Food and Agriculture Organization of the United Nations

GEOSPATIAL APPLICATIONS IN EMERGENCY IMPACT ASSESSMENT

Second edition

Geospatial applications in emergency impact assessment

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by

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Contents

Figures

Tables

Foreword

The increasing frequency and intensity of natural hazards, including floods, droughts, volcanic eruptions, earthquakes, dust storms and wildfires, as well as human-induced crises, including violence and conflicts, oil spills, dam failures, toxic wastes, industrial pollution, transport accidents, factory explosions, fires and chemical spills have devastating effects on food security and represent a substantial risk to sustainable agriculture and the livelihoods of people around the world. Thus, much attention has been given to reducing disaster risk and the likelihood of a hazard occurring, mitigating the impacts of a disaster, and establishing early action and responses, quickly and efficiently.

Governments and other planning institutions generally manage natural hazards and crises by undertaking impact assessments and are constantly seeking greater accuracy and timeliness of geospatial information. These assessments are usually carried out under financial and technical constraints and encounter challenges in obtaining up-to-date information.

Geospatial technologies are a powerful hazard impact assessment tool that can be used to assess the effects of hazards on the agriculture sector, properties, lives and livelihoods, and monitor the impacts and post-disaster damage for post-disaster recovery, reconstruction and rehabilitation. The timely provision of geospatial information is crucial in the decision-making process and can protect and mitigate damage, save lives and livelihoods, and rescue citizens. Real-time access to data and the use of high-resolution spatial datasets can provide essential information to scientists and engineers, helping them to better understand, categorize and manage risks.

This report highlights the crucial role of recent geospatial technological advances in providing supportive responses to disasters and crisis situations. In particular, the latest advances are described, examples of applications in different countries and contexts are presented, key challenges are identified and recommendations for effective responses are proposed. It also illustrates the multiple uses and integration of different geospatial tools, data and applications, and provides details on impact assessment data requirements, with a focus on agricultural resources using multiple national case studies. This publication can help national stakeholders and technical partners benefit from advanced geospatial technologies in emergencies for agriculture sector impact assessments and monitoring.

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This report is the result of a joint effort of the Geospatial Unit at the Land and Water Division, and the Data in Emergencies Team in the Office of Emergencies and Resilience in FAO. It summarizes the role and application of geospatial tools in disaster impact assessments. It also further highlights the challenges, opportunities and lessons learned. Selected case studies are presented to illustrate how geospatial assessments can further our understanding of hazard impacts, and also highlighting limitations which need to be tackled in the future.

Special thanks to a wide range of platforms and stakeholders, including FAO Country Offices, the United Nations Institute for Training and Research (UNITAR), United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM), Joint Research Center (JRC) – European Commission (EC), European Space Agency (ESA), National Aeronautics and Space Administration (NASA) and other partners for their wide application and support in terms of providing data and images as well as highlighting the contribution of integrated geospatial platforms in analysis and dissemination of geospatial data. We also thank the Agrifood Economic Division, Statistics Division, and Forestry Division at FAO as well as Environmental Systems Research Institute (ESRI) for their support in different ways for conducting these assessments.

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Abbreviations

ASTER	advanced spaceborne thermal emission and reflection radiometer
AOD	aerosol optical depth
AOI	area of interest
AI	artificial intelligence
ANN	artificial neural network
ADAM	advanced disaster analysis and mapping
CEO	open foris collect earth online
CO	carbon monoxide
CCD	coherent change detection
DEM	digital elevation model
DIEM	Data in Emergencies
DPM	damage proxy map
EO	earth observation
ESRI	Environmental Systems Research Institute
EVI2	enhanced vegetation index 2
ECMWF	European Centre for Medium-Range Weather Forecasts
EWS	early warning system
FRP	Fire Radiative Power
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Corporate Database for Substantive Statistical Data
GB-InSAR	ground-based interferometric synthetic aperture radar
GIS	geographical information system
GADM	database of global administrative areas
GAUL	Global Administrative Unit Layers
GAEZ	Global Agro-Ecological Zoning
GPS	global positioning system
GEE	Google Earth Engine
GDP	gross domestic product
HDX	humanitarian data exchange
HOT	humanitarian openstreetmap team
HYSPLIT	hybrid single-particle lagrangian integrated trajectory
ICT	information and communication technology

IoT	Internet of things
InSAR	interferometric synthetic aperture radar
IPC	integrated food security phase classification
LANCE	land, atmosphere near real-time capability for earth observing system
LDCs	least developed countries
LIDAR	light detection and ranging
LMICs	lower-middle-income countries
MODIS	moderate resolution imaging spectroradiometer
MLP	multilayer perceptron
NASA	National Aeronautics and Space Administration
NCDC	national climatic data center
NGDC	national geophysical data center
NOAA	national oceanic and atmospheric administration
NDVI	Normalized Difference Vegetation Index
OSM	Open street map
RVI	radar vegetation index
RS	remote sensing
SRTM	shuttle radar topography mission
SEDAC	socioeconomic data and applications center
SVM	support vector machine
SAR	synthetic aperture radar
UVAI	ultraviolet aerosol index
UAV	uncrewed aerial vehicle
UNDRR	United Nations Disaster Risk Reduction
UNOSAT	United Nations Satellite Centre
UNSALB	United Nations Second Administrative Level Boundaries
VHR	very high resolution
VIIRS	visible infrared imaging radiometer suite
WDS	World data service

Executive summary

Significant natural and human-induced hazards, crises and conflicts regularly cause economic and social damage to the agriculture sector, consequently impacting the most vulnerable regions across the globe, which are highly dependent on this sector. It is estimated that economic losses resultingfrom natural hazards have increased fourteen times since the 1950s. There is a growing need for effective, timely and accurate disaster risk reduction assessments, as well as the development of sustainable solutions and that are effective in overcoming the effects of disasters, as reflected in the United Nations Sendai Framework for Disaster Risk Reduction 2015-2030. The impact of hazards can be reduced through mitigation, preparedness, response and recovery. Geospatial technologies have made significant progress over the past decades, including in the area of Disaster Risk Reduction.

Innovation in geospatial technologies includes the increasing availability of very high spatial resolution optical and radar data, advanced algorithms and artificial intelligence to process and analyse big data on cloud-based computing platforms. Despite significant advances in geospatial technologies in disaster management, several challenges remain, including differences in data accessibility and technological constraints, as well as the availability of trained personnel to obtain, analyse and interpret the data. A key overarching challenge is how to rapidly integrate remote sensing inputs with other geospatial layers and field data to produce timely, clear and actionable outputs to guide decision makers in emergency situations. Meeting this challenge requires clear processes and standard operating procedures, as well as action oriented and easily accessible dissemination platforms.

This report highlights the essential role of geospatial technologies for hazard impact assessments and their applications in this field. This report presents a set of studies in different countries and context on floods, volcanic eruptions, pests and conflicts that reflect the challenges, opportunities and lessons learned for national stakeholders and technical partners to benefit from advances in geospatial technologies to assess and monitor potential impacts of disasters.

The report makes recommendations to build capacity, improve data coordination and management, and make better use of technological innovations. Finally, the Annex illustrates one way in which FAO is responding to the challenges highlighted in the report through the Data in Emergencies (DIEM) Geospatial Hub, housed in the FAO Office of Emergencies and Resilience.

1. Introduction

Floods, droughts, volcanic eruptions, earthquakes, dust storms and wildfires, as well as man-made crises, including violence and conflicts, oil spills, dam failures, toxic wastes, industrial pollution, transport accidents, factory explosions, fires and chemical spills, have a significant impact on the environment, livelihoods and infrastructure worldwide, resulting in significant economic and social harm and damage (FAO, 2015). Economic losses resulting from natural hazards are estimated to have increased fourteen-fold since the 1950s (Sivakumar, 2014) and the loss in the agriculture sector in least developed countries (LDCs) and low and lower-middle income countries (LMICs) is estimated as USD 108 billion between 2008 and 2018, (FAO, 2021). The effects of natural hazards, conflicts, pests and diseases are greater in these countries dueto the lack of essential resources, basic infrastructure and adequate disaster and/or conflict management systems. This contributes to social insecurity and creates conflicts related to the scarcity of natural resources. There is a growing need for comprehensive and timely disaster risk assessments, as well as the development of sustainable and effective solutions to overcome the adverse effects of natural hazards and conflicts.

The need for impact assessments is recognized in the United Nations Sendai Framework for Disaster Risk Reduction 2015-2030, which recommends "to promote and improve, through international cooperation, including technology transfer, access to, sharing and use of non-sensitive data and information, as appropriate, geospatial and space communications and technologies and related services", as well as "disseminating risk information by making the best use of geospatial and space-based technologies and related services" at global and regional levels (UNDRR, 2015).

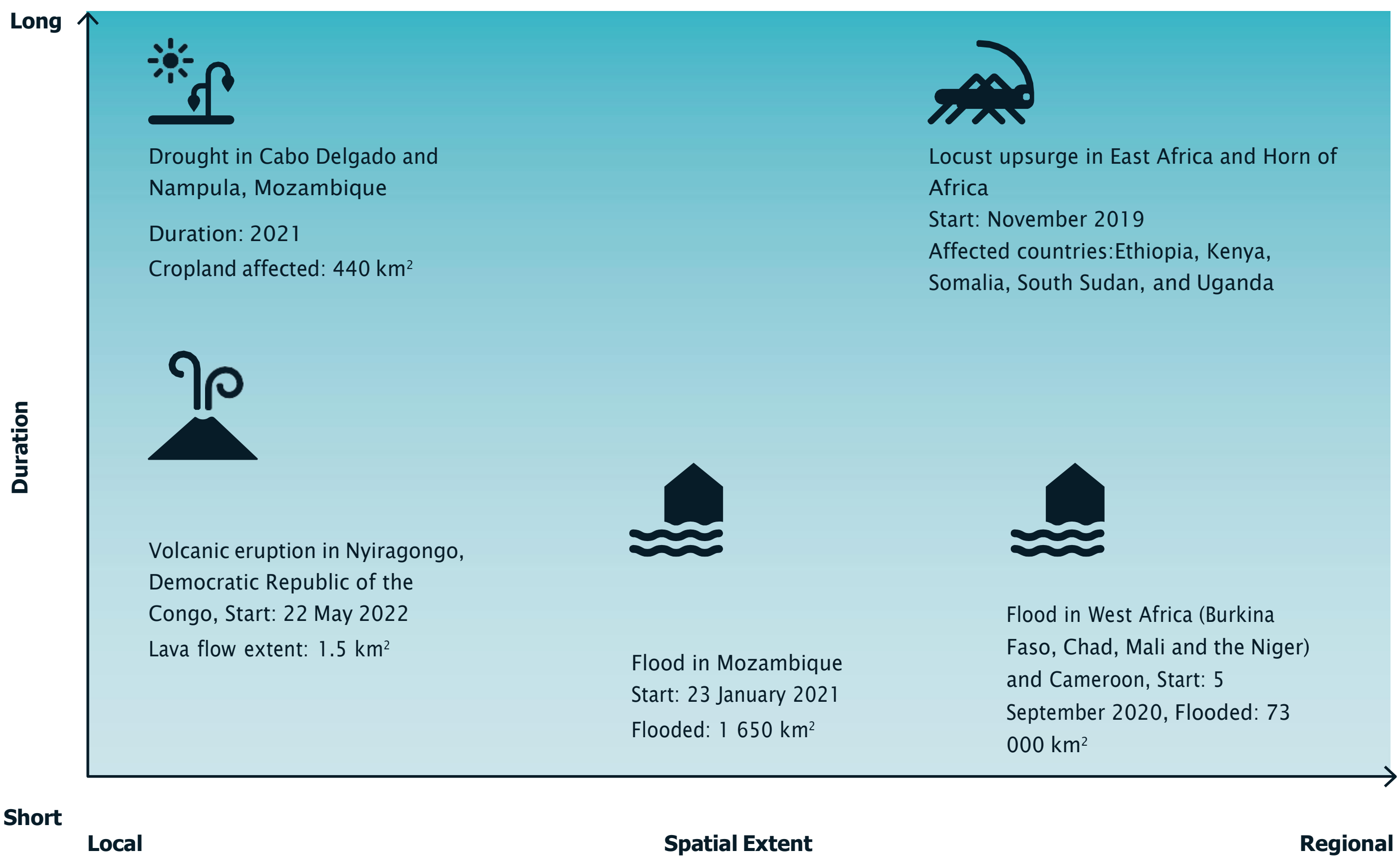
Impact assessment of emergencies are very diverse depending on the type of hazard, the needs of the impacted areas and the means available to conduct the assessment. The process mobilizes various information (past and present), from primary, secondary, and tertiary sources, via remote sensing datasets or information collected in the field. Typically, remote sensing refers to satellite, airborne or proximal sensing information. Field measurements refer to the collection of socioeconomic and/or biophysical information from the ground. The information can be collected atregular time intervals, such as in the context of the census or national or subnational monitoring systems, or can be irregular, for example during specific and non-perennial measurementcampaigns. Also, the assessments bring together different forms of information used by the multiple entities involved directly or indirectly in hazard impact assessments. Looking more closely at the different types of impacts helps identifying the diversity of data and informationrequired.

The impact assessments can also be conducted in various ways, using different datasets, depending on the changes observed in water, land, vegetation, geology, atmosphere, infrastructure and population. For example, the impacts of floods, tsunamis, cyclones and other extreme climatic events can be identified, among others, by assessing changes in water extent, depth and water color. Similarly, landslides and land degradation can be monitored by changes in soil properties and vegetation. Drought, diseases, pests and fires can be characterized by changes in vegetation. Volcanic eruptions, nuclear contamination, earthquakes, and conflicts can directly impact the livelihood of local and/or regional populations. In most cases, the agriculture sector can be impacted at different levels because of its dependence on natural resources, and its spatial and temporal variability is important and often more complicated and dynamic than other sectors.

The agriculture sector, represented in a systematic way, can be characterized by many agro-edaphic, climatic, and socioeconomic factors. Some of the widely used characteristics are the size of farms, types of crops, income, capital, labour, level of education, climate, types of soil, etc. In most cases, information concerning the agriculture sector, at the national or subnational levels, is represented in agricultural statistics, derived from agricultural censuses and aggregated at the administrative level. Administrative delineations can, up to a certain limit, represent the agronomic context and be used to provide more concise or aggregated information, based on national or subnational statistics, of the status of the sector for a given geographical area.

Impact assessments also involve diverse perspectives considering a wide diversity of information and dimensions, multidisciplinary approaches, and a good knowledge and experience in handling various information. Spatio-temporal dimensions are particularly important to consider and are specific to the context of the impact evaluation. The approaches to measuring the impact of a flood or a conflict may be very different depending on the parameters, including the spatio-temporal dimensions (Figure 1). For example, there may be localized conflicts over a relatively small area or prolonged conflicts over large areas. The same applies to floods, earthquakes, and other natural hazards. Data collection processes can also be rapid (in the field, as well as through remote sensing) or relatively slower (e.g. agricultural censuses). The methodological approaches generally have to adapt to the type of impact and to the data and means available.

Figure 1: Characterization of disasters considering spatio-temporal dimensions

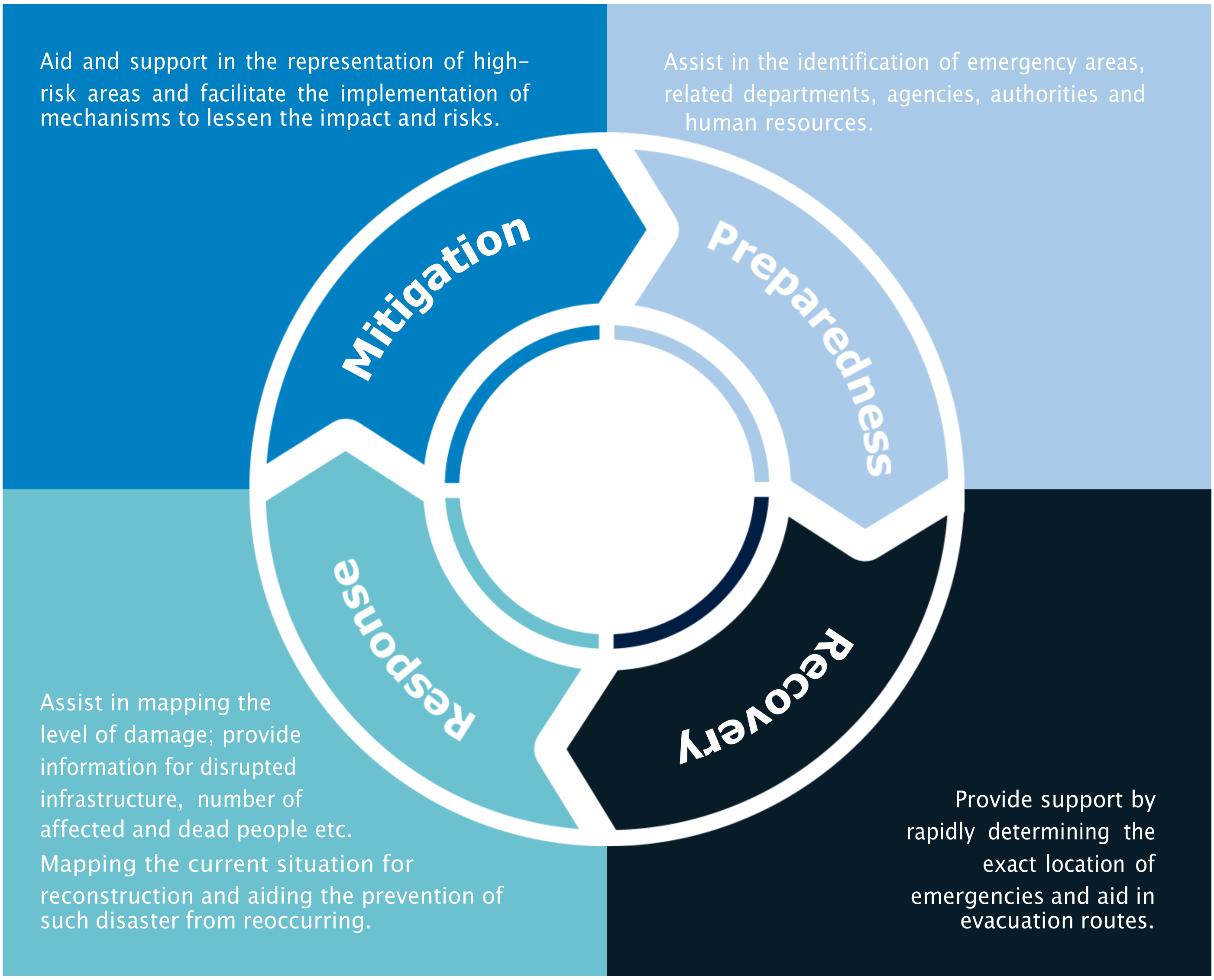


Source: Elaborated for this report.

