and conflicts

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where water and sanitation systems may be destroyed or damaged (Kruger, 2026; Lid, 2026; Mercy, 2023). Resilience is defined as "the capacity for individuals, communities and nations to anticipate, prevent and recover from shocks and stresses, both gradual and sudden" (Busker, 2023). Resilience spans from disaster prevention and preparedness through adaptation and recovery to transformation, with the ultimate goal of systems becoming stronger and less vulnerable to future crises (Busker, 2023; Pizzi, 2021). The humanitarian-development-peace "nexus" framework frames interventions to build resilience, thereby helping to break recurring crisis cycles (Busker, 2023; Pizzi, 2021). A Humanitarian context is defined as a situation where emergency assistance needs to be provided "to save lives, alleviate suffering, and protect human dignity" (Song, 2023).

These definitions cover natural disasters, protracted and sudden displacement and conflict situations. Food and water issues may worsen acutely in such environments due to their higher risk profile and will often disproportionately affect vulnerable populations like children and women (Sphere, 2018). The 'digital frontlines' concept involves the implementation of digital technologies at crisis locations-such as in camps, in remote villages or within areas of displacement-with the aim of enhancing resilience and service delivery. There are several compounding factors driving the urgent need for digital solutions. Climate change is intensifying extreme events such as droughts and floods that impact food and water availability. Rapid urbanization has led to an increase in vulnerable people residing in camps or informal settlements that are underserved by basic services. Conflict and displacement in many areas continue to exacerbate food insecurity, particularly in some of the most severely affected regions globally (Crabtree & Obadi, 2024). Global supply-chain disruptions stemming from events like the pandemic and conflict in various regions have exposed the fragility of food markets, while the COVID-19 pandemic highlighted the necessity for remote delivery of assistance. The number of people experiencing extreme food insecurity is increasing dramatically: the WFP estimates that catastrophic food crisis (IPC5) has risen from ~85,000 in 2019 to 1.4 million by 2025 (FOA, 2023).

Similarly, water stress is worsening worldwide; however, tools and data that could inform water resource management often fail to reach those who need it most in unstable settings (IWMI, 2024). These challenges relate to multiple SDGs, such as SDG 2 (Zero Hunger), SDG 6 (Clean Water) and SDG 13 (Climate Action), making digitally driven resilience efforts a key policy priority. The spectrum of intervention ranges from emergency relief to long-term planning, with a focus on technologies that could forecast, anticipate and address shocks while ensuring inclusive, context-sensitive interventions (Krishnan, 2022; Kruger & Schutte, 2026).

With secondary method of information source, this paper provides an overview of the key definitions, technology solutions and eight case studies of the application of digital tools to strengthen food and water resilience in various crisis contexts and regions. Deployment challenges (e.g. Issues of power, connectivity, data privacy and protection, costs, local capacity and inclusion) are discussed, along with

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an analysis of how impact is assessed and evidence of how these tools have helped improve situations. Enabling factors for the deployment of such technology (e.g. Policy, funding and partnership) are examined. The paper also uses tables to provide comparisons of the technologies and case studies and a mermaid flowchart illustrating a typical deployment pathway, in addition to exploring the ethical implications of data use and highlighting areas for future research. The paper concludes with actionable recommendations for practitioners, donors and researchers and is based on sources including peer-reviewed academic research, UN and NGO data.

## Conceptual Clarification

Food security is understood as “the condition of people having physical and economic access to sufficient, safe and nutritious food at all times to sustain an active and healthy life” (Abay, 2026). The four dimensions of food security (availability, access, utilization, stability) need to be fulfilled to achieve full food security (Kreutzer, 2024; Krishnan, 2022). This can quickly be compromised by a crisis, for example through lack of available food or damaged supply chains.

Water, Sanitation and Hygiene (WASH) is a "key sector for life saving and human dignity in the humanitarian sphere" and refers to provision of safe, affordable and adequate quantities of water, adequate excreta and refuse disposal, and access to facilities and services for personal hygiene (Beduschi, 2022). These services, in the form of water kiosks, toilets and sanitation facilities, are often disrupted during humanitarian crises like conflict and disaster and their quick provision or restoration are vital to prevent outbreaks and disease (Kruger, 2026; Lid, 2026; Mercy, 2023). The capacity to anticipate, prevent or recover quickly from shocks and stressors (Busker, 2023) refers to the capacity of individuals, groups and systems to absorb stress and trauma, maintain essential functions, and adapt and transform (Busker, 2023). Resilience may be developed through interventions aimed at a broad range of stages – from prevention, preparedness and risk reduction to recovery and adaptation, in line with a "humanitarian-development-peace nexus" approach (Busker, 2023; Pizzi, 2021).

A situation requiring emergency assistance, usually characterized by "threats or impacts of conflict or natural disasters" which require assistance to "save lives, alleviate suffering and protect human dignity" (Song, 2023). In these situations food and water related risks can be significantly higher, and vulnerable groups such as children and women may be particularly affected (Sphere, 2018). Applying the term 'digital frontlines' refers to deploying digital tools within these humanitarian settings in order to provide or improve food and water resilience.

