

18. Disaster Forecasting in Agriculture: Early Warning Through Geospatial Tools

Gariyashi Tamuly¹, Bisma Majid²

¹Subject Matter Specialist, Agrometeorology

Krishi Vigyan Kendra, Baksa, under AAU

²Plant Pathology, SKUAST-Kashmir, Shalimar, J&K.

Abstract

Disasters in agriculture pose growing threats to global food security, and geospatial tools now offer a powerful means of early warning and response. This article reviews how remote sensing, geographic information systems (GIS), and spatial modelling support the monitoring of droughts, floods, and locust invasions in crop systems. It presents evidence of functional early warning systems and case examples from China, Pakistan, and global reviews. The article explains how geospatial data integrates hazard, exposure and vulnerability in agricultural contexts. It then examines implementation barriers and suggests practical steps for policymakers and farmers. The conclusion emphasises the need to mainstream geospatial tools into agricultural disaster planning to protect yields, livelihoods, and food supplies.

1. Introduction

Agricultural production increasingly faces serious risks from weather extremes, pests and environmental changes. Disasters such

as droughts, floods or locust swarms can wipe out harvests and threaten livelihood and food systems. Traditional reactive responses often come too late to minimise damage. Early warning systems that detect hazards and alert decision-makers in time offer a more proactive path. Geospatial tools – including remote sensing imagery, GIS mapping, and spatial modelling – have emerged as critical enablers of such systems. They allow data from satellites, sensors, and terrain to be organised spatially, analysed, and applied to agricultural risk management. This article examines how those tools support disaster forecasting in agriculture, reviews key hazards and monitoring methods, presents case studies of application, identifies barriers to adoption, and outlines practical strategies for integrating geospatial early warning into farming and policy systems.

2. Geospatial Tools and Their Role in Agricultural Disaster Forecasting

Geospatial tools encompass technologies that capture, store, analyse and display geographic or spatially referenced data. In

agriculture disaster forecasting, they perform several key functions. First, remote sensing satellites and sensors can monitor land surface conditions—such as soil moisture, vegetation health, or water extent—over large areas and at frequent intervals. These data feed into GIS platforms that allow the layering of hazard data (for example, drought index maps), exposure data (crop locations, land use), and vulnerability information (soil fertility, farmer resources). For example, GIS allows a map to overlay crop types, water-stress zones, and previous yield losses. One review described how GIS in agriculture can monitor water risk, flood and drought risk zones, track runoff or evapotranspiration.

Second, geospatial tools support modelling and prediction. A study in China developed a drought risk assessment model using geospatial techniques, fuzzy logic, and standard risk components (hazard, exposure, vulnerability, and mitigation capacity), achieving a prediction rate of 88.6%. Third, geospatial systems support timely decision-making and communication. They can generate maps, alerts, and dashboards for planners, extension services and farmers. A review of geospatial technology for disaster risk reduction noted that geospatial platforms enable early warning, analysis of hazard-

impact relationships, and prioritisation of response. These functions make geospatial tools a backbone of contemporary agricultural disaster forecasting. They allow you to move from reacting after damage to anticipating and preparing in advance. That shift has implications for farm productivity, resilience and policy design.

3. Monitoring Key Hazards: Drought, Flood, Locusts and Other Threats

Agricultural disasters take diverse forms. Among the most consequential are droughts, floods and pest invasions such as locusts. Geospatial tools support the monitoring of each.

Drought

Drought is complex: reduced precipitation, higher temperature, low soil moisture, and crop stress. Early warning is critical because drought onset may be slow-moving, but its effects can build over months. A review of drought early warning systems emphasised that monitoring, risk assessment, and decision support must integrate geospatial data to enable timely action.

In the Songnen Plain of China, researchers used geospatial techniques to develop a drought risk model that accounted for hazard, exposure, vulnerability, and mitigation capacity. They achieved 88.6% validation accuracy.

Such spatial assessment enables authorities and farmers to identify high-drought-risk zones, allocate irrigation, adjust planting schedules, or secure inputs before stress.

Floods

Floods can destroy crops quickly, damage soils and disrupt planting seasons. Geospatial tools assist by mapping flood-prone zones, inundation, and impacts. For example, a case study in Vietnam used a geospatial model to assess the impact of extreme flood events on agriculture in Quang Nam province.

Another study of the August 2022 Pakistan floods linked satellite imagery to crop-specific loss estimates in the Indus plains, allowing data-driven assessment of food security impacts.

These tools enable early flood risk warning, rapid post-event damage assessment, and targeted interventions for farms.