Geospatial technologies are among the tools used for hazards agricultural impact assessment. Over the past few decades, there has been a continuous growth in computing power in terms of processing speed, data storage capacity and analysis, and computer graphics capabilities. Similarly, information technology applications in the geospatial domain have made significant progress. This trend is also reflected in the increasing use of geospatial technologies such as remote sensing and geographic information systems (GIS) used in data collection, analysis and visualization. With the introduction of mobile GIS solutions, cloud-based data storage, crowdsourcing methodologies, internet of things (IOT), big data, and machine learning models, this trend is set to continue.

Although natural events cannot be avoided, potential disasters and their consequences can be managed by developing and implementing appropriate disaster management plans to minimize the loss of lives and assets. Geospatial technologies play an important role in all four components of the disaster management cycle (Figure 2), namely, mitigation, preparedness, response, and recovery. In this context, geospatial technologies, such as remote sensing, GIS, GPS, and other emerging technologies (Ramanamurthy *et al*., 2008), have much to offer in the quest to reduce disaster risks in the agriculture sector, with different applications in the various phases of the disaster management cycle (Figure 2).

Figure 2: Disaster management cycle and geospatial support



Source: Elaborated for this report.

Example of high spatial resolution images from WorldView constellation on a flooded area in Sudan, Kassala city 2022. © Maxar

Despite the capabilities of geospatial tools and technologies in disaster management, most practitioners still face several challenges, including differences in data accessibility and technological constraints between developing and developed countries, as well as the availability of trained personnel to obtain, analyse, and interpret the data. Additional bottlenecks include dealing with the huge amounts of data generated by earth observation (EO) instruments, a lack of robust field, national, and statistical datasets, and limited technical innovations for certain areas.

The aims of this report are to: i) highlight the essential role of geospatial technologies in any disaster emergency; ii) describe their applications in this field; and iii) provide national case studies reflecting challenges, opportunities, and lessons learned. The report is expected to support national stakeholders and technical partners to benefit from advanced geospatial technologies during emergencies to assess and monitor the potential consequences.

2. Emerging geospatial technologies for disaster management in the agriculture sector

Remote sensing forms the core of geospatial applications to disaster management due to its rapid data acquisition capabilities in the pre- and post-disaster phases (Joyce *et al.*, 2009), as well as its ability to obtain information of difficult-to-access areas. Remote sensing data includes satellite imagery, aerial images (e.g. from manned and unmanned airborne vehicles) and data collected from proximal sensors, e.g. ground-based interferometric synthetic aperture radar (GB-InSAR), terrestriallaser scanning and infrared thermography (Casagli *et al.*, 2017).

In recent decades, satellite-based observations and their geospatial products have proven to be highly valuable tools in each phase of the disaster management cycle. Earth observation missions, with increasing temporal and spatial resolution, have become an essential element in the acquisition of real-time data to feed into operational early warning systems, crop production models, and the monitoring of yield and production. They can also support and provide information about loss and damage from disasters through various disaster impact assessments.

In particular, imagery from spaceborne instruments (e.g. MODIS, ASTER, Landsat 4, 5, 7, 8, 9 and Sentinel-1 and 2) can be employed to generate hazard and disaster risk maps. Optical and radar imagery are routinely used to map and evaluate the distribution of risk over wide and remote areas. For example, images from synthetic aperture radar (SAR) sensors can be adopted during the disaster response phases as they are not affected by dense cloud conditions and the time of day. Whereas optical satellite data are used to monitor changes induced on agricultural land following a disaster and may be more suitable for disaster response and recovery.

The use of satellite imagery for crop monitoring has been limited during the past decade, mainly because of the cost associated with higher spatial and temporal resolution commercial data, including the costs related to the use of unmanned aerial vehicle (UAV) for finer resolution datasets. Currently, the significant progress in making higher resolution analysis-ready satellite data accessible, combined with cloud-computing platforms and the growing use of UAVs, fielddata collection tools, as well as other geospatial technologies, has increased the application ofsuch data to support of resilient agriculture and food security.

The application of airborne (UAV) and ground-based (terrestrial laser scanner) datasets is less common in emergency impact assessments, however they can still prove to be useful, allowing for the investigation of indicators at a finer spatial resolution and with more precision compared to satellite-based observations. Examples include the use of aerial imagery to assess the damage of urban structures following a seismic event (Calantropio, 2018); the high-resolution mapping of morphological features from UAV digital imagery following a landslide (Casagli *et al.*, 2017); flood extent mapping using UAV optical imagery (Hashemi-beni and Gebrehiwot, 2021); assessing the impacts of landslides using a terrestrial laser scanner to build a three-dimensional (3D) surface model (Casagli *et al.*, 2017) and GB-InSAR to identify deformation zones (Xiao *et al.*, 2021).

GIS is a crucial tool in disaster risk assessment for the generation of maps, the analysis of risk indicators, and the visualization of data and scenarios by providing critical information following a disaster, for example, the number and location of affected people (Munawar, 2021). GIS can combine data sources of varying accuracy, scales, and formats into one source for mapping, modeling, and decision making based on spatial data (Sylka, 2020). GIS approaches are typically employed for the analysis of remote sensing data. For example, the identification of regions vulnerable to landslides via the evaluation of land cover maps based on the classification of satellite imagery and additional information (e.g. topography and geomorphology), or the mapping of flooded areas using digital elevation models (DEMs) (Manfré *et al.*, 2012). In fact, most geospatial applications in disaster risk assessments require the integration of remote sensing, GIS, and global navigation satellite systems (GNSS).

Location is a crucial component of disaster management (Westlund, 2010), and thus GNSS (or commonly known as GPS) data is almost always adopted in the assessments of disaster and crisis situations as it provides rapid and accurate location information (Manfré *et al.*, 2012). Obtaining GPS data is also inexpensive (Sylka, 2020). In addition to providing locations of factors in a disaster assessment, GPS technology also has more complex applications. For example, the assessments of landslides by combining interferometric SAR (InSAR) with a GPS monitoring network (Ma *et al.*, 2022) and the estimation of infrastructure damage following a disaster (Raj K *et al.*, 2016). Saha *et al.* (2018) proposed an autonomous quadcopter, to aid in disaster management (e.g. the provision of essential supplies, water spraying during fires, live broadcasting of difficult to reach situations, etc.) based on high-precision GPS.

The great advances in technology and informatics have launched geospatial approaches to another level, with the integration of emerging technologies and applications. This includes artificial intelligence, which mimics human intelligence in computers (Mohan and Mittal, 2020). For example, Schedl *et al.* (2021) presented an airborne robotics system for automated search and rescue missions based on synthetic aperture sensing, and Tadokoro *et al.* (2019) proposed a robotic system for tunnel disaster response and recovery. Machine learning, a branch of artificial intelligence, denotes algorithms and software that are able to perform a task without explicit instructions (Abid *et al.*, 2021). For example, Munawar and Ullah (2019) developed a model that integrates image processing and machine learning (ML) algorithm, for damage assessments following floods based on UAV images. The internet of things (IoT) is defined as a network of physical objects (e.g. sensors, buildings, vehicles) that are able to collect and exchange data via networks, software and electronics. (Rauniyar *et al.*, 2016). Example applications of Internet of Things as geospatial tools for disaster assessments include the mounting of sensors on trees to indicate the presence or risk of fires based on temperature, carbon monoxide (CO) concentrations, etc. (Saha *et al.*, 2017) and Grillo, an accelerometer platform that alerts users of potential earthquakes and tsunamis via Wi-Fi (Ray *et al.*, 2017).

Crowdsourcing, defined as “a collaborative problem-solving activity, performed online, to work on a certain, well-defined, and simple task by an undefined and large group of contributors” (Grote *et al.*, 2019), has become a popular tool for disaster assessments, with the ability to obtain close-to real-time information and increased awareness of the current disaster situations (Clark and Gui, 2018).

A team of agricultural engineers from the Department of Agriculture and Food and Agriculture Office for the United Nations continue their week-long drone training and mapping in different areas of the Pampanga province, considred as one the provinces that is part of the 'rice bowl' of the Philippines or the ones supplying rice in the Philippines on 05 JULY 2018. © FAO/VEEJAY VILLAFRANCA

For example, Dede *et al.* (2019) fused participatory mapping and crowdsourcing with remote sensing and GIS for flood risk assessments. Ogie *et al.* (2019) evaluated PetaJakarta.org,[1] a project based on social media that aimed to collect flooding information in Jakarta from community input and has now been replaced by the disaster mapping platform PetaBencana,[2] which extends crowdsourced flood maps to other cities in Indonesia. Web-based platforms such as Humanitarian OpenStreetMapTeam create open crowdsourced maps in the event of a disaster using data inputs from volunteers.[3] Furthermore, Nizamuddin *et al.* (2019) developed a web-based GIS platform with the aim of providing key GIS data for disaster management, including inundation areas, earthquake hazard levels, and populations affected by disasters, accessible to all users of GIS applications.

The vast increase in smartphone usage has resulted in the integration of smartphone applications as geospatial tools in disaster assessments. Yamori and Sugiyama (2020) describe Nige-Tore, a smartphone application for tsunami evacuations, where users can check flooded areas, evacuation routes, etc.; and uRep is a smartphone application that integrates crowdsourcing, allowing users to report disasters via a geo-tagged photo in the absence of a network via GPS (Goncalves *et al.*, 2014).

[1]https://petajakarta.org/banjir/en/index.html

[2]https://petabencana.id/

[3]https://www.hotosm.org/

In the Niger, as in many other parts of the Sahel, climate shocks have resulted in recurring droughts with devastating impacts on the region's already vulnerable populations. RBA UN Agencies (FAO, WFP and IFAD) along with the Government of the Niger and other partners visited the agropastoral Maradi region of the Niger to understand the context and local priorities. © FAO/IFAD/WFP/Luis Tato

3. Assessing the potential impacts of crises and shocks on agriculture using geospatial technologies

Natural hazards, pests, diseases and conflicts adversely impact the communities and the agriculture sector in a variety of ways, including crop failure, damage to the environment, infrastructure, and communication networks, which pose a serious threat to sustainable agriculture, food security, and livelihoods.

In addition, agricultural products are highly sensitive to climate change (Dalezios *et al.*, 2019), and thus extreme climate events typically exert detrimental effects. Direct impacts include damages to crops, animals, and machinery, while indirect impacts encompass production losses, an increase in production costs, and reduced production capacities following natural hazards and/or conflicts (Sivakumar, 2014). For hard-hitting disasters, the aftermath can alter the markets, leading to the migration of populations (Naqvi and Monasterolo, 2021).

The reductions in crop and livestock production following disasters and crises between the years 2008–2018 were estimated to result in billions of dollars in losses: 30 billion USD in sub-Saharan and North Africa; 29 billion USD in Latin America and the Caribbean; and 49 billion USD in Asia.

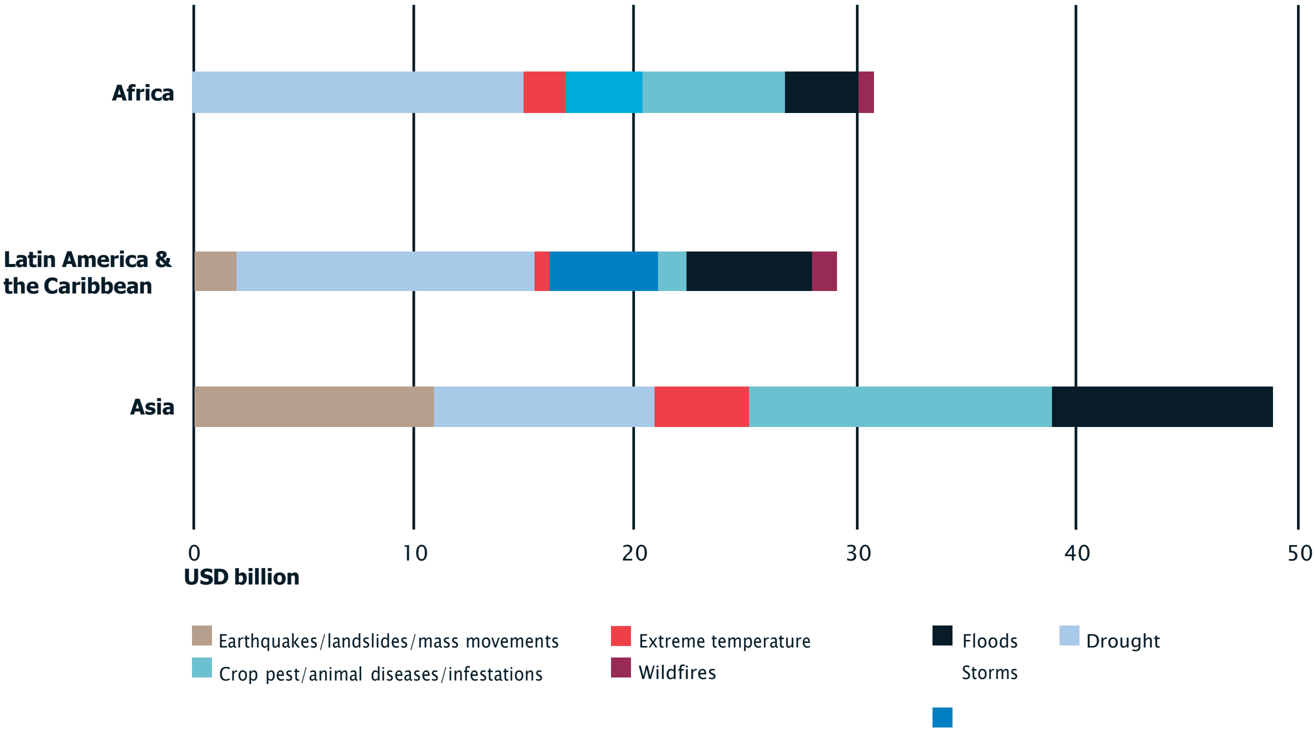
Drought is identified as having the greatest impact on the decline in agricultural production, followed by floods (FAO, 2021). Shimada (2022) determined cereal production in Africa to be the worst-hit crop by disasters, particularly drought (maize) and storms (rice and fonio).

In China, from 1982 to 2012, floods reduced crop yield by up to 6.8 percent and up to 11.6 percent by drought, with maize and soybean being the most affected by drought (Shi *et al.*, 2021).

Recent years have seen multiple disaster events and crises (e.g., the COVID-19 pandemic, the appearance of extensive desert locust swarms in Africa and the Atlantic hurricane season), exerting great impacts on agriculture (Figure 3).

COVID-19 has had a particularly strong effect on farmers, reducing access to inputs, farmland, and labour (FAO, 2021). For example, farmers across the globe could not sell their products due to border restrictions, and agricultural facilities were closed to meet social distancing requirements (Mishra *et al.*, 2021).

Figure 3: Total losses in crop and livestock production by region and disaster, 2008-2018



Source: FAO. 2021. The impact of disasters and crises on agriculture and food security. Rome. https://www.fao.org/3/cb3673en/cb3673e n.pdf

The impacts of COVID-19 are further amplified following the occurrence of other disasters, resulting in a so-called compound disaster. For example, regions in the United States of America, southeastern Australia, South America, and Africa experienced drought during the COVID-19 pandemic, which reduced crop yields and revenues, while COVID-19 exerted additional impacts on food supply and demand, possibly resulting in bankruptcy and unemployment in the agriculture sector (Mishra *et al.*, 2021).

3.1. Rapid onset and slow onset hazards

A hazard can be defined as "a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage" (UNISDR, 2015). Each hazard type is characterized by its location, spatial distribution, intensity or magnitude, frequency, and probability. Hazard characteristics vary by type and include identity, extent, nature, intensity, scope, predictability, and manageability (USAID, 2011).