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# Recent Digital Innovations and Technologies Humanitarian Applications

The humanitarian sector has a rapidly growing number of digital solutions in the areas of food and water. We have broken these into a few broad categories. **Mobile/SMS Applications -** These tools use phones to allow two-way communications, to collect data, and to distribute assistance. For WASH applications include the UNICEF RapidPro SMS platform used in rural Zimbabwe that allowed communities to report broken pumps by text, drastically speeding up repairs (Veeger, 2025) Mobile-based solutions offer WASH services including nutrition advice, cholera alerts, smartphone-enabled surveys. For Food/agriculture, mobile apps can share market prices with farmers, manage beneficiary registration, and chatbots (e.g., WFP's WhatsApp chatbot) can provide up-to-date information to crisis-affected households (Waldron, 2019).

Remote Sensing and Satellite Imagery - Technologies like satellite imaging can analyze the physical world remotely for purposes such as tracking weather, agriculture and water resources. For example, USAID's FEWS NET analyzes satellite-based NDVI (vegetation index) and rainfall data across countries and uses these to anticipate periods of famine that could arise from drought or flood (World, 2024). Satellites provide critical information about location of floods, storms and locust populations. Combined with climate and soil data models, satellite data can trigger earlier warning systems and guide allocation of resources for food assistance. In the WASH sector, satellite data was used to pinpoint locations of deep groundwater sources during geophysical investigations in Madagascar. It is also helpful to monitor ground and surface water levels in drought-stricken regions.

IoT sensors - Network of sensors can collect real time data about the physical world, and infrastructure. In water sectors a variety of sensor based solutions are emerging: such as the smart hand-pump a sensor on the pump that collects usage and break down information and send the data through a communication device to a remote operator. In Kenya, using these sensors reduced average pump breakdown duration from 27 days to just 3 days by using cell phone communications (World, 2026). Other simple sensors measure things such as chlorine levels or turbidity, feeding local data into central monitoring dashboards. In Food/Agriculture context, we see growing use of sensors to measure soil moisture, climate and livestock data, and soil sensors to collect data about agriculture crop production for a range of purposes using LoRa, cellular, and Satellite based IoT (GSMA, 2023).

Drones / UAVs - Flying drones for various purposes, including to take photos, conduct measurements, and in some cases to carry small objects. A growing range of humanitarian applications have been piloted, from the use of drones to map flood extents or areas of collapsed structures for logistical planning in disasters, to carrying medicines and vaccinations to hard to access locations. These can be used to deliver water containers, or kits for water testing. Some researchers envision drones playing a

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larger role in delivering aid and carrying out crop surveys in conflict-ridden areas (Food and Agriculture Organization of the United Nations., 2024).

Blockchain and digital ledger - The application of blockchain technology to a single central, yet distributed ledger for recording aid transfers or beneficiaries' entitlements across organizations. WFP's building blocks blockchain offers a shared platform with a single database for each beneficiary. In refugee camps in Jordan and Bangladesh this has been used to distribute money and food assistance, allowing the organizations involved to be neutral. As of 2022, Blockchains have delivered over $555m to 1.35m refugees, saving $3.5m in fees, and has been used in Bangladesh for the distribution of water and sanitation supplies (Mercy Corps, 2023; IWMI, 2024).

AI/ML - Artificial Intelligence / Machine learning: This is used to interpret data and generate predictive outcomes, often combined with Big Data sources. WFP's HungerMap Live, for example uses ML on climate, conflict, economic and satellite data to identify where food insecurity is likely to occur (Veerger et al., 2025; Waldron et al., 2019). The Safe Water Optimization Tool (SWOT) utilizes ML on water quality data to optimize chlorination levels in refugee camp settings (WFP, 2021). These are also applied to analyse image data, optimise logistics and forecast nutrient deficiencies.

Digital Cash / Transfer Platforms - These systems enable financial transfers to individuals and communities, using technologies such as mobile money, digital vouchers or smart cards. 80% or more of adults in Somalia rely on mobile money as their primary financial service (Hormuud's EVC-Plus) (Sphere, 2018). Cash transfer systems using these technologies allow beneficiaries to choose which items they wish to buy and significantly reduce theft of cash transfers. WFP utilizes mobile money solutions, including Safaricom M-Pesa, in Kenya and for food vouchers in Somalia and has shown effectiveness when EVC-Plus is used in Somalia (IWMI, 2024; FOA, 2024).

Digital Logistics and Data Dashboards - systems that aggregate multiple data sources to provide improved information and insights on the ground. This could include shared logistical planning tools (e.g. WFP's SCOUT), information hubs for aid organizations (e.g. ReliefWeb) or a national data portal that draws together various data sources, such as that run by the Ministry of Health in Zimbabwe, to support district level planning and operations (Waldron et al., 2019; IWMI, 2025). COVID or Food Security Dashboards, pull together data from a variety of humanitarian sources including health reporting, conflict data, displacement numbers and price monitoring to enable a better informed, more coordinated response.