Pest and Disease Invasions

Biotic threats such as locust swarms or disease outbreaks also pose agrarian disasters. Geospatial and remote-sensing systems increasingly detect potential breeding grounds or spread dynamics. For example, a very recent study developed a geospatial deep learning model to predict desert locust breeding grounds in Africa, achieving accuracy above 80%.

By identifying high-risk breeding zones before swarms form, the system provides

early warning and targeted control measures for farmers and ministries.

Integrative Multi-Hazard Monitoring

Some research now seeks to integrate multiple hazard types, modelling how combined events (for example, drought followed by pest outbreak) may impact agriculture. One work proposes multi-hazard early-warning systems for agriculture using sequential deep learning and temporal explainability.

Such integrative forecasting suits agricultural contexts where multiple threats may converge, and where spatial tools allow the layering and analysis of hazards, exposure, and vulnerability.

4. Case Studies of Early Warning and Impact Assessment

In this section, I present selected case studies that illustrate how geospatial tools support early warning and assessment in agricultural disasters.

China: Drought Risk Assessment in Songnen Plain

In the Songnen Plain, Gao et al. (2023) developed a comprehensive drought risk model. It integrated hazard (climate-derived indices), exposure (cropped area), vulnerability (soil and socioeconomic), and mitigation capacity (irrigation infrastructure). Using geospatial techniques and fuzzy logic, the model achieved an AUC value indicating strong predictive

performance (88.6 %).

This case shows the value of spatially detailed models for agricultural regions. It also shows how exposure and vulnerability matter, not just hazard alone.

Pakistan: Flood Impact on Crop Production

The August 2022 floods in Pakistan's Indus plains provided a stark test of geospatial assessment. The study by Qamer et al. (2023) used multisensor satellite data to estimate crop-specific production losses in Sindh province.

The approach allowed estimation of damage in the immediate aftermath. Geospatial mapping enabled policymakers to target relief, plan replanting, and address food security implications. This shows how geospatial tools contribute to damage assessment, not just forecasting.

Global Early Warning Systems for Drought

A review of drought early warning systems (DEWS) emphasised that many systems exist globally, but integrating geospatial data, risk assessment, and farmer-usable communication remains a challenge. It pointed out that effective DEWS require spatially resolved hazard data, exposure and vulnerability layers, and well-communicated information to users.

Although not specific to agriculture, this review emphasises the importance of

spatial tools in designing early warning and decision-support frameworks.

Geospatial Technology for Disaster Risk Reduction

In a broader context of disasters, a 2024 study by Aggarwal et al. (2024) outlined how surveying and GIS improve disaster resilience, covering hazard assessment, mapping of vulnerable locations, and early warning for communities. While not limited to agriculture, the concepts apply to agricultural landscapes too.

This reinforces that agricultural disaster early warning is part of broader spatial risk systems.

These cases illustrate key principles: geospatial tools help monitor hazards, map exposure/vulnerability, estimate impacts, and support targeted responses. They underline that spatial detail, timely data, user-oriented outputs, and integration with decision-making matter.

5. Challenges in Implementation and Adoption

Despite their promise, geospatial early-warning systems in agriculture face substantial challenges.

Data Availability, Accuracy and Timeliness

Remote-sensing and GIS systems depend on timely, high-quality data. For some regions, imagery is low-resolution or infrequent. Soil moisture data, crop maps or

sensor networks may be incomplete. In specific developing-country contexts, legacy infrastructure is weak. For example, early warning reviews note that linkages between local, national, and international data systems are weak.

Without reliable spatial data, hazard mapping and exposure assessment may be flawed.

Technical Capacity and Integration

Implementing geospatial tools requires skills in GIS, remote sensing, spatial modelling and data management. Many agricultural advisory systems or farms lack staff with these capabilities. A framework for locust prediction emphasised deep learning and multi-sensor integration methods that are not yet accessible to all stakeholders.

In addition, integrating spatial tools into existing agricultural extension services, decision-support workflows, or farmer advisory platforms remains a challenge.

Cost and Resource Constraints

Hardware, software licences, sensor networks, satellite imagery subscriptions and training all cost money. For many agriculture systems, especially small farms or resource-poor regions, investment may appear prohibitive. Without a clear business case or return on investment, adoption may lag. Some reviews flag that benefit-cost assessments are often lacking.

Stakeholder Engagement and Communication

Early warning is only helpful if users (farmers, extension agents, policymakers) act on the information. Mapping vulnerable zones or issuing alerts is only the first step. Reviews emphasise that DEWS must link to decision calendars, action plans and communication channels.