Natural hazards can be grouped as geological, hydrometeorological, and biological-based on their origin, and further classified into short-term and long-term hazards. Rapid onset natural hazards are any naturally occurring hazards that last for a short period of time and can cause injury, damage, and/or illnesses, and include earthquakes, flooding, and fires that may or may not be related to climate change. Slow onset hazards denote any naturally occurring hazards that last for a long period of time and cause severe injury, damage, and disruption, such as prolonged droughts, desertification, land degradation etc. Conflict is defined as a clash between inter and/or intra groups, countries and regions arising out of a difference in understanding, interests, requirements and people. Conflicts can be of short (e.g. fight or battle between two or more groups) and can be for long (e.g. war) duration. As a general rule, the longer the hazard and/or conflict the more severe it is likely to be.

The significant consequences of natural hazards and/or conflicts across the globe, as well as the projected increases in disaster-related risks, place great emphasis in acquiring and understanding accurate information related to risks using geospatial technologies for all stages of disaster management, including risk identification and reduction, developing preparedness solutions, and prioritizing effective response and recovery efforts. Table 1 reports the contributions of geospatial data and tools in various hazard risk assessments.

Table 1: Contribution of geospatial data and tools in hazard assessments.

Hazards	Brief description	Examples
Floods/flash floods (presented in this report)	Floods occur with heavy rain. They are sudden events with a high frequency and wide geographic distribution. Flash floods are short-term hazards with a high peak discharge, rapid increase in flood flow rate.	Baseline information including shoreline position, elevation, water extent, historical flood extent, land cover/use information, etc. Geospatial technology allows for the rapid observation and monitoring of flood extent and flood severity on land and crops based on high-resolution satellite or aerial imagery (optical and radar). Image processing algorithms for flood analysis include water classification, object extraction (to detect key infrastructures), and edge detection (to identify water lines), Additional algorithms include the use of artificial neural networks (ANN) for water flow simulations and prediction of water elevation (Munawar and Ullah, 2019). Hydrodynamic and DEM models can be applied for flood simulations. Results can be integrated with other data sources (e.g. agricultural statistics, elevation, slope, distance to rivers, irrigation regime, soil type, location of schools and hospitals, etc.) to derive economic impact assessments. Participatory mapping can be employed to obtain data, for example, flood level data.
Diseases and pests (presented in this report)	Occur when ecological and weather conditions favor breeding for insects. Insects work as a group rather than as individuals and within a few weeks' swarms form and search for food. They can be both short and long-term.	Baseline information for proxy variables such as vegetation health, land productivity, yield, and productivity. Geospatial tools and data are used to monitor proxy variables and impacted land areas. Crop health and soil conditions can be monitored, and crop yield can be forecast from satellite and UAV imagery, as well as proximal spectral measurements. Imagery and spectral measurements can also be used for the detection of diseases and pests based on certain indicators (e.g. vegetation indices). Data relating to disease and pests can be obtained from field sensors on temperature, rainfall, relative humidity, etc. Crowdsourcing can be employed to obtain up-to-date information of pest infestations.

Volcanic eruptions (presented in this report)	Volcanic eruptions occur when molten rock and gases originating from the Earth's crust are released via volcanoes. They are categorized as short-term hazards and their occurrence can result in the formation of other hazards (e.g. tsunamis, landslides).	Baseline information, such as the mapping of agricultural infrastructure and communities, crop type, crop extent, crop statistics, and preparation of land cover/use, assessment of ash cover/direction and identification of craters, etc. can be obtained from satellite and aerial imagery, ground sensors, and national and field data. Satellite imagery and air parcel trajectory modeling can be used to trace the path of volcanic plumes. Gases and aerosols released from volcanic eruptions can be monitored using ground sensors and satellite imagery. Meteorological data (temperature, precipitation, relative humidity, wind speed) is required to assess the impact of the volcanic plume. SAR interferometry is used to create deformation maps for ongoing risk evaluations.
Conflict (presented in this report)	Conflicts are human hazards and include armed combat, terrorist attacks, violence against civil populations, theft and looting, and kidnapping (Arias *et al.*, 2012). These are both short- and long-term hazards.	Baseline information for agricultural structures (greenhouses, orchards, crops, etc.,), militant and firing activity, damaged areas, and communities (access routes, affected populations, households, settlements, etc.) using very high-resolution imagery in re- mote or inaccessible areas. Satellite night- time light products can be used to monitor conflict activity. The Coherent Change Detection method applied to public and commercial SAR imagery can be used to assess damages to infrastructure.
Drought	Droughts are long-term hazards that are characterized in terms of their severity, location, duration.	Baseline information of various indices for drought assessment allowing for drought monitoring, drought severity, extent, du- ration, and intensity. Drought indices are based on numerous indicators including precipitation, evapotranspiration, soil moisture, temperature, groundwater, etc.). Drought can also be estimated using spectral indices (e.g. vegetation and water indices) and land surface temperature deter- mined from remote sensing datasets or modeling that use remote sensing data as inputs.

		Results can be integrated with other data sources (e.g. agricultural statistics and meteorological data) to derive economic impact assessments. Specifically, SAR sensors are sensitive to soil moisture and have been demonstrated to be indicative of detecting soil moisture anomalies (Greifeneder *et al.* 2019).
Fires	Fires are short-term hazards and can be- come uncontrollable. Biomass fires are both naturally and anthropogenically induced. Wildfire hazards must be considered to identify the local threats and risk towards people and wildlife, and to educate and motivate the community.	Baseline information for fire occurrence, intensity, and hotspots from satellite imagery can be used for the rapid assessment of impacted areas and monitoring. Emissions from biomass burning can be monitored from satellite, aerial, and proximal remote sensing observations. Used with additional geospatial tools (e.g. land cover and land use maps, ecoregions, slope and elevation maps, burned area), national data (crop statistics, population, infrastructure, road networks), and climate data (temperature, rainfall, wind speed) and field data (biomass estimates, biomass types).
Landslides	Landslides are slides and flows of unconsolidated materials. They occur due to heavy rain or the rapid melting of snow or ice. These are frequent long-term natural hazards and have significant con- sequences on humans and the environment.	Baseline information including lithology, slope (angle and length), morphology, land cover/use, lineament density, distribution, altitude, drainage, digital terrain maps, geo- logical maps, roads, etc. Combined with data on temperature, rainfall, water table, evapotranspiration, seismicity. Rapid impact assessment of the impacted areas including agricultural land, residential areas, etc.
Land degradation	Land degradation typically occurs in arid, semi-arid, and dry sub-humid areas. It is a long-term silent and invisible crisis.	Baseline information for historical vegeta- tion, soil, and water changes, vegetation and water indices, land cover, land use, yield estimates, land productivity, carbon stock, etc. Phenomena such as land cover changes or erosion propensity can be defined by GIS models. Such tools and data support national monitoring landscape restoration activities.

Storms	Storms are a result of the simultaneous occurrence of strong winds and rain. They are classified as short-term hazards.	Baseline information includes sea wave height, wind speed, precipitation, surface currents, land cover/use, etc. during storms.
Tidal surge / tsuna-mi	Tsunamis are period waves generated following other hazards such as earth-quakes, undersea landslides, and volcanic eruptions.	Baseline information including nearshore bathymetry, land elevation, infrastructure, communities, land cover/ use, etc. These datasets and tools support the rapid im-pact assessment of the impacted area and changes in nearshore bathymetry. Internet of Things and smartphone apps for tsunami early warning systems.
Extreme weather events	Heat waves typically occur in mid-latitude regions during the hot months. Heat wave temperatures exceed the long-term averages of the day and night over a pro- longed period. Extreme cold spells are also life-threatening. Heat waves are typically short-term hazards.	Baseline information of long-term water temperature, water supply, the extent of sea, lakes, ice, river ice, evapotranspiration, water productivity, terrestrial surface temperature, salinity, extreme events, etc.
Earthquakes	Earthquakes are short-term hazards that occur due to the sudden release of slowly accumulated strain energy at the collision zones between tectonic plates.	Information for damage and monitoring assessments (e.g. damaged buildings, roads, access routes, infrastructure, land cover maps, location of water bodies). Support response and relief decisions (e.g. Internet of Things sensor systems for earthquake detection in earthquake-prone regions, smart- phone apps for evacuations).

Note: Rapid deployment of field verification teams using tools such as KoBo collect and Survey as well as crowd sourced verification exercises can be critical to ground truth remote sensing and modelling outputs. These methods come with in-built geo-location capabilities.

3.2. Data requirements for hazard impact assessments

FAO has over 30 years of experience in the development and use of geospatial data,methods, and tools, applied to national, regional, and global sustainable development planning and implementation. FAO support countries in the application of appropriate geospatial solutions to create sustainable food systems and resilient agriculture. Following the occurrenceof a hazard, an assessment of the damage and needs is carried out to determine the emergencyresponse actions. Table 2 provides details of the data required for the disaster impact assessments.

Table 2: Spatial data requirements for impact assessments and examples of data sources in addition to national data sources

Data	**Area of interest (AOI)**
Content	For any disaster risk/impact geospatial assessment, the first required datais the AOI to set the boundaries of analysis. Typically, a first assessment is conducted to identify the observed damages and then the subnational boundaries (at district or village level) that encompass the damaged area are set as the AOI/s. This has the advantage of allowing comparisons and the integration with socioeconomic and agricultural statistics.
Example data sources	HDX,[4] GAUL,[5] GADM,[6] and UNSALB.[7]
Data	**Earth observation (EO) data**
Content	The availability and use of high-resolution satellite imagery have increased dramatically in recent years. The crucial benefit of remote sensing is the observation of large and often remote or inaccessible areas, typically at a fraction of the cost of ground-based surveys in disaster impact assessments. The main types of remote sensing systems used in disaster assessments are optical (Sentinel-2,[8] Landsat 8[9] and 9[10]), thermal, radar (Sentinel-1[11]), and LiDAR. Land cover maps are an integral part of disaster risk assessments and denote any data collected on the ground to characterize the status of natural resources. Land cover maps are combined with EO data for damage assessments. Additional key products of EO data include fire hotspots, fire radiative power (FRP), atmospheric gas concentrations, AOD, UVAI, vegetation and water indices, soil maps, snow/ice cover, atmospheric winds, and surface temperature.
Example data sources	Sentinel-1, Sentinel-2, Landsat, MODIS, Worldview, and LANCE.

[4]https://data.humdata.org/organization/hdx
[5]https://www.fao.org/in-action/countrystat/news-and-events/events/training-material/gaul-codes2014/en/
[6]https://gadm.org/index.html
[7]https://www.unsalb.org/
[8]https://sentinel.esa.int/web/sentinel/missions/sentinel-2
[9]https://www.usgs.gov/core-science-systems/nli/landsat/landsat-8
[10]https://www.usgs.gov/core-science-systems/nli/landsat/landsat-9
[11]https://sentinel.esa.int/web/sentinel/missions/sentinel-1

Data	**Aerial and proximal remote sensing datasets**
Content	Aerial imagery offers data at a greater spatial resolution compared to satellite products, although its availability is limited. Useful image types include RGB, multispectral, and IR, allowing for land cover classifications, waterbody identification, damage detection (buildings, roads, infrastructure), monitoring of crop health, digital elevation model (DEM) etc. Airborne Lidar data can be employed in flood assessments, identification of damaged infrastructures etc. Proximal remote sensing datasets can be obtained at a fine spatial scale and include multispectral, hyperspectral and IR measurements.
Example data sources	Field campaigns, university research projects, EarthExplorer, and OpenAerialMap.
Data	**Socioeconomic data**
Content	For the validation of disaster impact assessments, it is important to have and/or to prepare socioeconomic data using geospatial tools and applications. Commonly used socioeconomic data is listed below: · Population and household data at lowest administrative level; · Gross Domestic Product (GDP) or income data; · Social vulnerability data including poverty, population density, rural population, agriculture sector employment, literacy, GINI index; · Ecosystem vulnerability data including forests, protected areas etc.; · Coping capacity data (e.g. access to markets, road networks, early warning systems etc.); · Adaptive capacity data; · Livelihood data; and · The Integrated Food Security Phase Classification (IPC) data.
Example data sources	WorldPop,[12] SEDAC,[13] IPC,[14] DIEM, GIEWS, and VAM.
Data	**Crop data**
Content	Crop calendar, crop type, crop production, irrigation schemes and land cover and/or use data etc.
Example data sources	GAEZ,[15] FAO Crop Calendar,[16] GEOGLAM Crop Calendar,[17] and GIEWS.[18]
Data	**Water management information**
Content	Canals, rivers, and water bodies etc.
Example data sources	EO classifications.

Spatial data requirements for impact assessments and examples of data sources in addition to national data sources

Data	**Ancillary data**
Content	Road networks, households, infrastructure, bridges, airports, and ports etc.
Example data sources	OSM,[19] and SEDAC.
Data	**Meteorological data**
Content	Temperature, wind speed, precipitation, and relative humidity etc.
Example data sources	Regional monitoring stations, NASA Giovanni,[20] and NOAA NCDC.[21]
Data	**Crowdsourcing**
Content	Up-to-date data during disasters and crises from citizens.
Example data sources	Social media, Citizen Science,[22] Open Cities Africa,[23] Open Cities Asia,[24] and HOT.[25]
Data	**Field data** (FAO Data in Emergencies (DIEM) team)
Content	· Validation of land cover maps and other EO products. · Act as training data when cloud cover limits EO data. · Crop phenological measurements. · Soil samples.
Example data sources	Collaboration with national partners.

To view and process the data in Table 2, a GIS software is required, such as QGIS, ArcGIS, ENVI, GRASS GIS, and SAGA GIS. Such software can be used with a graphical user interface (GUI) and via a command line interface (CLI). Processes and visualization can be automatized and extended using various scripting languages (e.g. Python, IDL, R, Shell, C++). The data can be converted into different formats and information understandable by non-experts of geospatial software. For example, total area affected by flooding, number of people vulnerable to extreme storms, crop types most affected by a heat wave etc. There are also numerous cloud computing based platforms that can be employed to view and manipulate data, for example Google Earth Engine, SEPAL[26] ArcGIS Online, Mapbox, Mango Map, and GIS Cloud.

[12]https://www.worldpop.org/
[13]https://sedac.ciesin.columbia.edu/
[14]http://www.ipcinfo.org/
[15]https://gaez.fao.org/
[16]https://cropcalendar.apps.fao.org/#/
[17]http://cropmonitor.org/
[18]https://www.fao.org/giews/en/
[19]https://www.openstreetmap.org/
[20]https://giovanni.gsfc.nasa.gov/
[21]https://www.ncdc.noaa.gov/cdo-web/
[22]https://www.citizenscience.gov/#
[23]https://opencitiesproject.org/
[24]https://opencitiesproject.github.io/
[25]https://www.hotosm.org/
[26]https://sepal.io/

4. Experiences and lessons learned

4.1. Floods

Flooding caused by cyclones or hurricanes, heavy rains, snowmelt, tidal waves, and collapsed dams is one of the most devastating hazards, affecting the lives, and socioeconomic and ecological systems of populations across the globe. There has been a rise in reported flood events in the past few decades, from 30 events per year in the 1970s to 246 in 2006 (FAO, 2021). Flood hazards are reported to be the most common and destructive of all disasters and are a constant threat to life and property (Forero-Ortiz *et al.*, 2020; Dano, 2020; Psomiadis *et al.*, 2021), resulting in tremendous losses (e.g. destruction of houses, goods, crops and fields, livestock, and land degradation) and social disruption each year (Abdo, 2020). The damages are magnified in lower-income countries where infrastructure systems, including drainage and flood protection, tend to be less developed. Around 1.47 billion people globally are directly exposed to the risk of intense flooding and over a third are poor (Rentschler and Salhab, 2020). Floods can cause considerable damage to agriculture each year worldwide, reducing crop production (Chen *et al.*, 2019). The loss of crops due to flooding is a function of its extent, depth, and duration (Rahman and Di, 2020), with the most damage caused at greater flood depths and with longer durations. A key effect of flood events is the O^2 availability in the submerged component of the plant, which can act as a limiting factor of plant development, affecting soil chemical characteristics such as pH, and consequently impacting the metabolic process of plants (Dat *et al.*, 2004).