The digital innovations listed above are often complementary. For example, a drone flight could provide imagery data that is then analyzed by an AI algorithm and viewed on a central data dashboard. The table below summarises the key technologies by their humanitarian use case, example and limitations:

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| Technology | Applications (food/WASH) | Advantages | Limitations |
|---|---|---|---|
| Mobile/SMS Apps | Community feedback on water points (e.g. SMS reporting of pump breakdown)beneficiary registration and two-way info; chatbots for health/food info. | - Low barrier (works on basic phones) Direct community engagement; fast alerts. | - Requires mobile coverage/power Literacy/language barriers <br>- Data management needed. |
| Remote Sensing | Crop/drought monitoring (FEWS NET); flood mapping; water resource surveys (Madagascar). | -Large-area coverage; objective data. Early warning for climate shocks. | - Clouds/obstructions can obscure. Need expertise to analyze data. May need ground-truthing. |
| IoT Sensors | Water pump usage/quality sensors (smart handpumps), soil moisture sensors; livestock trackers. | - Real-time local data. Can trigger automated alerts (e.g. pump failure). | - Requires power (battery/solar) Internet connectivity challenges. Initial cost per sensor. |
| Drones/UAVs | Rapid area mapping post-disaster; delivery of medicines; aerial surveys of camps, crops. | - Access remote/inaccessible terrain. High-resolution imagery quickly. | - Flight regulations; weather limits use Limited payload (especially heavy items). Cost of operations. |
| Blockchain | Coordinating cash/voucher aid from multiple agencies (e.g. WFP *Building Blocks* in refugee camps) | Immutable, auditable records. Neutral coordination (no central authority). | Requires digital IDs for beneficiaries Tech complexity, training needed Scalability of blockchain performance. |
| AI/ML | Food insecurity forecasting (HungerMap); optimizing water treatment (SWOT); image analysis. | Can detect patterns in big data. Improves prediction and resource allocation. | Needs large training data (bias risk) “Black box” models, trust issues Ethical concerns (data, bias). |

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| | | | |
|---|---|---|---|
| Mobile Cash/Vouchers | Cash assistance via mobile money (e.g. Somalia EVC-Plus); e-vouchers for food markets. | High speed and transparency. Empowers beneficiary choice. | Excludes those without phones or networks. Potential fraud if not carefully controlled. |
| Data Dashboards | Real-time monitoring portals (HungerMap, RWIMS) for situational awareness; logistics dashboards (WFP SCOUT). | - Integrates diverse data sources. Easy sharing of analysis with all partners. | Depends on data quality/coverage. Users require training Sensitive data privacy concerns. |

Table 1: Overview of Digital Technologies Applied in Humanitarian Food Security and WASH Programming, with Applications, Advantages and Limitations

## Case Studies of Digital Innovations

This section presents a diverse range of examples of digital technologies applied to food and water resilience in humanitarian settings, detailing the context, the technology used, outcomes/metrics, timeline, and stakeholders involved in each.

### Zimbabwe (Rural WASH Monitoring - SMS Reporting & Dashboard)

In rural Insiza district, UNICEF integrated an open-source SMS platform (RapidPro) into the national Rural WASH Information Management System (Busker, 2023). This pilot phase, which took three months to complete from November 2017, successfully covered 53,000 people, including 8,000 children, and registered 1,100 community informants (UNCTAD, 2023; UNICEF,2026). Community members can send SMS alerts when water points or latrines are in disrepair, automatically updating an online RWIMS dashboard that is accessible to officials (. The rapid reporting led to a dramatic decrease in reporting lag: 89% of repairs are now carried out within 3 days, compared to weeks previously (Kreutzer, 2024). Key stakeholders included UNICEF Zimbabwe, the national government, local pump mechanics, and funding from Swiss and UK aid (IWMI, 2024; Johns, 2024). Early lessons from this initiative emphasize the critical need for government ownership and long-term sustainability planning to scale up successfully.

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Figure 1: A UNICEF field officer in Zimbabwe monitors the functionality of a community water pump and reports it using a mobile app (RapidPro).

Over 1100 community informants have been trained to provide an update on water/pump functionality via SMS.

## Zimbabwe (RWIMS Dashboard)

Working in conjunction with SMS reporting, Zimbabwe's RWIMS web dashboard offers real-time maps and statistical data on water and sanitation infrastructure (UNCTAD, 2023). This GIS-based portal (screenshot) combines user reports with government data, providing local officials and pump mechanics with smartphone access to prioritize repairs. According to the district WASH chief, "The burden of scavenging for WASH data is a thing of the past... Most exciting is the ability of the system to be accessed on the go through smart phones (FOA,2024)". This case effectively demonstrates the value of integrating community reporting with cloud-based dashboards for accelerated service delivery.