In agricultural contexts, cultivating trust, clarity of messages, and actionable recommendations matters.

Institutional and Governance Barriers

Agricultural disaster early warning requires coordination among meteorological services, agriculture ministries, GIS agencies, and local extension services. Institutional silos and weak governance impede integration of spatial tools into planning and action. A review of geospatial technology for disaster resilience noted that institutional capacity-building remains essential.

Thus, implementation involves not only technology but also institutional change.

Scaling and Localisation

Many studies show promise in specific pilot regions or case studies. Scaling those systems across regions with heterogeneous cropping systems, soils, and socio-economic conditions remains difficult. Local adaptation of hazard thresholds,

vulnerability models and decision triggers is essential.

Together, these challenges mean that, while geospatial tools are technically capable, real-world adoption in agriculture disaster forecasting still requires a focus on capacity, resources, user engagement, and institutional integration.

6. Practical Strategies for Integration in Agriculture Systems

To effectively integrate geospatial early warning systems into agriculture, you can follow a structured strategy.

Begin with a hazard-exposure-vulnerability mapping exercise. Use remote sensing and GIS to map hazards (drought zones, flood-prone fields, pest-breeding areas), overlay exposure (cropped areas, crop types), and overlay vulnerability (soil conditions, irrigation, farmer resources). For example, you could map soil moisture anomalies and crop water stress indices to highlight high-risk fields before drought. The China Songnen Plain study followed this structure.

Second, build monitoring and alert workflows. Acquire suitable imagery or sensors at appropriate frequencies (daily, weekly) and integrate them with GIS dashboards that update hazard maps. Establish threshold triggers and communication channels—for example, alerting farmers when the vegetation index

drops below a threshold in a zone. The drought-early-warning review noted that monitoring and decision support are key.

Third, link to decision support and action planning. Early warning is only valid when decision-makers respond. For agriculture, this may mean adjusting planting and irrigation, selecting resilient varieties, activating crop insurance, or providing targeted support. For example, Pakistan flood assessment enabled targeted relief for affected crop areas.

Fourth, build capacity and partnerships. Develop training for extension agents and farmers on interpreting geospatial maps and alerts. Partner with meteorological agencies, GIS units and local agriculture departments. Institutional coordination matters. The broader disaster GIS review emphasised capacity building.

Fifth, ensure sustainable data and infrastructure. Use open-source GIS tools where possible, consider low-cost sensor networks, and establish data-sharing protocols. Ensure system maintenance and funding.

Sixth, evaluate and refine. Collect outcome data (yield losses avoided, response times, cost savings) and refine hazard models, thresholds and communication systems. The Songnen Plain model used ROC/AUC to evaluate prediction performance.

Seventh, scale gradually. Begin with high-

risk regions or pilot crops, build experience, then expand across regions, crops and hazards. Local adaptation of models and thresholds ensures higher relevance.

By following these practical steps, you can embed geospatial early warning into agricultural systems. This supports proactive decision-making, reduces disaster losses, and improves the resilience of food production systems.

7. Conclusion

Agriculture faces increasing disaster risk from droughts, floods, pest outbreaks and climate variability. Geospatial tools—remote sensing, GIS mapping, and spatial modelling—offer powerful capabilities for forecasting, early warning, and impact assessment in agriculture. They enable you to see field-level risk zones, monitor hazard progression, estimate exposure and vulnerability, and target responses before significant losses occur. Case studies from the Songnen Plain (China), the 2022 Pakistan floods, and global drought-warning systems illustrate that spatial systems can improve predictions, map losses, and support decision-making.

However, technology alone is not sufficient. Implementation requires reliable data, technical capacity, institutional coordination, clear communication and resource investment. It demands that early warning become early action: farmers,

extension agents, and policymakers must act on alerts and integrate geospatial outputs into planning. Practical strategies – mapping hazards/exposure/vulnerability; building monitoring workflows; linking to decision support; capacity building; data infrastructure; and evaluation – will help move systems from pilot to scale.

If agricultural systems adopt these spatial-based early-warning frameworks, the benefits are tangible: fewer crop losses, more efficient use of inputs, and better protection of livelihoods and food security. As disasters grow in frequency and intensity, integrating geospatial early warning into agriculture is no longer optional. It is essential. The process starts with mapping risk today, building capacity, and putting alerts into practice. With that foundation, you can protect production, respond swiftly to threats, and build resilient farming systems for the future.

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