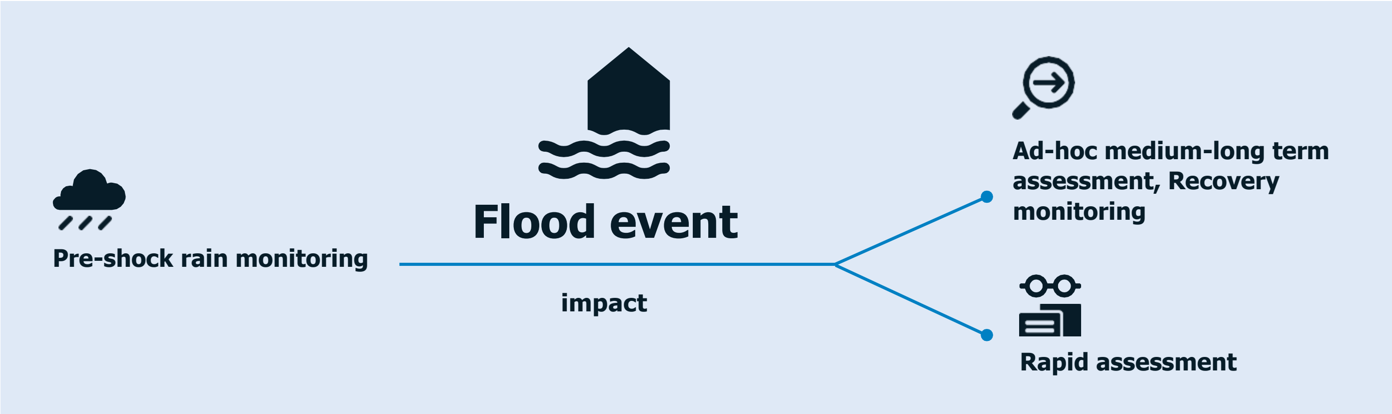
At the global level, a better understanding of flood risk is highly important considering the implication of climate change scenarios. Surges in flood magnitude, return period, and peaks are likely under an increase in extreme rainfall events. Flood exposition is also on the rise due to projections of future populations (Arnell and Gosling, 2016). Furthermore, floods have implications both in food production (e.g. crop damage) (Hazran *et al.*, 2017; Jonathan *et al.*, 2020) and in the urban contexts (e.g. damages to houses, vehicles, roads etc.), where flood events cause major economic impacts (Jongman, 2018).

Fortunately, since the beginning of the twenty-first century, there has been a steady proliferation of satellite sensors apt to assist during disaster response and recovery operations. The ability to monitor floods with sensors onboard satellites is well known and in recent years, progress in applied research has led to a significant increase in the maturity of EO-based products and services to assist flood disaster responses at the global level.

Schumann *et al.* (2018) critically assessed the applicability of remote sensing from satellites to map and monitor floods with the aim to assist disaster response activities. The proliferation of EO data over recent years has caused a shift from a data-poor to a data-rich environment. Consequently, innovative methods and products have been developed, leading not only to a better understanding of flood processes at various spatial and temporal scales but also to global initiatives and applications that utilize and promote remote sensing for improved decision-making activities, particularly in developing nations and during emergencies.

Flood impact assessments can be performed considering two temporal approaches: i) a medium-long term assessment during the recovery phase; and ii) a fast rapid assessment to cover a first overview of the flood scenario (Figure 4).

Figure 4: Flood impact assessment options



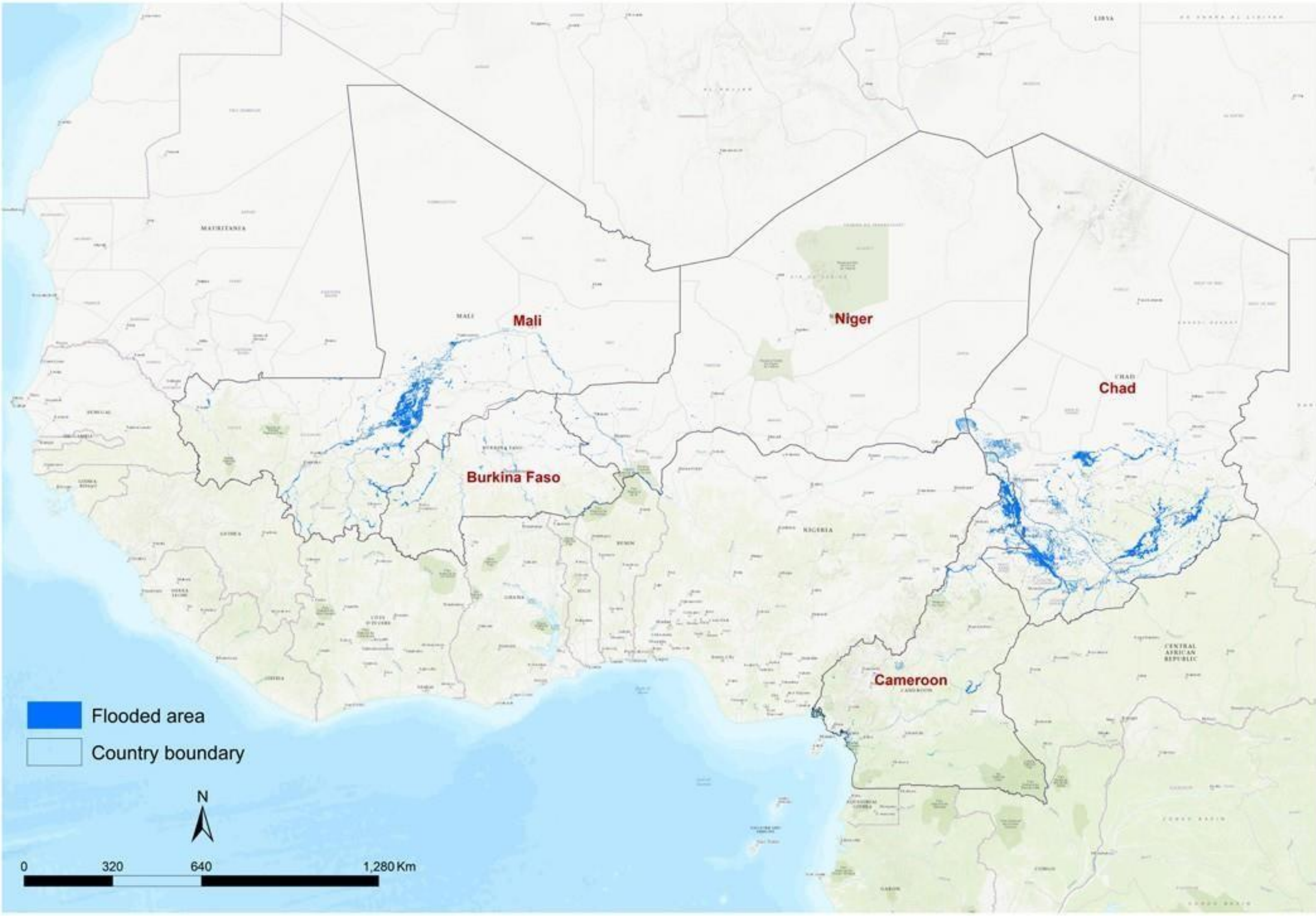
The medium-long term approach is useful to describe the flooding events in 2020 and 2021 due to cyclones/hurricanes, particularly in Bangladesh, West Africa, Mozambique, and Fiji. A technical overview based on the various impact assessments conducted after Cyclone Amphan in Bangladesh, Cyclone Yasa in Fiji, flooding in West Africa, and Cyclone Eloise in Mozambique will be described here.

The majority of flood events (approximately 201) and related consequences were recorded in 2020, in which close to 23 percent more floods were recorded compared to the annual average of 163 events, and 18 percent more flood deaths than the annual average of 5 233 deaths. The impacts of flooding were experienced significantly throughout Asia and Africa and affected 7 million people, causing 1 273 deaths in Africa alone. Indonesia had the highest number of flood events (25), while monsoon flooding in South Asian countries such as Bangladesh affected 5.4 million people and caused 448 deaths in Nepal. India experienced the third deadliest event that caused 1 922 deaths. Furthermore, a series of summer flood events occurred in China, affecting almost 14.3 million people and resulting in 397 deaths (CRED and UNDRR, 2021).

The analysis combines satellite datasets (optical: Sentinel 2 and Landsat; radar: Sentinel 1) with other geospatial datasets (e.g. land cover, crop information, population data) and field/ground data. The AOIs were selected based on flood event reporting and available country administrative boundaries or sources including HDX, GAUL, and GADM. For coarse flood ex-tent analysis, the NOAA visible infrared imaging radiometer suite (VIIRS) product, provided by WFP, was used to extract zonal statistics. Priority areas within the AOI were then selected (Figure 5).

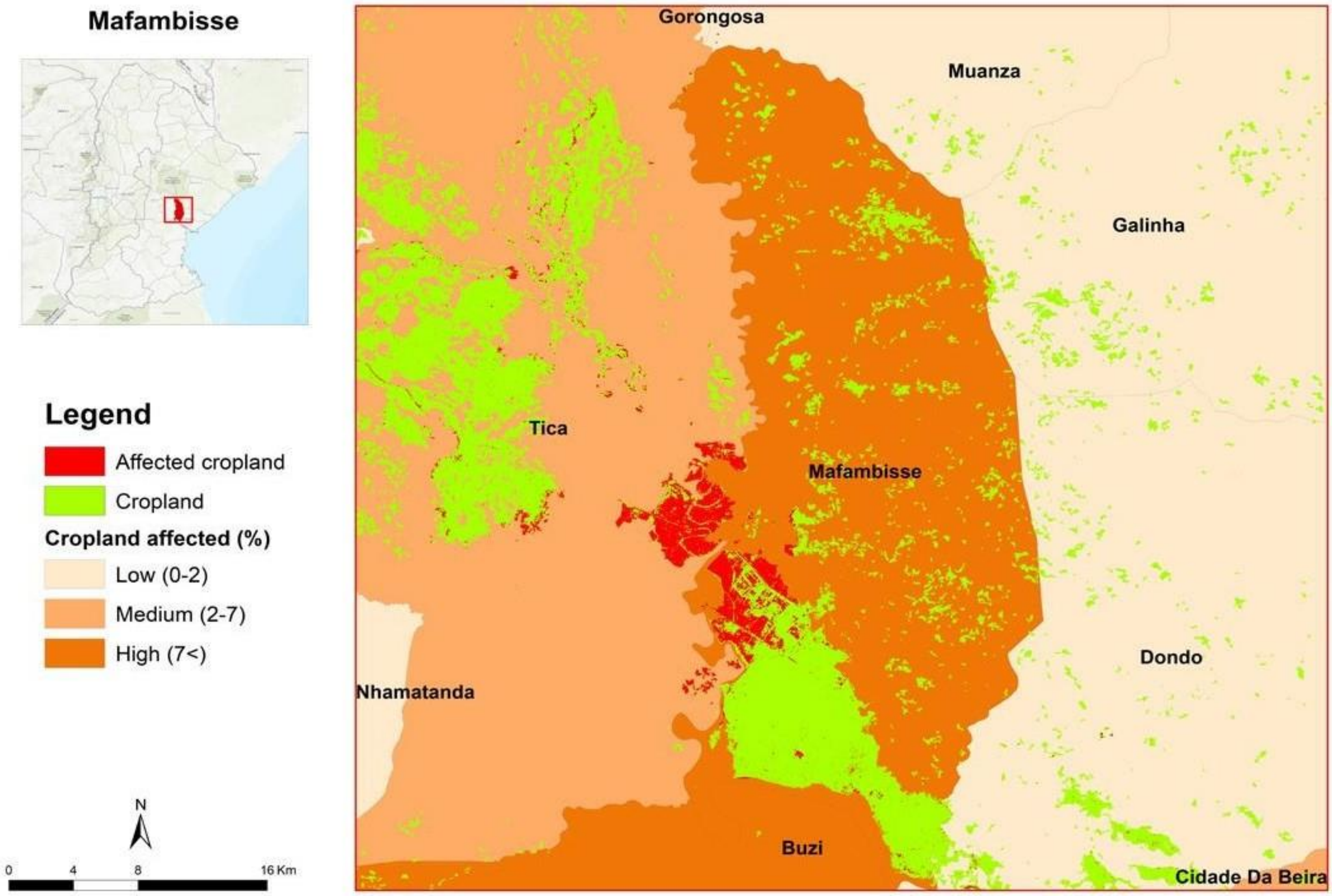
A finer resolution analysis was conducted using available land cover data and crop statistics to assess the impact of floods on crops at different administrative units (Figure 6). By combining SRTM and flood extent data, flood depth was determined for the AOIs (Figure 7). The impact of flooding on households was assessed by combining flood extent, access to water and sanitation, and household density at the union level (Figure 8).

Figure 5: An example of flood extent in West Africa during the period August – November 2020



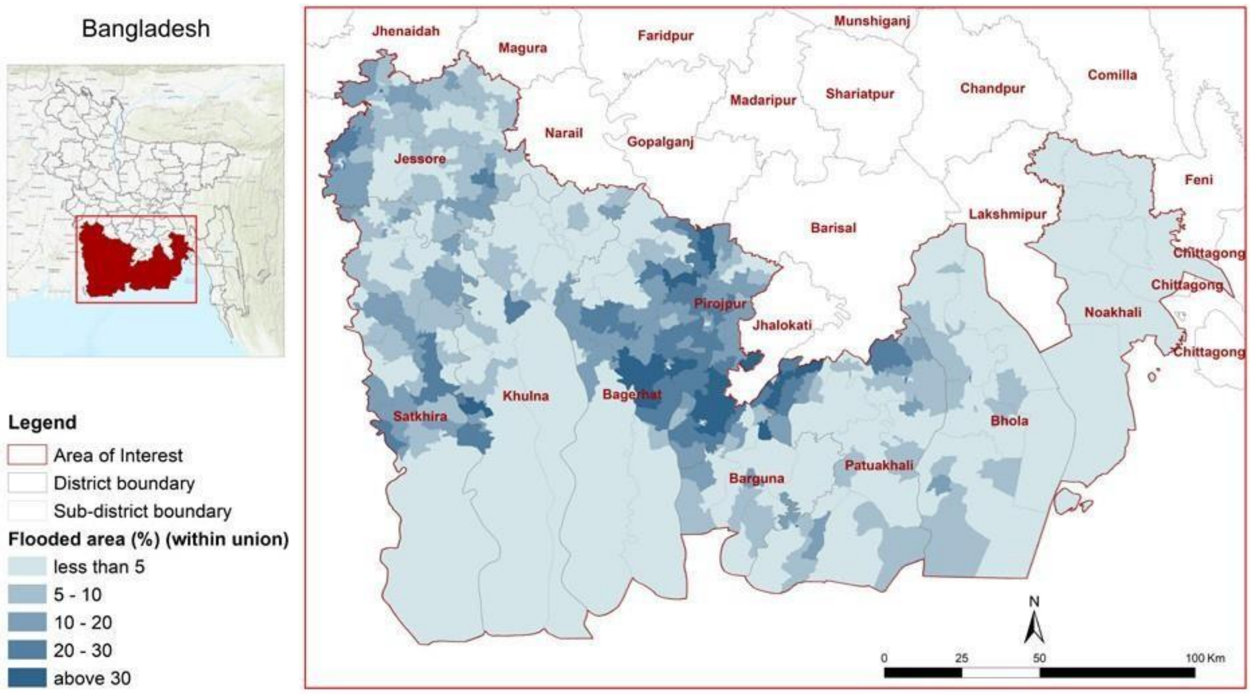
Source: FAO. 2020. A rapid geospatial assessment of flood impact in the West African countries of the Niger, Burkina Faso and Chad. Rome, Italy.

Figure 6: Flooded cropland due to the Eloise cyclone in Mafambisse, Mozambique in 2021



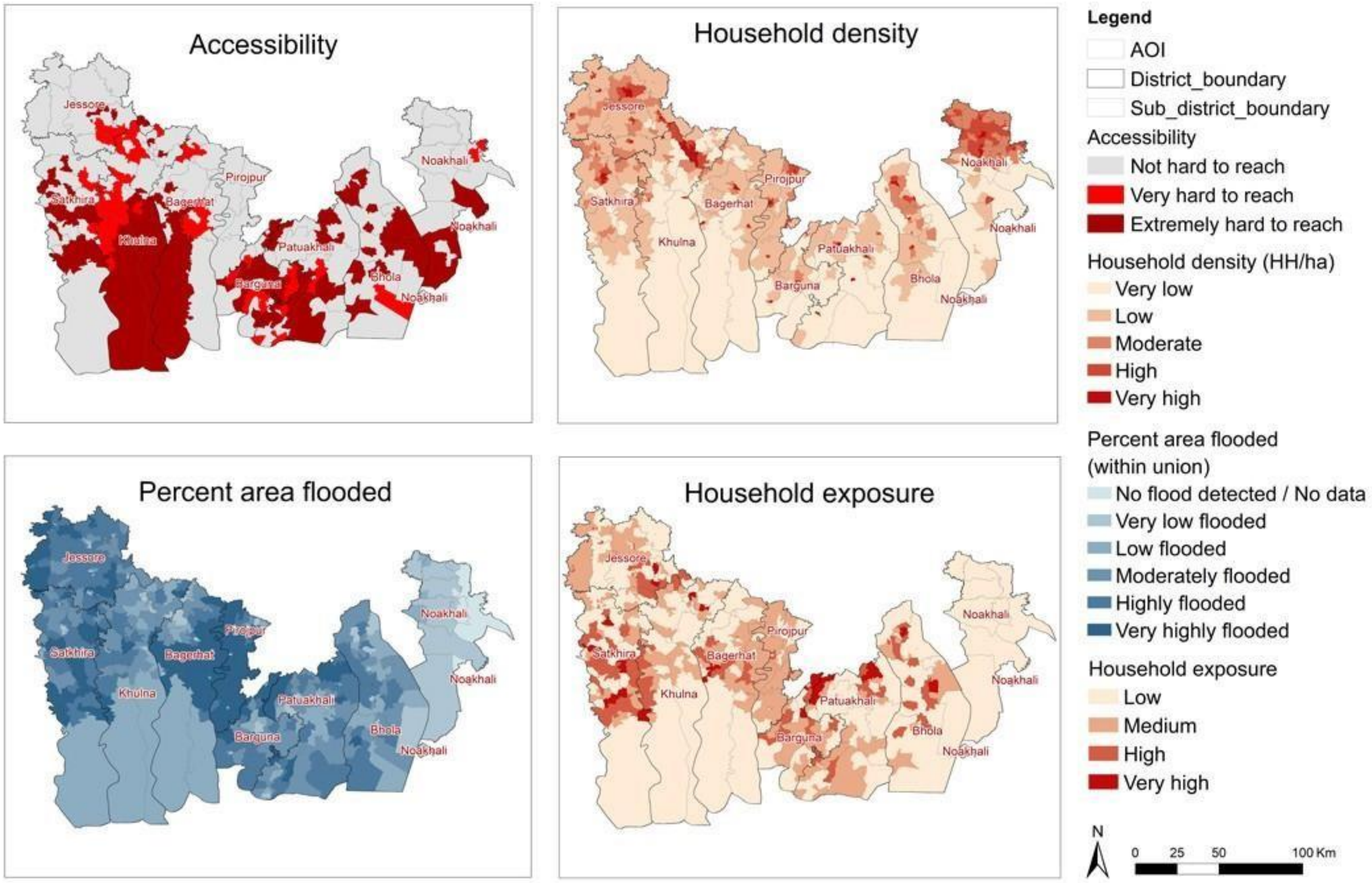
Source: Ghosh, A., Mushtaq, F., Jalal,R. and Henry, M. 2021. Rapid remote sensing and geospatial analysis for the flood impact assessment of Cyclone Eloise on crop production in Mozambique. FAO, Rome, Italy.