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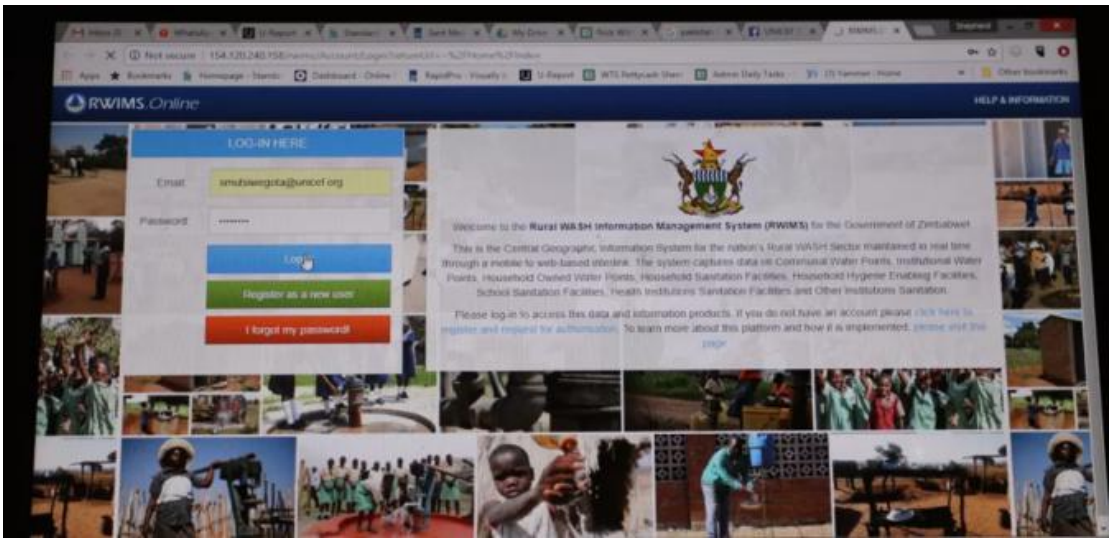


Figure 2: RWIMS Online in Zimbabwe collates all the SMS data received from communities along with the official data, in a dashboard form enabling effective real-time tracking of rural water and sanitation (Song et al. 2023).

## Madagascar (Deep Water Search - Satellite + Geophysics)

During the 2017-2018 drought in southern Madagascar, UNICEF tested an innovative approach to locating new groundwater sources. By employing high-precision geophysics (techniques common in the oil and mining industries) alongside satellite imagery, experts were able to analyze the structure of deep fractures where fossil water was suspected to exist (UNICEF, 2024; Liden, 2026). While two test boreholes were drilled-one in Tsihombe (85m deep) which yielded water with extremely high salinity and another (105m deep) which was dry-the methodology itself proved viable. Although these pilots did not immediately yield usable water, the extreme scarcity was confirmed, and the methodology was refined to incorporate detailed hydrogeology with geophysical surveys for an increased probability of success. This project (October 2017 to December 2018) was funded by the UNICEF Innovation Fund. The primary lesson learned from this effort was that cutting-edge scientific techniques (remote sensing + geophysics) can guide expensive drilling operations, but these must be combined with local hydrogeology for success.

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Figure 3: In rural south Madagascar a child drawing water from a shallow and salty source, drought.

UNICEF utilized satellite imagery and geophysics to locate deep ground water, and drilled test wells in 2018.

## Kenya (Smart Handpumps - IoT Sensors)

The FundiFix initiative deployed GSM-enabled flow-sensors on village handpumps. A pilot project in 2012 revealed that this technology reduced average pump downtime by 90% (from 27 days to just 3 days) and maintained 98% operational availability for the monitored pumps. The sensors automatically triggered a repair response from local contracted technicians. Community water committees were given real-time reports, enabling better coordination of maintenance efforts. This public-private partnership (Oxford University and local county governments) was supported by donors and mining companies, channeled through county water trusts (United Nations High Commissioner for Refugees, 2020, September 24). This initiative resulted in dramatically faster repairs and increased reliability of water services and serves as an excellent example of how IoT monitoring can transform rural water maintenance systems in low-resource environments.

## Jordan & Bangladesh (Building Blocks - Blockchain Cash/Vouchers)

WFP's Building Blocks is considered the largest blockchain platform within the humanitarian aid sector. This platform facilitates multi-agency cash transfers for refugees. To date, over one million refugees in

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Jordan and Bangladesh have received assistance through the platform (WFP, 2021). Each beneficiary receives a single blockchain account where cash or voucher entitlements from different agencies can be deposited, allowing them to be redeemed at local shops. As of 2022, WFP's Building Blocks platform had facilitated US$555 million in cash assistance for food and vouchers across 25 million transactions (WFP, 2024) and had saved an estimated $3.5 million in bank fees. The platform has also been utilized to deliver UNICEF WASH and UNFPA health supplies to refugees in Bangladesh. A crucial aspect of Building Blocks is its ability to prevent duplicated aid-in 2022 it flagged $35 million worth of duplicate aid in Ukraine, enabling assistance to reach more than 185,000 additional families. Key partners included WFP (lead), UN Women, UNICEF, UNFPA, and various tech organizations, with funding from WFP and donors, as well as significant in-kind contributions of software. Lessons from this initiative highlight that while blockchain can enable efficient aid coordination, digital identity is a necessary component. WFP now makes the Building Blocks code open-source to facilitate wider adoption (WFP, 2024).