Figure 7: Flood severity by unions and districts (percent flooded area) due to Amphan cyclone in Bangladesh



Source: Ghosh. A., Gultan, E., PouemeDjueyep, G., Henry, M., Billah, M., Hasanat, M., Jalal, R., Ritu, S., Das, A., Manalili, M., and Schumann, G. 2020. Rapid remote sensing assessment of the impacts of flood due to cyclone Amphan in Bangladesh. FAO, Rome, Italy.

Figure 8: Flood severity by unions and districts (percent flooded area) due to Amphan cyclone in Bangladesh



Source: Ghosh. A., Gultan, E., PouemeDjueyep, G., Henry, M., Billah, M., Hasanat, M., Jalal, R., Ritu, S., Das, A., Manalili, M., and Schumann, G. 2020. Rapid remote sensing assessment of the impacts of flood due to cyclone Amphan in Bangladesh. FAO, Rome, Italy.

The differences observed between the aforementioned assessments are related to: (1) the standardization of administrative boundaries; (2) the availability and access of national or local land cover data; (3) recent agricultural statistical data; (4) the availability and access of agricultural data at different administrative boundaries/units; and (5) population data at different administrative boundaries/units.

When national administrative boundaries were not available, boundaries from HDX, GAUL, and GADM were used to extract the AOIs. In the absence of national land cover data, the local land cover legend and land cover map were prepared using a combination of radar imagery (Sentinel 1), optical imagery (Sentinel 2, Landsat), and training data via cloud computing platforms (e.g. SEPAL, GEE), and a machine learning algorithm (Random Forest). Moreover, when national agricultural statistical data was not available, data from FAOSTAT and Global Agro-Ecological Zone version-4 were used.

The main challenges encountered during the assessments were: (1) understanding the impact of flooding on crop production based on flood depth, frequency, and duration; (2) the absence of ground/field data; (3) the absence of crop calendar information (crop type, etc.); (4) the absence of crop data at different administrative units/boundaries; and (5) the absence of updated population data at different administrative units/boundaries.

Therefore, for improved flood impact assessments in the future, it is recommended that: (1) the AOIs are clearly defined using standardized administrative boundaries; (2) the required information is provided in a timely manner; (3) data can be provided related to agriculture (crop types, crop calendar, and crop statistics) at different administrative boundaries/ units; (4) a person is assigned responsible for specific data collection tasks; (5) the latest updated population data at different administrative boundaries/units can be provided; (6) available flooding damage data/reports are used; (7) ground validation or household surveys are employed for severity data on the damages and socioeconomic impacts of floods; (8) very-high spatial resolution satellite imagery is used for locations that are not accessible; (9) different AOIs and/or the total flood extent coverage for the identified AOIs, river discharge, storm surge height, flood permanence models, etc.; are accounted for and (10) the impact of floods on embankments and other infrastructure is considered.

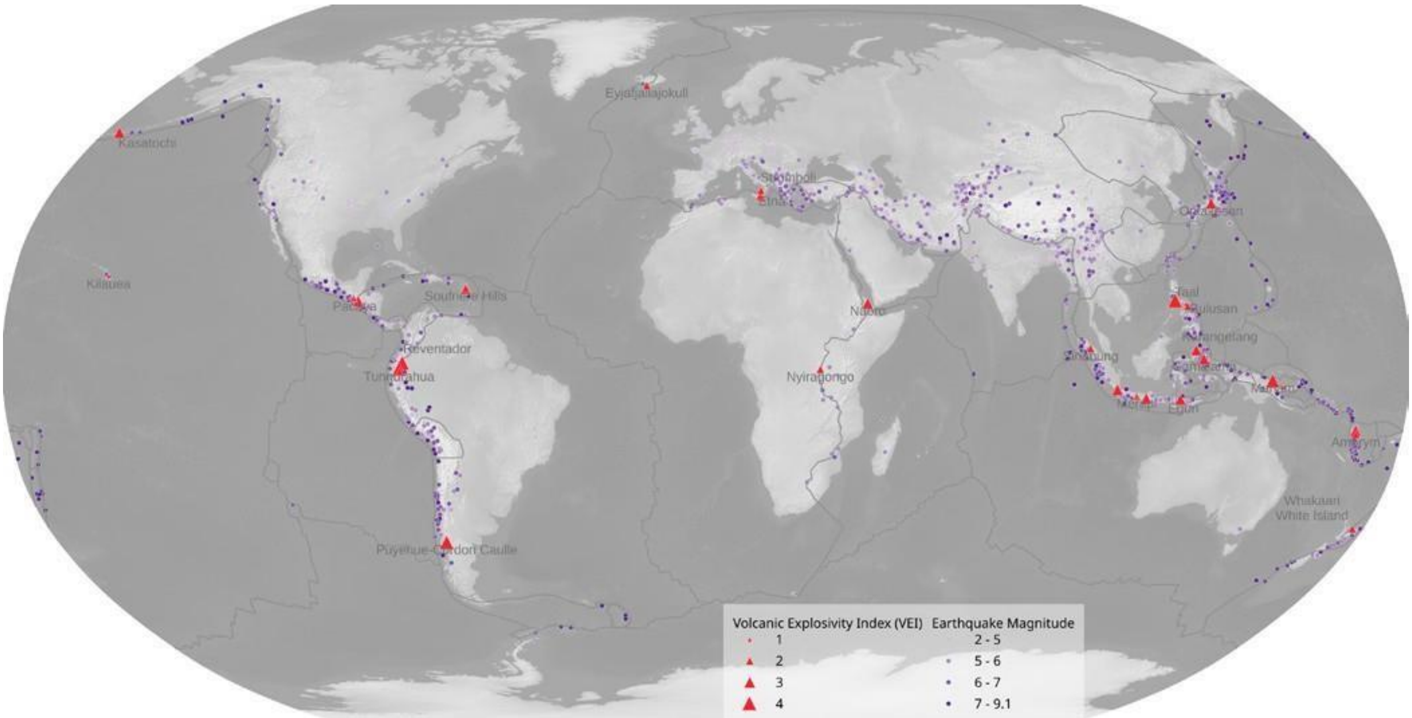
4.2. Volcanic eruptions

Volcanic eruptions are multi-hazard events with numerous impacts, from minor damages to societies to total devastation and mass fatalities (Deligne *et al.*, 2017). Their effects can be significant at local, regional, and/or global scales based on the size of the eruption. Large human population hotspots have been threatened by volcanoes, and their influence in terms of the socioeconomic development for these regions is vital. Consequences of eruptions include injuries and deaths, population displacement, economic losses, and the interruption of agricultural activities (Annen *et al.*, 2003). They can also have an impact on climate, for example, the aerosols released during the eruption reduce the amount of incoming sunlight reaching the Earth's surfaces, thus having a net cooling effect. This is more prominent when eruptions are powerful enough to reach the stratosphere, due to greater amounts of gaseous species and longer aerosol residence times (Cole-Dai, 2010). Lava eruptions can last minutes to decades and can produce concurrent, sequential, and/or recurrent hazards, for example, the damage or burial of buildings, agriculture, and other infrastructure (Jenkins *et al.*, 2017). Ashfall can have serious detrimental effects on agricultural crops depending on the crop growth stage and ash thickness, and volcanic fluids can pollute water bodies.

There are numerous active volcanoes worldwide (Figure 9). Here, the recent impact assessments for volcanic eruptions conducted in the Democratic Republic of Congo (2021) and Saint Vincent (2021) are presented. Through the disaster charter, the key information obtained focused on the lava flow, earthquakes, infrastructure damages, and impacted agriculture due to ash cover and lava flow.

Lonuimay volcano erupting. © FAO/R. Grisolia

Figure 9: Map of active volcanoes and recent earthquakes from 2001 to 2021



Sources:

Earthquake: National Geophysical Data Center / World Data Service (NGDC/WDS), N.C. for E.I. (NOAA). 2022. NCEI/WDS Global Significant Earthquake Database [online]. [Cited 20 June 2022]. https://www.ngdc.noaa.gov/hazel/view/hazards/earthquake/search

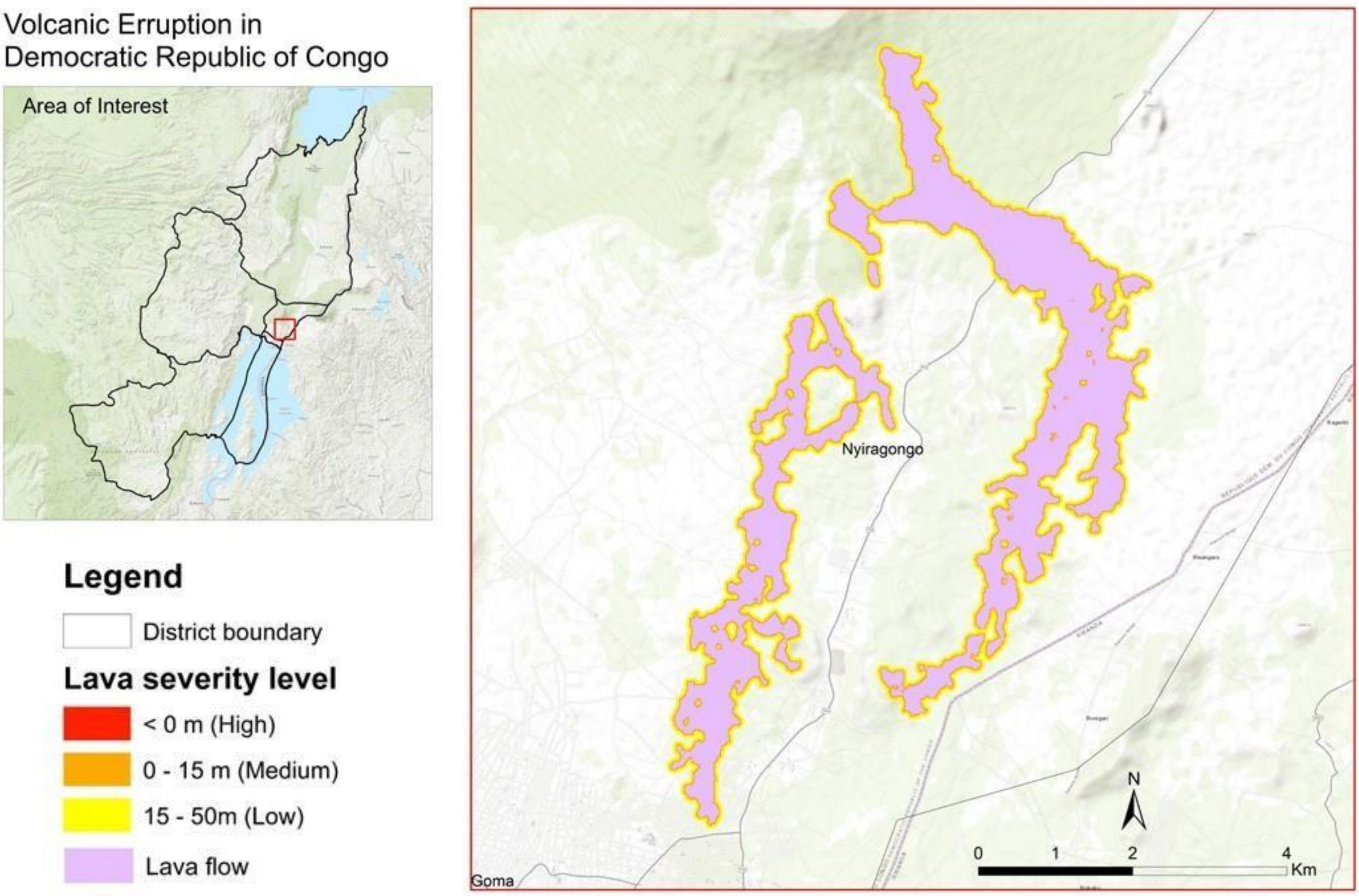
Plate boundaries: Bird, P. 2003. An updated digital model of plate boundaries. Geochemistry, Geophysics, Geosystems, 4(3). https://doi.org/https://doi.org/10.1029/2001GC000252

Basemap data: Modified from Natural Earth.

Volcanic eruption: National Geophysical Data Center / World Data Service (NGDC/WDS), N.C. for E.I. (NOAA). 2016. Significant Volcanic Eruptions Database [online]. [Cited 20 June 2022]. https://www.ngdc.noaa.gov/hazard/volcano.shtml

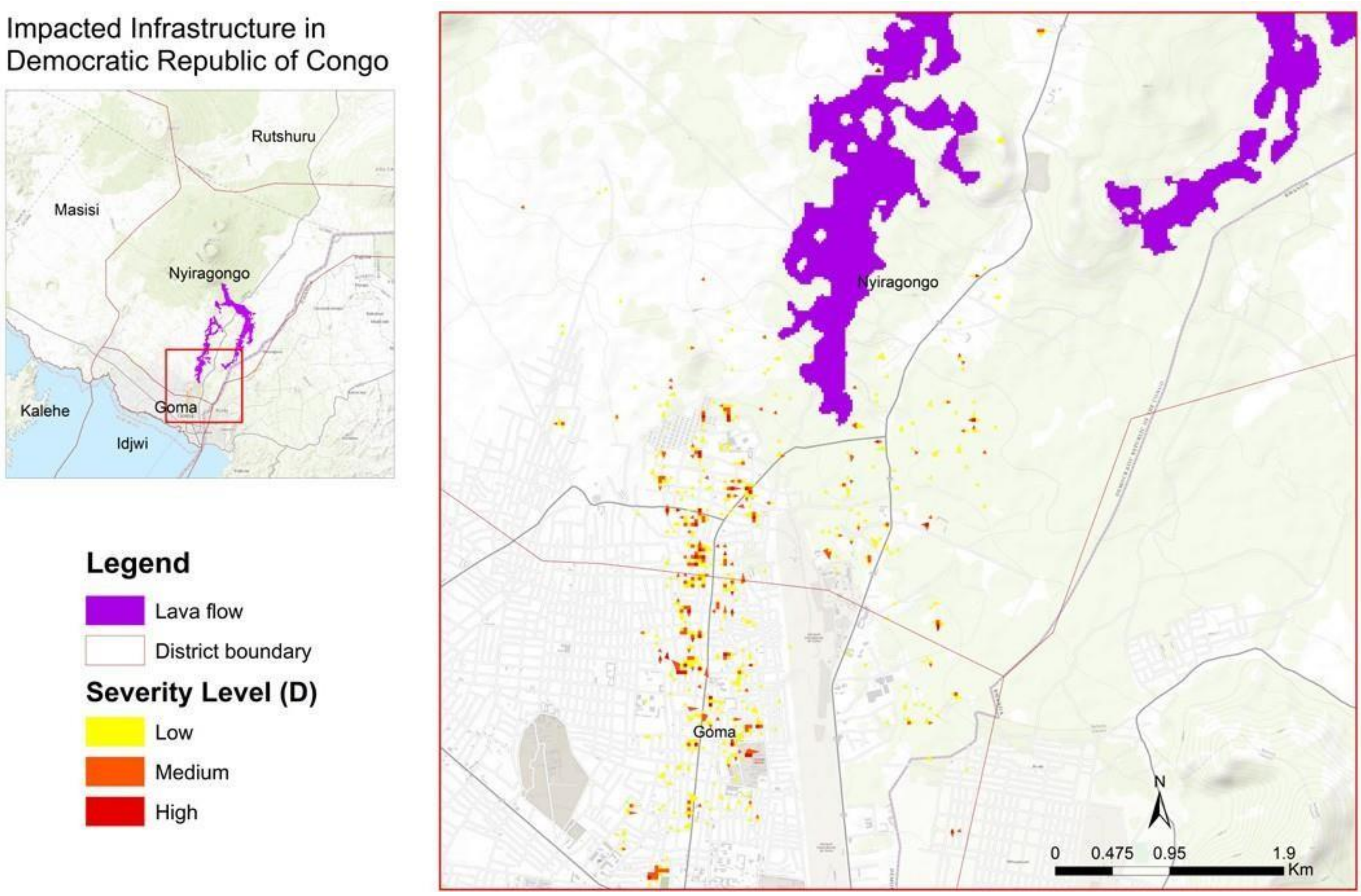
Satellite imagery (Sentinel 1 and 2) was combined with other hazard specific socioeconomic indicators (e.g. cropland, land cover, households) as well as ground data using administrative boundaries for this analysis. AOIs were selected for the specific hazard zones and administrative boundaries (Figure 10). Lava flow was extracted using Sentinel 1 imagery from Google Earth Engine to determine severity levels. The Sentinel-1 based coherent change detection (CCD) technique was used for the creation of damage proxy maps (DPM) to assess the craters and damaged built-up (households, residential and commercial buildings, and roads) areas (Figure 11). The Normalized Difference Vegetation Index (NDVI) was calculated using Sentinel-2 imagery and land cover to assess the impacted cropland within the AOI (Figure 12) for the assessment of the La Soufrière volcanic eruption in Saint-Vincent Island.

Figure 10: Lava severity level in Nyiragongo, Democratic Republic of the Congo following the volcanic eruption in 2021



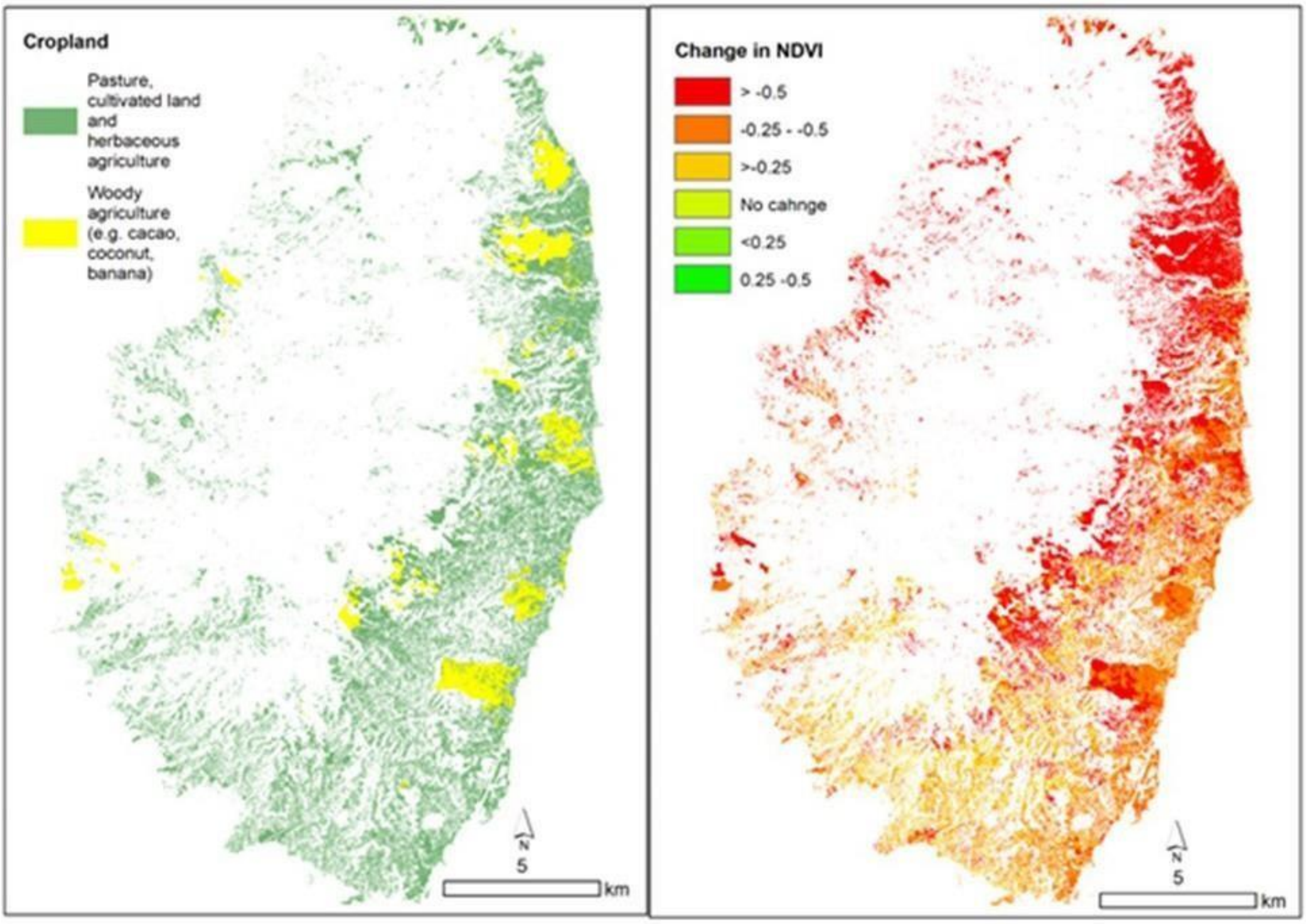
Source: Mushtaq, F., Vollrath, A., Ghosh, A., Jalal, R., and Henry, M. 2021. A rapid geospatial damage assessment after Nyiragongo volcanic eruption in the Democratic Republic of the Congo. FAO, Rome, Italy.

Figure 11: Impacted urban infrastructure in Nyiragongo, Democratic Republic of the Congo following the 2021 volcanic eruption. Lava flow produced through backscattering S1 analysis and severity level from S1 damage proxy map



Source: Mushtaq, F., Vollrath, A., Ghosh, A., Jalal, R., and Henry, M. 2021. A rapid geospatial damage assessment after Nyiragongo volcanic eruption in the Democratic Republic of the Congo. FAO, Rome, Italy.

Figure 12: Impacted cropland in La Soufriere, Saint Vincent and the Grenadines following the 2021 volcanic eruption



Source: FAO, 2021. A rapid geospatial assessment of impacts from La Soufrière's volcanic eruption on infrastructure and cultivated land. Rome, Italy.

The key differences observed between the aforementioned assessments are related to the availability of: (1) administrative boundaries; (2) national/local land cover data; (3) recent agricultural statistical data; (4) agricultural data at different administrative boundaries/units; and (5) population data at different administrative boundaries/units.

Due to the absence of national administrative boundaries, boundaries from HDX, GAUL and GADM were used to extract the AOIs. Open street map (OSM) was employed to extract the buildings layer for the lava impact assessment.

Due to the absence of national land cover data, an ad-hoc local land cover legend was prepared to create a pre-hazard land cover map based on supervised classification using radar (Sentinel 1) and optical (Sentinel 2, Landsat) imagery as the predictive variables, and autonomously collected training data using cloud computing platforms (e.g. SEPAL, GEE).

As there was no cloud free optical imagery available following the volcanic eruption, the NOAA HYSPLIT model was used to categorize ash zones (i.e., high, medium, low) using the Radar Vegetation Index (RVI) to assess the impact of ash on crops.[27] When national agricultural statistical data were not available, data from FAOSTAT and Global Agro-Ecological Zoning version 4 were used along with land cover.

[27]https://www.arl.noaa.gov/hysplit/

The key challenges encountered during these assessments were: (1) the lack of available cloud- free optical images over the volcanic eruption, thus preventing the accurate assessment of vegetation changes using NDVI; (2) the ambiguous AOIs and availability of updated vectorized local administrative boundaries ; (3) the absence of ground/field data; (4) the absence of crop calendar information (crop type, phenological stage etc.); (5) the absence of crop data and statistics at different administrative units/boundaries; and (6) the absence of local updated/ latest population/ household data at different administrative units/boundaries.

Based on these challenges, we recommend the following in order to improve future volcanic eruption impact assessments: (1) clearly define AOIs using administrative boundaries; (2) the use of RVI in the case of unavailable optical imagery; (3) the timely provision of essential and recommended data; (4) the provision of available data related to agriculture (crop type, crop calendar, crop statistics) and infrastructure (roads, number of buildings, households) at different administrative boundaries/units; (5) assign a central person for specific data collection tasks; (6) provide the latest updated population data at different administrative boundaries/units; (7) provide available damage data/reports due to the volcanic eruption; (8) use ground validation or household surveys for the data collection on the severity of damages and socioeconomic impacts; (9) employ very-high spatial resolution satellite imagery for difficult-to-access locations; (10) strengthen the collaboration between local, national, regional, and international organizations/ institutes; and (11) increased use of geospatial tools and technology in rapid analysis.

4.3. Pests and disease

Pests and disease epidemics are biological hazards, posing serious threats to humans, animals, and plants. They often overlap with other disasters and lead to cascading effects, increasing risks and embedding vulnerabilities, for example, threats to the human food chain, livestock production, and trade. The occurrence of pests and diseases in Africa resulted in an agricultural production loss of USD 6.5 billion between 2008-2018 (FAO 2021a). According to IPPC (2021), up to 40 percent of agriculture crop production and yields are lost annually due to pests and diseases worldwide. Plant diseases cost the world economy over 220 billion USD, and invasive insects at least 70 billion USD each year.[28]

The desert locust (*Chistocerca gregaria*) is considered to be one of the most serious agricultural pests across the globe, particularly in West and North Africa, the Middle East, and Southwest Asia (Lecoq, 2019). Its regular attacks pose a significant risk to agricultural production and have adverse impacts on food security in over 50 countries (Brader *et al*., 2006).

Numerous strategic approaches have been adopted to control locust outbreaks in a timely manner based on technical expertise. Control measures include urgent, large-scale aerial and ground pest control operations such as surveillance, trajectory forecasting, and data collection (Piou *et al*., 2019; Latchininsky *et al*., 2016; Cressman 1996; Cressman 1997). The locust crisis is monitored by FAO, thanks to the systematic analysis performed by the Locust Working Group, who have also created a dedicate locust hub.[29]

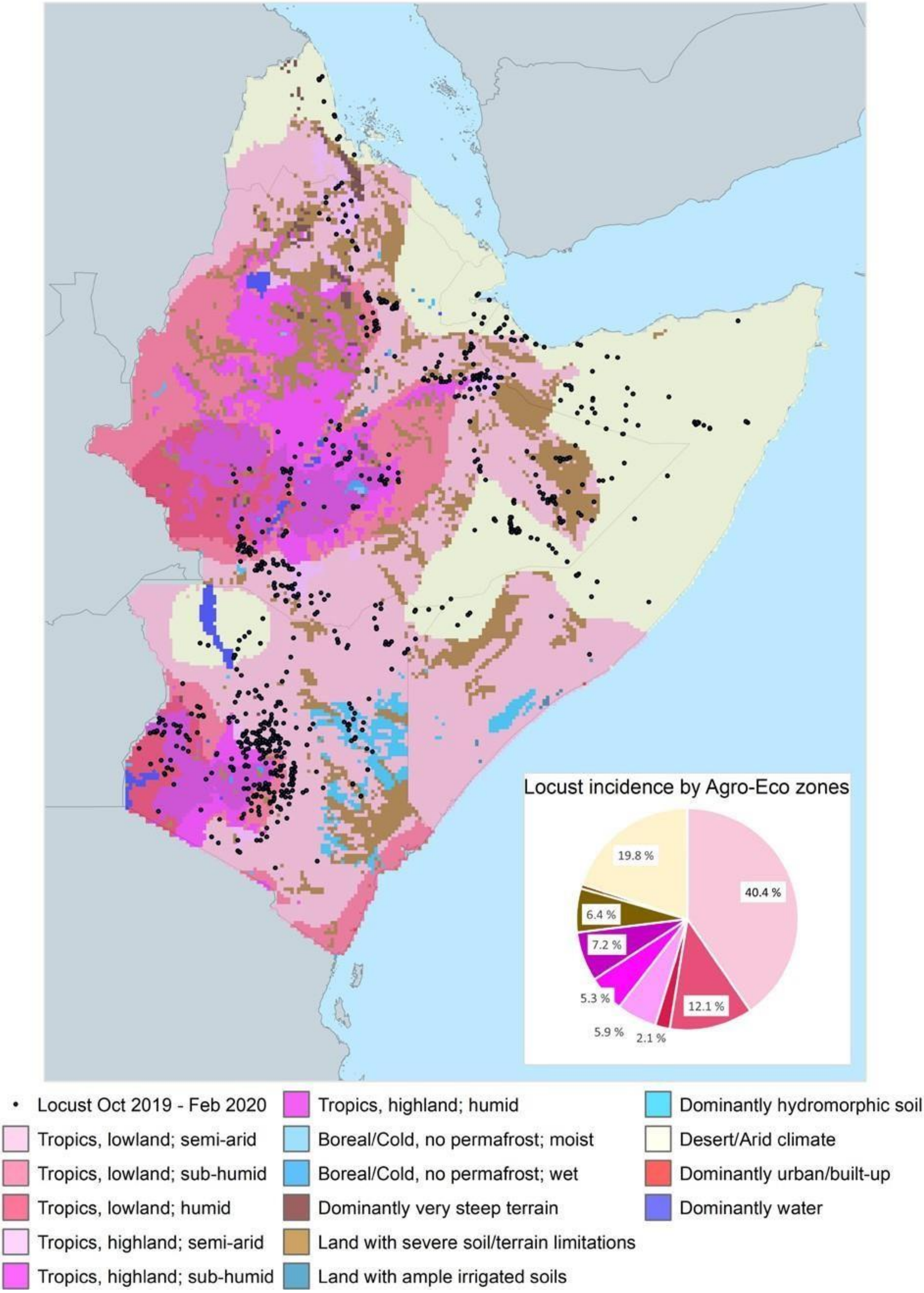
Due to the magnitude of the 2019-2020 locust outbreak in the Horn of Africa, the FAO geospatial unit began to understand the potential application of geospatial and Earth observation techniques on the locust impact assessment.[30] Different geospatial exercises have been performed, for example, in an EO assessment, the decrease in vegetation indices (e.g. NDVI) has been linked with the loss of vegetation mass resulting from the locust swarm passage. This analysis recognized that at the regional level, coarse spatial resolution remote sensing data such as MODIS NDVI (MOD13Q1) are not effective in the locust impact spatial discrimination, however, the implementation of medium, high spatial resolution images (e.g. Sentinel 2) allowsthe exploration of the relationship between NDVI values and locust presence. The fast movements of locust swarms and the increase in greenness due to rainy events that typically accompany the locust outbreak present a challenge for the impact assessment by EO techniques.

[28]https://www.fao.org/news/story/en/item/140292 0/icode/

[29]https://www.fao.org/ag/locusts/en/info/info/index.html

[30]https://storymaps.arcgis.com/stories/a0617d35d0 054d34a824d324e197f949?play=true&speed=fast

Figure 13: Incidence of locust by Global Agro-Ecological Zones in the Horn of Africa in 2020

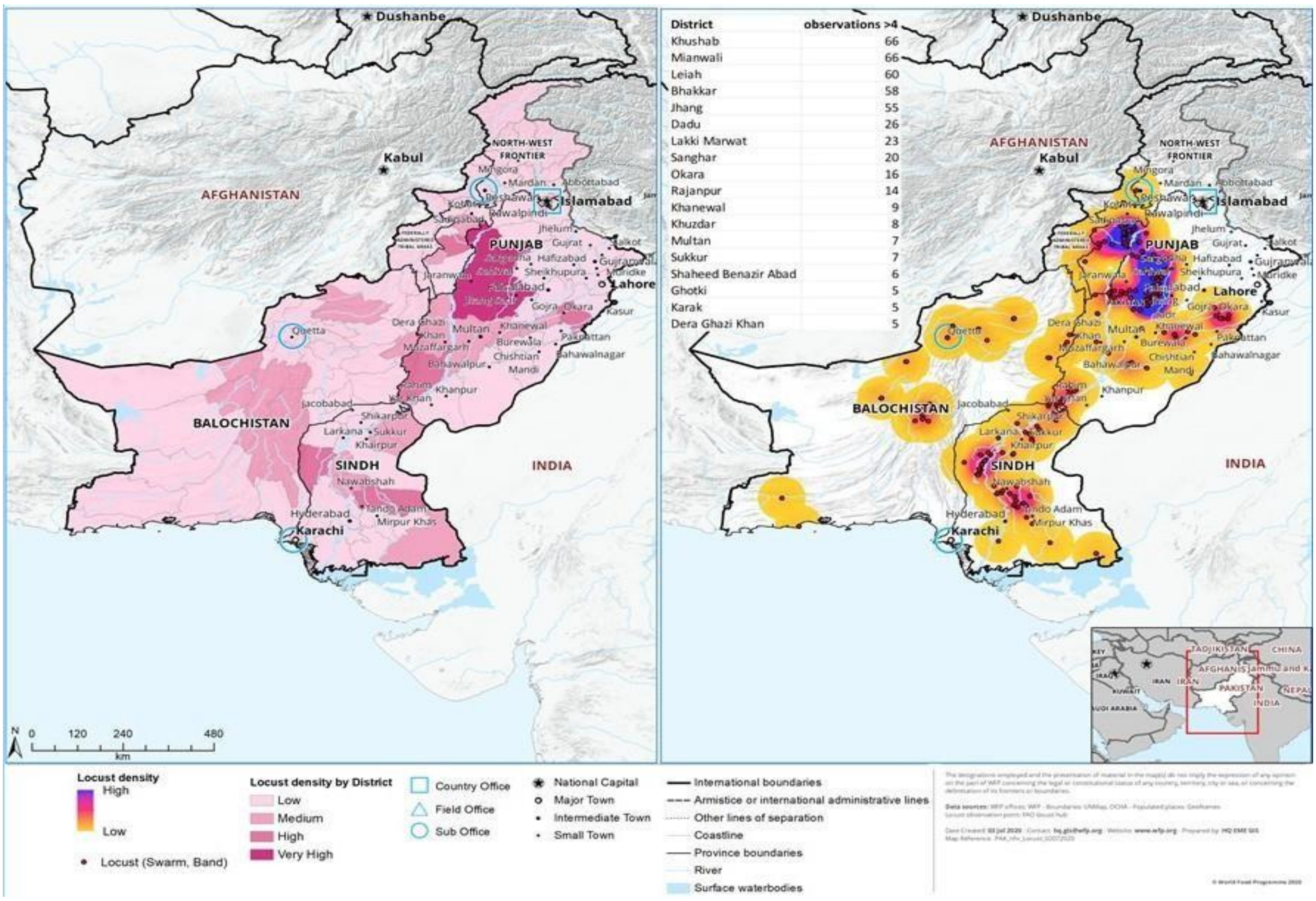


Source: Elaborated for this report.