## FEWS NET (Satellite-Based Food Early Warning)

The USAID-funded Famine Early Warning Systems Network (FEWS NET) is a prime example of the use of remote sensing for food resilience. Since its inception in 1987, the USGS and its partners have been using satellite data (monitoring NDVI vegetation, rainfall, and streamflow) in 17 African countries (UNESCO, 2026) to predict potential food crises. For instance, FEWS NET has successfully issued famine warnings based on analysis of rainfall deficits and crop stress in periods such as the East African droughts of the 2010s, allowing for the preemptive delivery of food aid. The system integrates biophysical data with household surveys to inform government and NGO decision-making. While specific monetary figures are difficult to quantify, FEWS NET's contributions are well-recognized, with timely forecasts having enabled millions of drought-prone individuals to receive assistance before crises escalate. Key partners include USAID, NASA/NOAA, the FAO, and regional scientific centers. Lessons learned underscore the long-term value of investing in satellite data capabilities for invaluable food security early warning.

## Global Food Security (HungerMap Live - AI Dashboard)

Launched in 2026, WFP's HungerMap Live is an AI-driven platform that provides real-time analysis of food insecurity across over 50 countries (WFP, 2024). By integrating various food security indicators (including IPC classifications), market prices, weather forecasts, and conflict data, it generates real-time maps illustrating the severity of hunger, with a particular focus on 16 "hunger hotspot" countries facing acute needs. WFP estimates that every $1 invested in anticipatory action based on such forecasts can yield savings of at least $7 in response costs (WFP, 2024). For example, in 2025, the platform identified emerging food crises, enabling early food distribution that averted the worst possible outcomes in terms of malnutrition. HungerMap Live was developed with the support of Google.org and the Gates

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Foundation and is utilized by WFP, national agencies, and donors for prioritizing aid interventions. The platform experienced rapid rollout, influencing programming in real emergencies (e.g., Ukraine, Horn of Africa) by mid-2026. This case highlights the transformative potential of AI-powered dashboards in humanitarian planning, especially when informed by robust data.

## Somalia (Mobile Money for Cash Aid)

Digital cash is mainstream in the perpetually fragile, post-conflict environment of Somalia. There is high adult mobile money penetration (over 80%), with EVC-Plus being dominant through Hormuud Telecom. Humanitarian actors (e.g. WFP, UNICEF) are now distributing cash and vouchers using EVC-Plus via mobile money transfers. A recent report found it greatly improved humanitarian delivery effectiveness through better financial inclusion, user-friendliness and accessibility. For example, when a drought caused a surge of needs for urgent cash in Somalia, near-universal beneficiary reach was seen with emergency cash programs activated through EVC-Plus. The impacts observed included faster delivery times (since no physical cash was distributed), the ability to trace the transaction end-to-end, and high levels of beneficiary satisfaction. The platform's integrity is maintained by requiring One-Time Passwords (OTPs), reducing fraud. Stakeholders include local telecom providers (Hormuud), WFP's Innovation team, UNHCR and NGOs. The local regulator has adjusted its guidelines to accommodate such operations. This case shows how robust digital financial infrastructure can transform into "humanitarian infrastructure" that enables scaled and effective delivery of aid.

## Humanitarian Crises (Water Safety - Machine Learning Tool)

The Safe Water Optimization Tool (SWOT) is an international project by MSF and York University, designed to help manage water safety during emergencies. It is a machine-learning tool used to calculate optimal chlorine levels for water purification in camps, based on real-time water treatment data (IWMI, 2024). Since 2018, 7 NGOs have been operating the platform across 12 different countries in humanitarian emergencies and refugee settlements. By 2024, SWOT was supporting the provision of safe water to an estimated 700,000 individuals. In one instance where the platform was used to manage a water safety crisis in a South Sudanese refugee camp, chloride usage was reduced by 30%, leading to significant cost savings and better taste quality of the water without compromising safety standards. The platform itself is a web-based service that can run offline on low-bandwidth networks and has been refined through a partnership with ThoughtWorks. This example illustrates the significant potential of specialized digital solutions (often powered by machine learning and open data standards) for the optimization of complex WASH operations in the humanitarian sector.

These examples illustrate timelines from pilot phases (e.g. 3 months in Zimbabwe) to larger scaled implementations taking a few years. Measures for success vary based on projects but commonly include beneficiary reach (people affected and funds transacted) and service specific metrics (service up-time,

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response speed, cost savings). The Figure below summarizes a generic timeline for the deployment of a digital tool:

| Case Study (Location) | Context/Crisis | Digital Solution | Outcomes/Impacts | Stakeholders/Funders |
|---|---|---|---|---|
| Zimbabwe (Insiza) | Rural WASH (water-point failures) | SMS reporting + RWIMS dashboard | 53k people covered, 1.1k reporters; pump downtime ↓ from 27d→3d; govt. response time cut | UNICEF (lead), Zimbabwe gov't, local communities; donors: SDC, DFID |
| Madagascar (Androy) | Drought / Water scarcity | Satellite imagery + geophysics surveys. | Identified deep fractures; drilled 2 boreholes (85–105m); confirmed salinity issue; informed strategy. | UNICEF (WASH), Innovation Fund; local gov't agencies |
| Kenya (Kitui/Kwale) | Rural WASH | IoT-enabled smart handpumps | 10× ↓ in pump downtime; 98% uptime; 89% repairs <3d | Oxford Univ/FundiFix, County govts; donors: private (mining co.), county trusts |
| Jordan & Bangladesh | Refugee camps (conflict) | Blockchain cash ledger (Building Blocks) | 1.35M refugees served; US$555M cash disbursed; $3.5M fees saved; $35M duplicate-aid prevented | WFP (lead), UN Women, UNICEF, UNFPA; tech partners; donor funding |
| Africa (17 countries) | Food insecurity (droughts, floods) | Satellite/Earth observation (FEWS NET) | Early warning of famine/climate shocks; guides pre-positioning of aid; impacts millions (quantitative eval needed) | USAID/USGS, NASA/NOAA, FAO, SADC hydromet centers |
| Global food hotspots | Ongoing hunger crises | AI-powered hunger dashboard (HungerMap) | Monitors 50+ countries; used for anticipatory action; $1→$7 ROI on early aid | WFP (lead), Google.org, Gates Foundation |

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| | | | | |
|---|---|---|---|---|
| Somalia | Fragile state / drought, conflict | Mobile money (EVC-Plus) | 80% population cash-enabled; improved aid delivery effectiveness | Hormuud Telecom, WFP, UN agencies; Somalia govt; donor support |
| Global camps & field sites | Humanitarian WASH | ML-driven water safety app (SWOT) | Deployed in 12 countries by 7 orgs; improving water quality for ~700k people | MSF & York Univ. (developers), NGOs (users), ThoughtWorks (support) |

Table 2: Case Studies of Digital Innovations for Food and Water Resilience in Humanitarian Contexts, by Crisis Context, Digital Solution, Outcomes and Stakeholders

## Typical Digital Innovation Deployment Pipeline

Implementing a digital aid solution follows an iterative pipeline from design to scale. A simplified flowchart is shown below:

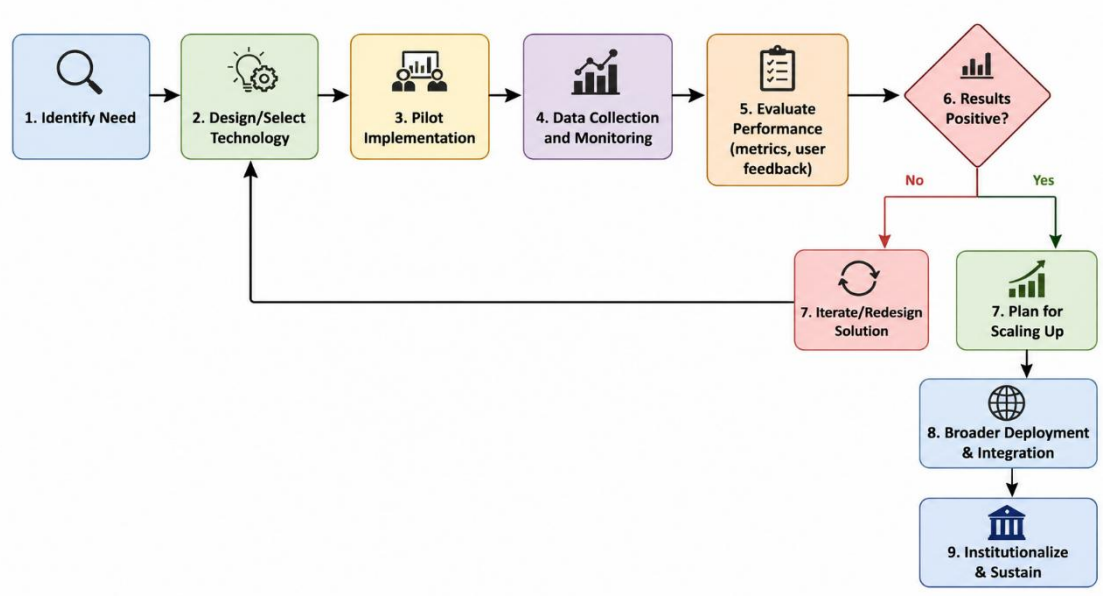


Figure 4: Typical digital innovation deployment pipeline in humanitarian settings
(Source: Authors' Draft, 2026)

Starting with needs identification, solutions are developed as prototypes and piloted. Data is collected throughout the pilot phase to identify strengths and weaknesses, leading to the refinement of the solution. If successful, the tool is then scaled up. Sustained support and buy-in from relevant stakeholders, including relevant institutions and a commitment to sustained funding, are crucial for ensuring the long-term viability and integration of the digital tool into the routine delivery of services.

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## Challenges of Deployment

A range of practical and ethical barriers hinder the effective deployment of digital solutions in crisis settings:

**Connectivity and Infrastructure:** Internet access and cellular networks are typically limited in many disaster zones, making real-time data exchange challenging. Similarly, inconsistent power supply exacerbates difficulties in charging devices. Even solar-powered sensors, for example, can operate for months at a time without maintenance.