Thus, the FAO geospatial unit also employed descriptions of the phenomena todevelop thematic maps. More specifically, if it was not possible to achieve a robust impact spatial discrimination by EO analysis, due to the high dynamicity of the locust outbreak and mutable biophysical conditions, descriptions of the locust incidence were adopted from the FAO locustdata hub (locust observation point). The global agro-ecological zones were overlaied considering the locust observation points to describe the swarm incidence on 'tropic semi-arid' areas suffering the strongest locust presence (Figure 13).

Moreover, by considering the locust observation points, it was possible to elaborate the locust density thematic map presented in Figure 14, which depicts the case of the Pakistan locust incidence description during the 2020 outbreak.

Figure 14: Point density maps showing locust observation (Jan–Jun 2020) in Pakistan



Source: Elaborated for this report.

This type of map provides an overview of the invasion. Here, the locust observation points (provided by the FAO Locust Hub) were used as the data input. The most impacted areas were then identified by determining the zonal statistics for each district and performing density analysis. This type of cartographic product can aid the resilience programs to understand which communities are most affected by the disaster.

In addition to the analysis by the FAO geospatial unit, the FAO Locust Hub played a crucial role by producing periodic bulletin publications, locust hub maintenance, and desert locust forecast calendars,[31] thus providing standardized and accurate information.

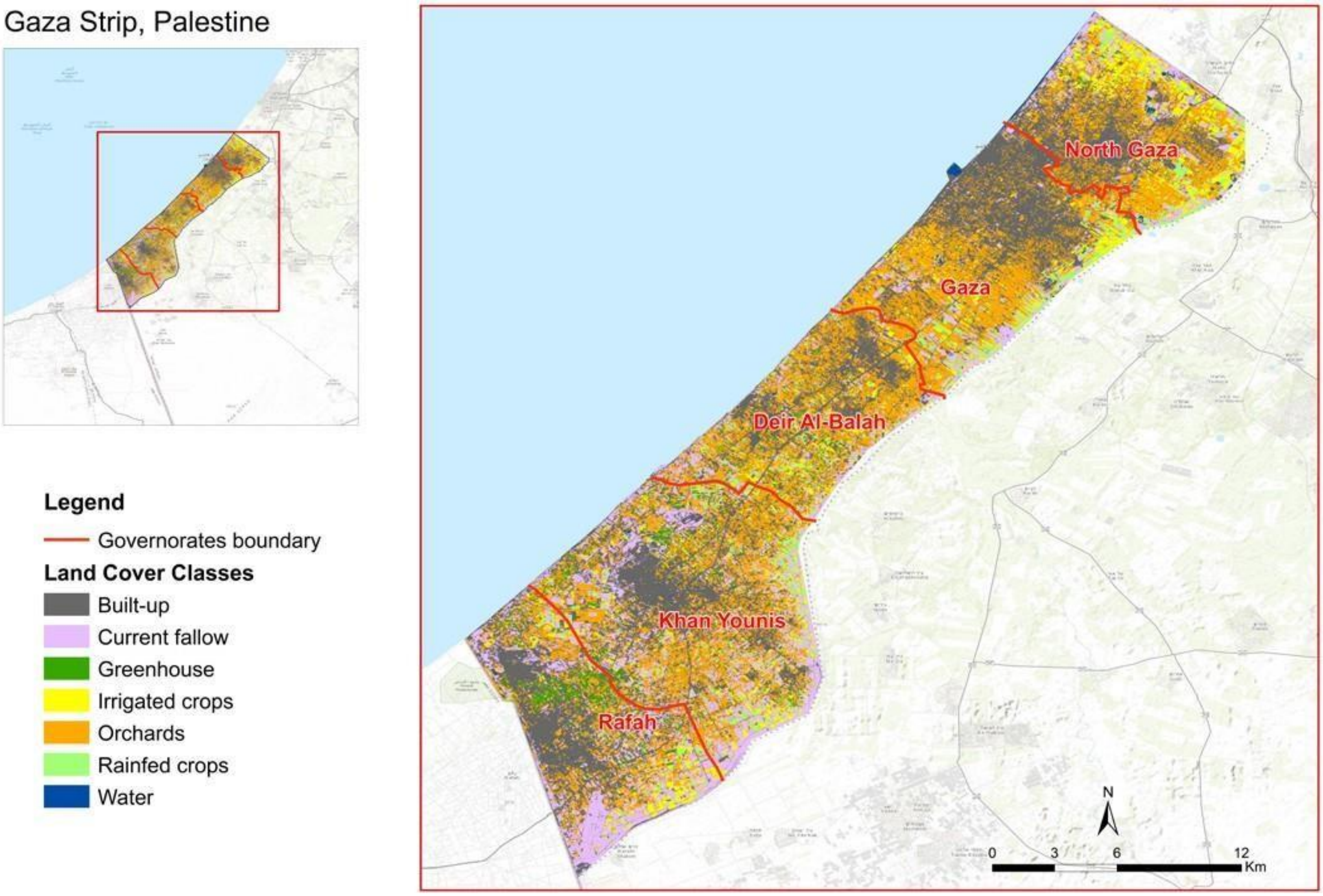
[31] https://www.fao.org/ag/locusts/en/info/info/index.html

4.4. Conflicts

People are more likely to be hungry when fighting, and conflict uproots populations from their homes, farms, and jobs. In addition, food shortages can also enhance social tensions and fuel injustices, which may ultimately trigger or exacerbate conflicts.

FAO (2021b) conducted an assessment to determine the impact of the May conflict escalation on the agriculture area in the Gaza Strip, Palestine. In this analysis, satellite imagery (Sentinel-1 and 2, VHR) was combined with other geospatial datasets (e.g. cropland types, built-up agricultural areas) and field/ground data. The AOI was selected based on the availablecountry and administrative boundaries of the Gaza Strip, consisting of five governorates (admin-2) (Figure 15).

Figure 15: Land cover map of the Gaza strip in Palestine

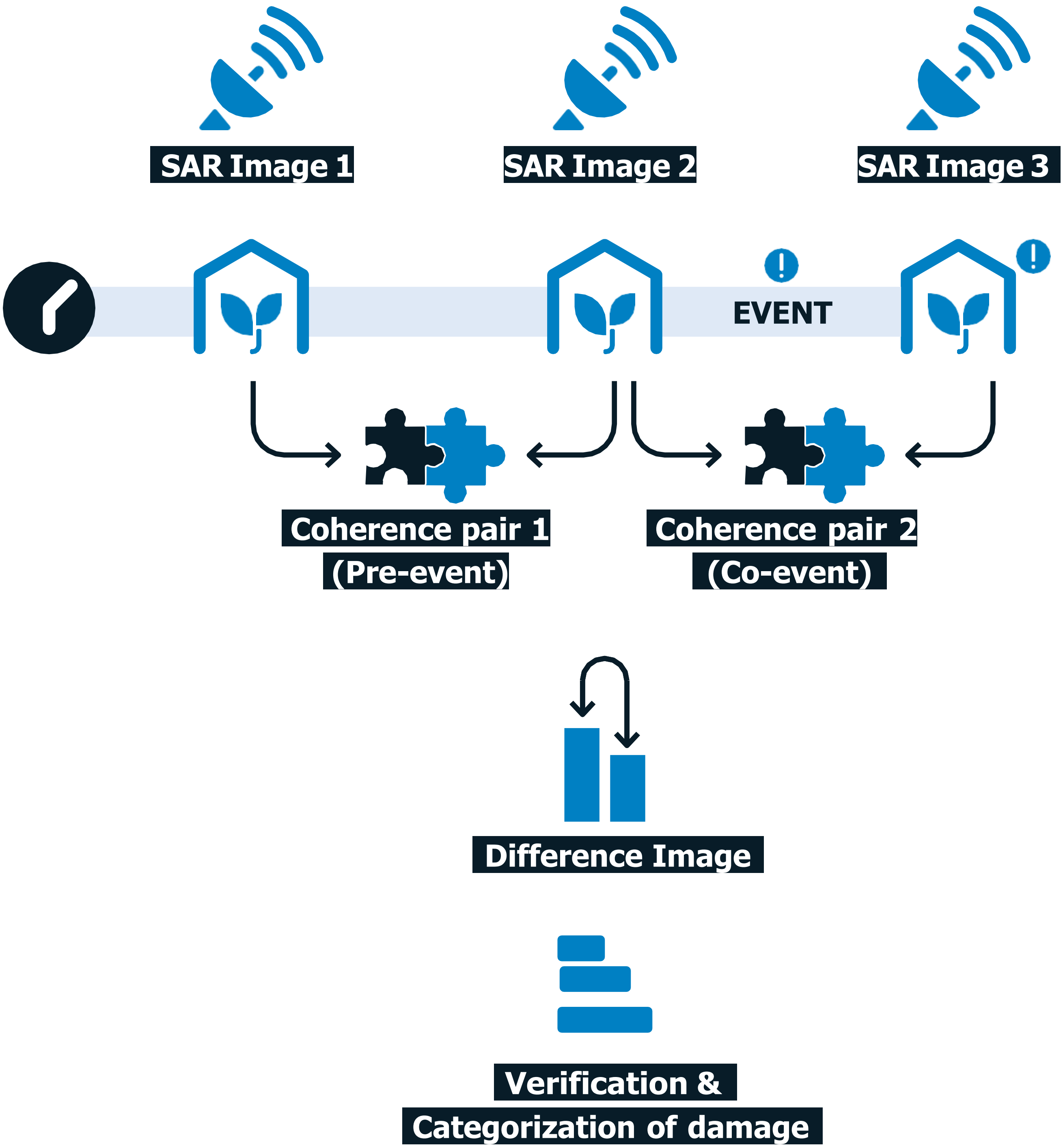


Source: FAO. 2021. Impact of the May conflict escalation on the agricultural area in the Gaza Strip. Rome. https://doi.org/10.4060/cb7167en

Sentinel-1 SAR and Sentinel-2 images (10 m resolution) were used to derive (DPMs) and a preliminary assessment of the impact on cropland, respectively. The high-resolution of the images allowed for the differentiation of crop types to eliminate the harvest period limitations. Additional very high-resolution imagery, such as WorldView-2 panchromatic and multispectral imagery (0.5 m resolution) and Pleiades multispectral imagery (0.5 m resolution) were also employed in this assessment.

The DPMs derived using the damage proxy mapping module on the SEPAL platform with Sentinel 1 data were used for the identification of damage to built-up areas and greenhouses. Sentinel 1 is equipped with SAR and is thus independent of cloud cover. SEPAL provides a module that uses CCD to produce the DPMs, which are based on three image pairs (two pre-event and one post-event). The coherence layers are calculated for each pair (Figure 16). By differencing between pre and post event layers, drops of coherence over urban areas indicate severe damages.

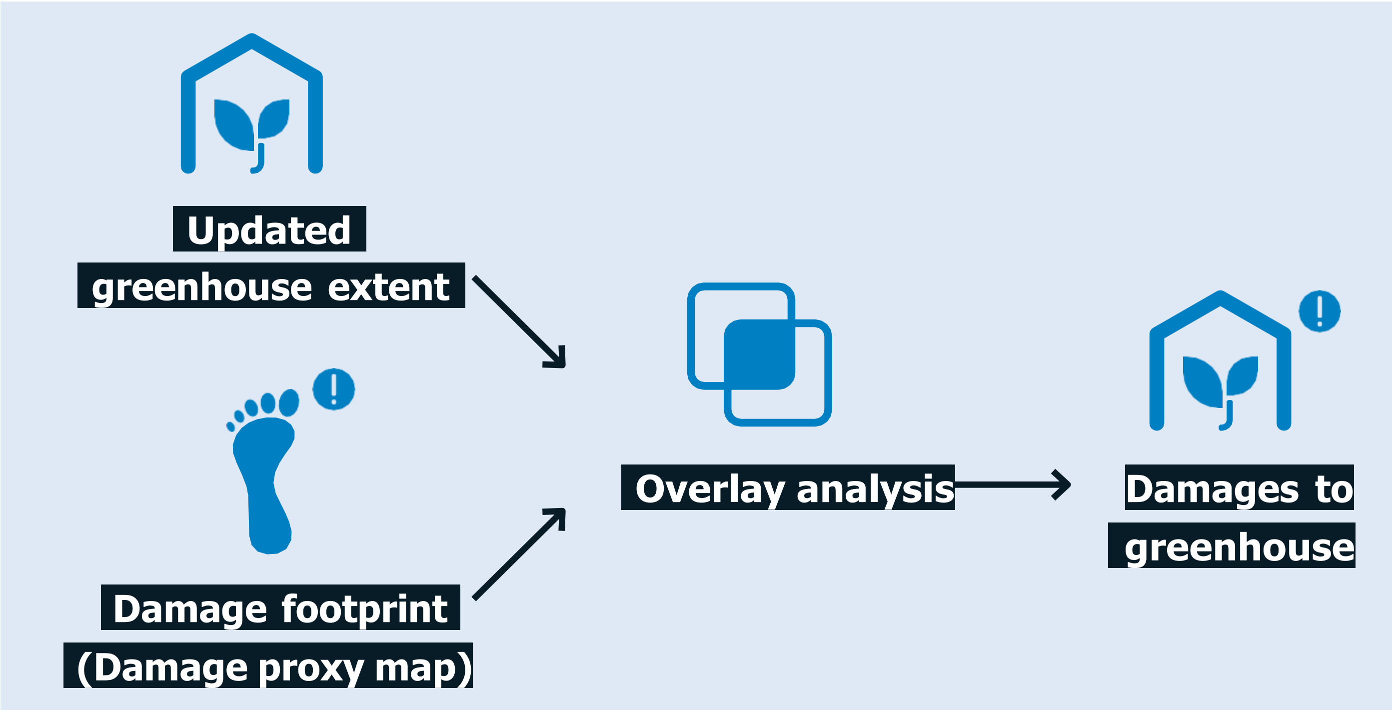
Figure 16: Workflow for the generation of the damage proxy map



Source: FAO. 2021. Impact of the May conflict escalation on the agricultural area in the Gaza Strip. Rome. https://doi.org/10.4060/cb7167en

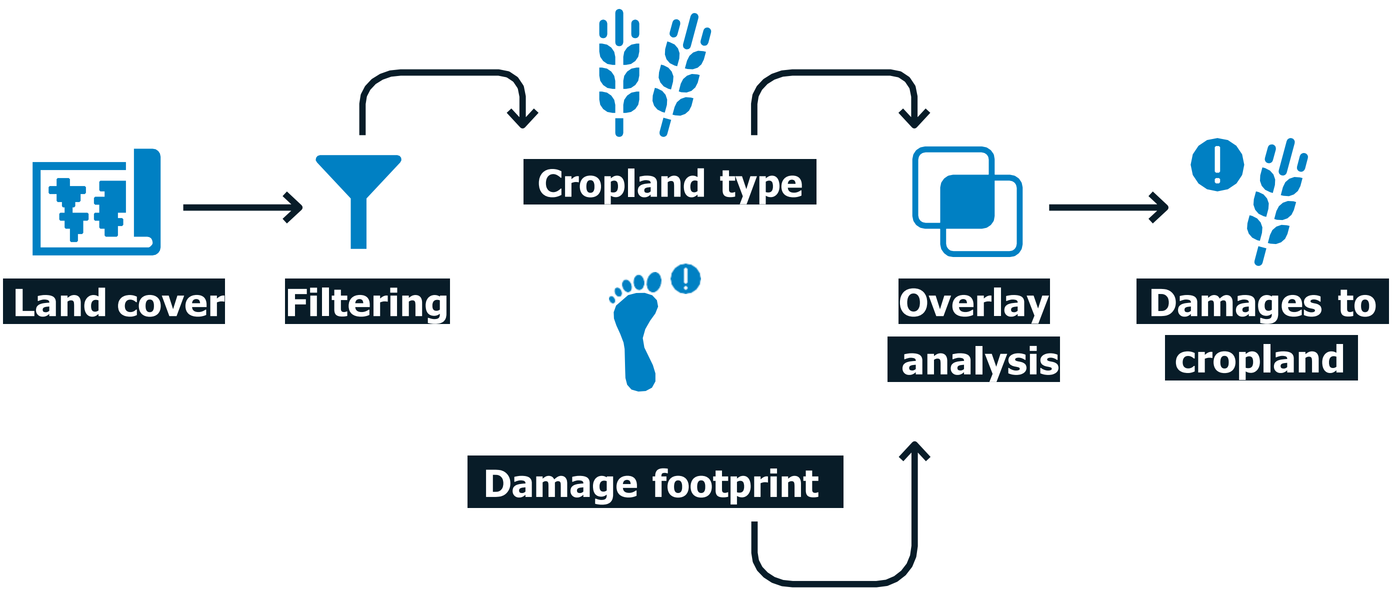
The land cover map was prepared using the land cover legend based on local knowledge and VHR data to assess the damage by crop type (Figure 15). The collection of training samples for the identification of the location information and associated land cover class was based on two separate approaches that employed VHR and Sentinel 2 images in the open foris collect earth online (CEO) tool and the expertise of local agronomists.[32] For the damage footprint mapping, a semi-automated pattern recognition method was used. To assess the damage to greenhouse, overlay analysis was conducted using the DPM and the updated greenhouse layer (Figure 17), while overlay analysis was carried out using the crop type map and damage footprint to assess the damage to crops (Figure 18). A multi-ring buffer of varying radii (15, 30, and 45 m) around the damaged location was created to locate the agricultural infrastructure (Figure 19) for the agricultural infrastructure damage assessment (Figure 20).