Local Capacity and Training: Humanitarian agencies must be able to rely on local personnel to support and maintain any given technology, especially in contexts with few ICT skills and where humanitarian workers are overburdened and likely to resist using tools without appropriate training. It is this reliance on local expertise that made the Zimbabwean government's adoption of their SMS system so critical in ensuring its sustained use.

**Cost and Sustainability:** Most startups in the humanitarian space are reliant on external donors and grants. Advanced technologies such as drones and sensors are expensive, making it difficult to roll them out in crisis situations where funding is often short-term and can make scaling up difficult. For instance, the UNICEF project in Madagascar was funded by a federal government grant, and it costs substantial amounts for commercial drilling services.

**Data Privacy and Protection:** Issues of consent, ownership and use of the data gathered about beneficiaries (such as mobile money identification or biometric data) must be approached cautiously to avoid unintended harm. Humanitarian agencies adhere to strict guidelines, such as those articulated by the ICRC in its Data Protection handbook.

**Interoperability:** Aid organizations commonly use multiple incompatible platforms, creating information silos that make coordinating activities between different humanitarian entities challenging (this is one reason the Building Blocks project has been so successful). APIs and open standards for platform intercommunication are still under development.

**Gender and Inclusion:** Those who are women, in marginalized groups or who lack digital literacy may have difficulty accessing services based on digital platforms due to their gender, literacy level, physical constraints or ownership of digital devices, which can thus exacerbate existing inequities. Programs need to tackle the gender-digital divide head-on, whether through shared devices, community kiosks, etc.

**Cultural and Language Barriers:** Tools must be sensitive to the local cultural and language context; SMS services must support local dialects, and chatbots or applications need content tailored to local

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practices. Misapplication of the tool or the message it conveys may result in negative uptake or even resistance.

Any of these barriers alone, left unaddressed, could limit the potential effectiveness and reach of a digital tool; a survey carried out in several crises indicates that as much as 30 percent of beneficiaries can be missed by mobile-based interventions due to a combination of issues relating to gender, literacy and connectivity. Therefore, disaster risk and emergency responses often require contingency plans for when certain digital interventions are unfeasible.




Figure 5: Timeline of Key Innovation for Impact

## Impact Evidence and Evaluation Methods

The availability of evidence for the impact of humanitarian digital tools is still evolving, and many current quantitative evaluations are limited in scope. Nevertheless, a number of evidence gathering methods are used. Monitoring & KPIs, metrics such as reach (number of people affected and funds disbursed) or number of transactions provide a sense of project scale. Building Blocks, for example, reported over $555 million disbursed and reaching 1.35 million people in 2024 alone (WFP). HungerMap monitors the percentage of the population currently experiencing food insecurity at different levels, though its utility is limited in its lack of depth regarding specific outcomes. In several instances, projects have been evaluated by comparing service delivery metrics pre-and-post intervention. Zimbabwe's SMS pump repair system reduced repair times from weeks to days, and theKenya smart pumps had over 98 percent up-time. These clearly operational-level metrics can directly correlate with the deployment of the digital tool.

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Cost-Benefit Analysis: Reports of cost-effectiveness such as WFP's observation that anticipatory aid planning saved $7 for every dollar invested (WFP, 2026) and the blockchain transaction that saved $3.5 million in bank fees (WFP, 2026) demonstrate significant return on investment. For User Surveys and Feedback, beneficiary and humanitarian worker surveys (such as the one conducted on the Somalia EVC-Plus initiative that highlighted the improved efficacy of aid delivery due to enhanced user-friendliness of mobile payments) help to build the case for certain digital tools. These surveys offer information about user adoption and potential barriers to use.

Independent Evaluations: Some specific project-focused independent evaluations (e.g. SIAHE for cash aid initiatives) incorporate a section on the digital modalities used, however more systematic overviews point out the scarcity of evidence-based and rigorously researched humanitarian digital interventions, many being anecdotal or qualitative at best. Greater investment in large-scale randomized trials and longitudinal studies measuring key nutritional and health indicators would significantly enhance the evidence base of the impacts of these tools.

Based on the above information, there is evidence to support the positive impacts of digital tools on reaching, time-efficiency, and cost-effectiveness of food and WASH assistance (e.g. Enabling better targeting of limited resources due to timely data collection). However, there is a clear deficit in data-driven evidence on long-term resilience outcomes, such as the correlation between digital foresight and the reduction of child malnutrition rates. Standardized evidence gathering and assessment approaches, such as the use of theory of change models, mixed methods, and a clear definition of impact metrics, will be essential to improving the rigor and generalizability of findings.

## Funding Policy and Partnerships for Food and Water Resilience

Various funding and institutional models support digital innovation. This begins with innovation funds, donor grants, and development programs are used. The EU funds approximately $200 million/year in humanitarian WASH (IWMI, 2025). The WFP Innovation Accelerator, started in 2015, has spent $323 million to assist 61m people with pilot projects. Global partnerships, including those with the EU, USAID, UK FCDO, and the Gates Foundation, often fund tech pilots with seed grants. The UNICEF Innovation Fund has provided seed money for early-stage WASH tech, while multilateral funds like the Green Climate Fund and Adaptation Funds also invest in agri-tech for resilience. Also, NGOs and the private sector frequently partner on innovations. Google and WFP collaborate on AI through the Ventures Accelerator. MSF and York University created the SWOT platform together, and major tech companies offer pro bono services like Microsoft's AI for Humanitarian Action and Google's Earth Engine. The GSMA Foundation has partnered with mobile operators to increase connectivity in refugee camps. These PPPs combine technical expertise and global platforms to humanitarian ends.

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For policy and coordination, digitalization is increasingly integrated into high-level coordination frameworks and donor/UN resilience strategies. The UN Innovation Network (co-chaired by WFP/UNICEF/UNDP) facilitates the sharing of best practices and the scaling of successful interventions, while the WHO and ICRC provide emergency guidelines for digital health and protection. Some governments, such as Somalia with its financial inclusion strategy, now mandate cash readiness (e.g. EVC-Plus). A universal policy for digital humanitarian aid is not yet in place, with initiatives still agency-driven. More so, in aspect of scalability, successful pilots are often transferred to national contexts with local partners. Building Blocks has made its blockchain code available to all legitimate humanitarian organizations, and the RWIMS model has been adapted for use in other countries. Interoperable solutions and common APIs for cash systems are encouraged, though pilot funding often runs out before solutions can scale without local integration into national programs and budgets for maintenance (e.g. Pump maintenance trusts in Zimbabwe).

## Ethical, Legal and Protection Issues

The use of digital technology in crises introduces a variety of unique ethical dilemmas. Collecting sensitive data, such as names, biometrics, and mobile numbers, can put vulnerable people at risk of harm if exposed. Humanitarian organizations follow data protection principles (consistent with GDPR and ICRC's Data Protection in Humanitarian Action guidelines) to ensure a do-no-harm approach. This includes obtaining informed consent for the collection of information, storing it securely, and only collecting data necessary for the project, encrypted during transfer. Furthermore, digital tools must be protected against cyber-attacks. For example, the systems holding sensitive information should be secure to prevent unauthorized access. Physical security of devices also matters, ensuring that components in camps, such as sensors, are not repurposed.

Digital tools must not discriminate against anyone. Agencies should not assume universal access, but instead ensure that marginalized groups receive the aid they need, while still providing in-kind alternatives if people lack technology access or prefer them (e.g. Mobile cash vs. Food distribution). Humanitarian neutrality means avoiding surveillance or coercion. For regulatory compliance, this includes navigating national data privacy, ICT, and tax regulations (especially concerning digital currencies) can be complex. The legal framework for cross-border mobile money or telemedicine needs to be understood. Partnerships with local telecoms should be undertaken in line with their licensing and security standards.

Beyond data protection and security, the "digital protection" challenges posed by these technologies are significant. All digital humanitarian interventions should incorporate a rigorous ethical review process, involving community advisory boards and adhering to relevant sector standards such as the CHS standards on protection and inclusion.

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## Policy Recommendations

The literature reveals many gaps that researchers and practitioners should focus on. Few evaluations comprehensively assess the impact of digital tools. While project reports detail outputs (e.g., the number of users reached), they rarely quantify impact (e.g. On rates of malnutrition or waterborne illness) or analyze cost-effectiveness.

There should be development of consistent methodologies and metrics for digital humanitarian interventions. This includes using randomized trials where possible, employing longitudinal studies, and conducting cost-benefit analyses to overcome the existing paucity of data-driven analysis. On inclusion and ethics, there should be focus on the digital gender gap and including people with disabilities, the elderly, and language minorities in digital tools. How can interventions be designed to benefit female-headed households as much as other beneficiaries? Also, exploring the use of lower-tech alternatives for areas with limited connectivity, such as satellite SMS gates, and adapting tools for new applications like machine translation for humanitarian aid.

Practitioners and NGOs are encouraged to invest in baseline data and connectivity: Essential for successful responses, ensure digital infrastructure (cellular/satellite and power) is available. Engaging the communities to ensure tools are co-designed with users and there are clear feedback mechanisms to address specific needs, as was key to the success of projects in Zimbabwe.

Donors and policymakers should fund long-term projects because digital tools require adequate time and resources for monitoring and evaluation. Invest in common infrastructure and data hubs rather than redundant pilot projects. Facilitate PPPs to leverage the technical expertise and resources of private companies. Establish regulations that facilitate digital cash and humanitarian apps, and include digital components in national disaster plans. Lastly, researchers should focus on rigorous studies of the cost-effectiveness of digital cash versus in-kind aid, algorithmic fairness and bias mitigation in AI tools, and the integration of IT with social sciences to understand behavioral outcomes.

## Concluding Remarks

In conclusion, digital innovations offer considerable potential to enhance food and water resilience in crisis situations. Successful case studies, such as those in Zimbabwe and Bangladesh, highlight specific benefits such as faster repairs and better aid coordination. However, substantial challenges remain in the practical implementation and evidence-based verification of these tools. A coordinated effort between practitioners, donors, and researchers is required to bridge knowledge gaps, address ethical concerns, and scale the most effective digital solutions. This report's comprehensive overview seeks to inform this collective effort to transform the "digital frontlines" into a potent engine for humanitarian resilience.

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