Figure 17: Flowchart of methodology used to assess the damage to greenhouses



Source: FAO. 2021. Impact of the May conflict escalation on the agricultural area in the Gaza Strip. Rome. https://doi.org/10.4060/cb7167en

Figure 18: Flowchart of methodology used to assess the damage to crops



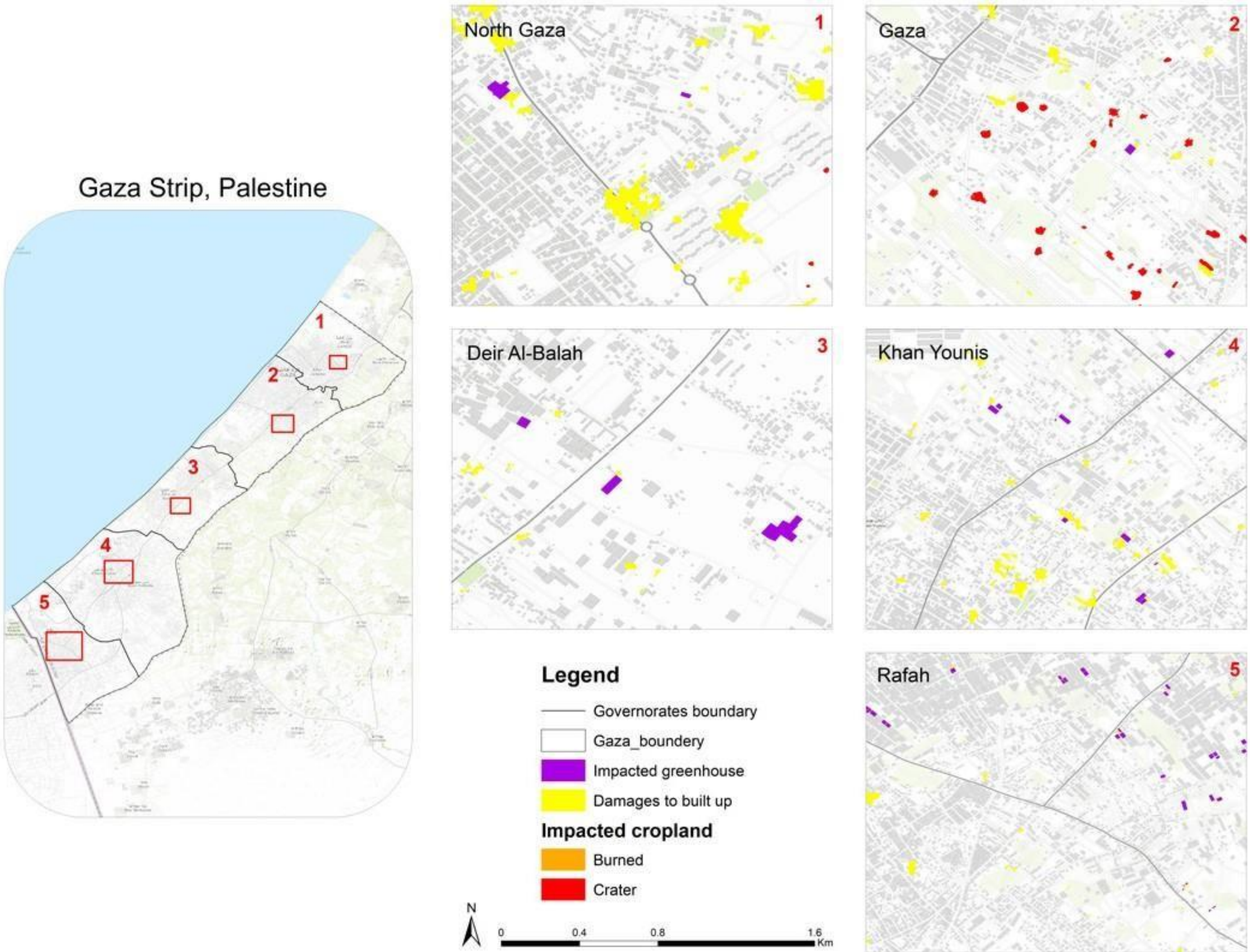
Source: FAO. 2021. Impact of the May conflict escalation on the agricultural area in the Gaza Strip. Rome. https://doi.org/10.4060/cb7167en

[32] https://openforis.org/tools/collect-earth-online/

Figure 19: A multi-ring buffer with radii of 15 m, 30 m and 45 m to detect agricultural infrastructure around the damage sites

Source: FAO. 2021. Impact of the May conflict escalation on the agricultural area in the Gaza Strip. Rome. https://doi.org/10.4060/cb7167en

Figure 20: Locations of the damage in the agricultural area caused in the Gaza Strip due to the May conflict 2021



Source: FAO. 2021. Impact of the May conflict escalation on the agricultural area in the Gaza Strip. Rome. https://doi.org/10.4060/cb7167en

When local administrative boundaries were not available from national platforms, boundaries from other platforms such as HDX, GAUL, and GADM were used to extract the AOI. In the absence of national land cover data, the local land cover legend and land cover map were prepared using a combination of radar imagery (Sentinel 1), optical imagery (Sentinel 2, Landsat), and training data using cloud computing platforms (i.e., SEPAL, GEE) and machine learning algorithms (Random Forest Classification etc.). When national agricultural statistical data were not available, data from FAOSTAT and the Global Agro-Ecological Zone version-4 were employed. UNOSAT damage assessment data was also utilized in this analysis.

The key challenges faced during the assessment were: (1) the restrictions imposed by the local authority for the field data collection in order to assess the damage and validate the results of EO analysis; (2) the crop type map prepared for the damage assessment was based on pseudo training samples, and thus it was not possible to validate the results with field data; and (3) the damage proxy map has a coarser resolution compared to land cover, increasing the possibility of false positives and higher damaged area estimations in the greenhouse damage assessment.

Based on these challenges, we make the following recommendations to improve future conflict impact assessments on agriculture: (1) clearly define AOIs using administrative boundaries; (2) employ field verification to quantify the uncertainty in the EO data; (3) provide available data related to agriculture for a better assessment of the actual damages (crop type, crop calendar, crop statistics, crop yield); (5) employ up-to-date infrastructure data (roads, number of buildings, households) at different administrative boundaries/units; (6) use RVI when optical imagery is unavailable; (7) assign a central person for specific data collection tasks; (8) provide available damage data/reports related due to crop production and agriculture; (9) use ground validation or household surveys to collect data on the severity of damages and socioeconomic impacts; (9) employ very-high spatial resolution satellite imagery for difficult-to-access locations; (10) strengthen the collaboration between local, national, regional and international organizations/institutes; and (11) increase the use of geospatial technology in rapid analysis.

FAO geospatial unit also perform rapid damage assessments with external partner collaborations such as UNOSAT. Such assessments can be part of a broader process to understand and give a dollar value to the damage and loss inflicted on the agriculture sector by conflict. FAO is actively involved in efforts to improve the integration of geo-spatial products in broader Damage and Loss assessments.

5. Challenges and recommendations

5.1. Challenges and opportunities in using geospatial data for hazard impact assessments

As illustrated in the previous examples, carrying out an impact assessment of a natural disaster, pest and disease epidemics, and/or conflict in the agriculture sector must be carried out within a limited time frame (usually as quickly as possible) and considering various specificities. This involves, for example, defining the geographical area of the impact, the level of the agriculture sector affected (livestock, perennial crop, annual, infrastructure, etc.), the impacted period, temporal variability (e.g. seasonality, growth) and spatial biophysical and socioeconomic characteristics. Also, depending on the data and the means available, the evaluation of the impact can vary considerably. With the increasing use of geospatial data and approaches combining remote sensing, terrain data and information technology, many opportunities are emerging, as well as challenges. The main challenges and opportunities for geospatial impact assessments are described below in four key areas related to (1) capabilities, (2) Data is missing, and technology is repeated, (3) technologies and (4) innovation.

5.1.1. Capacitation

The effective use of remote sensing datasets, GIS, machine learning and artificial intelligence, typically requires specialized skills and experience. One of the biggest challenges in the context of emergency in developing countries is the lack of available technical expertise in using geospatial technologies. In the last few decades, remote sensing has become an inevitable method for data collection. The need to include ancillary data (e.g. land cover maps, ground/field data, etc.) has long been acknowledged by the geospatial community. However, the integration of data obtained from remote sensing with that from the ground can be a complex task due to differences in data structure, acquisition, and storage. Combining different technologies and approaches using multiple methodologies, tools, and standards by different entities is effective, but complicates the data comparison, aggregation/disaggregation, and reporting processes. Integrating statistical and geospatial data has also proved to be a challenge, particularly with limited technical expertise. Limited institutional capacities in developing countries often have exacerbating implications in this regard. One way of addressing this issue is to harness the potential of geospatial platforms which integrate different sets of data using Standard Operating Procedures to produce actionable outcomes. The FAO DIEM approach is a promising example of such an integrative platform. In order to work most effectively, such efforts rely on sufficient capacity at all levels from local to global, and this remains a challenge. It is recommended to enhance technical and institutional capacity at the local to national level for data preparation, management and sharing.

Enhanced technical expertise can facilitate the development of geospatial databases aligned with national statistics that can improve the robustness and quality of data and hence ensure data-driven emergency response.

Strengthening technical capacity is also required to support storage efficiency, data integration, data sharing from different sources and data conversion from oneformat to another. This will allow for a smoother, more efficient, and accurate workflow for the data processing and management and thus facilitates the timely delivery of results.

Significant improvements have been made in virtual communications over the last few years, especially after the huge demand following the COVID-19 pandemic lockdown. Such improvements can be exploited as an opportunity to organize technical workshops, training, webinars, and consultations involving national, regional, and international stakeholders to strengthen the capacities and collaboration for emergency impact assessments. The capacity building of national to local stakeholders should be conducted in a suitable language to ensure a better understanding of geospatial tools, standard data acquisition methods (including field surveys/observations/ measurements, sampling, etc.) in ways that act synergistically with these tools and use high accuracy systems for data collection. Capacity development should include training on equipment (remote sensing tools, climatic monitoring stations etc.) as well as software (GIS software, scripting and programming languages and image processing skills etc.).

5.1.2. Technology

The recent advancement in the availability of Earth observation data and geospatial technologies has significant potential in providing precise and timely data in response to emergencies. However, challenges remain in the effective use of such data and tools, mainly due to the limited technical capacity, particularly at the national to local level. Rapidly assessing the impacts of natural hazards, pests, diseases and conflicts in LDCs proves to be difficult due to the lack of resources and limited knowledge and awareness of available advanced geospatial tools, technologies, platforms, and data. Accessing, storing, and working with the large volumes of Earth observation data required for geospatial impact assessment is also a challenge in LDCs due to the limited internet connection and high-performance computing resources. There has been an exponential growth of geospatial technologies in the last decade, however, selecting the appropriate tools and data for the assessments of the impacts of a diverse set of emergencies is often a challenge. In addition, the dissemination and sharing of results and information in a timely manner is also a complicated task. Various platforms help visualizing and disseminating the results from rapid impact assessment. One of them is the FAO's data in emergencies (DIEM) hub.[33] DIEM hub provides maps, dashboards and StoryMaps that are interconnected with other FAO systems, including the corporate data app. Transfer of data and information between platform such as between DIEM and ADAM contributes to sharing and knowledge transfer.

To ensure the effective use of advanced technology and data, the collaboration, and resource sharing between national, regional, and international communities (data providers, government, UN and other agencies) should be strengthened. Open platforms (e.g. Google Earth Engine) are breaking down the barriers to enable data accessibility, sharing, integration and analysis to support emergency impact assessments in a cost and time efficient way. For example, land cover is crucial for emergency impact analysis. To develop land cover, information on land cover maps legend classes is mandatory. The land cover legend registry (LCLR) provides land cover legend information at the local to global level.[34] Legend information from the LCLR can be integrated with earth observation data using SEPAL to prepare land cover datasets quickly and efficiently.

[33] https://data-in-emergencies.fao.org/

[34] https://www.fao.org/hih-geospatial-platform/en/resources/land-cover-legend-registry/

5.1.3. Data

Acquisition of meaningful data for a specific time, considering that hazards cannot always be predicted and given the limited time to perform a robust emergency impact assessment, is often challenging. Moreover, the acquired data should be of a certain quality (with proper documentation, spatial extent, representativeness, completeness, consistency, comparability, and others), basedon statistically sound sampling schemes and understandable by the recipient. Emergency impact assessment often requires information to be produced for the administrative unit for better management of emergency responses. Limited data collection within required administrative units (administrative boundaries), as well as the unavailability of field data and/or national/sub-national statistical data, is a challenge in this respect. Moreover, lack of formal and informal data sharing between relevant entities often leads to limited understanding of existing and potentially available data limiting timely production of required data and results in reduced utility of the data in decision making.

The COVID-19 has made it more difficult to access and collect quality field data from ground. Many countries have observational data quantity and quality issues, with a lack of national aggregated, consistent, and standardized information about the status of natural resources. Updated and reliable data on land and water classifications, land cover, crop type map, agriculture types, Digital Elevation Models, and others are required to strengthen national systems, including forecasting, early warning system (EWS) and disaster and/or conflict management systems to support rapid assessments, recovery and national plans, resilient agriculture, and sustainable livelihoods. Furthermore, the lack of unit and/or coordination and inconsistencies in data across different national organizations including agricultural, disaster risk reduction, statistical, and environmental management agencies must be overcome to improve the overall risk management performance.

Another key data-related challenge in geospatial disaster risk assessments is the huge and ever-increasing amount of earth observation data that has become available with the rapid advances in technology. New data products typically feature improvements on their predecessors in terms of accuracy, spatial and temporal resolution, and others. However, the amount, size, and perhaps complexity of the data is also increasing. This places a strain on the technical workflow, data storage and management of the risk assessments, on the requirement to implement accurate and timely automated data analysis procedures, as manually analysing huge datasets is inefficient for disaster response and impact assessments. Moreover, it is important to consider that newly released EO data products typically lack validation, and this should be accounted for in the assessment.

It is highly recommended to prepare national statistical data and geospatial databases using geospatial technologies for emergency situations to support national disaster and/or conflict management systems, resilient agriculture, and the livelihoods of the population.

So far, the underutilized source of data is commercial very high resolution (VHR) synthetic aperture radar (SAR) data. Since SAR can acquire imagery independent of cloud coverage and day or nighttime, it is a very valuable asset for deriving timely information. So far, the free and open data from Sentinel-1 is widely employed, but only has 6-12 days repeat cycle. Commercial systems such as the CosmoSkyMed constellation, or data from new space actors such as IceEye and CapellaSpace offer data capable of sensing the same area several times a week at very high resolution. Since SAR imagery is difficult to handle and to interpret, its provision must go along with automated tools that derive value added products such as flood masks or infrastructural damage.

5.1.4. Innovation

Rapid emergency impact assessments are constrained by limited time and adhoc funding. This often restricts the incorporation of new ideas in developing and implementing methodologies for rapid impact assessments. Despite the evidence of increased frequency and intensity of weather induced hazards, their measuring, mapping and prediction remain poor in certain sectors, for example, the accurate monitoring and prediction of flood dynamics. This is mainly related to the lack of measurements and ancillary data at the global level. In this context, remote sensing provides spatially contiguous data that is increasingly used to minimize the need for extensive field surveys, especially in remote areas and LDCs. The implementation of remotely sensed variables (e.g. digital elevation model, river width, flood extent, water level, rainfall probability, lava flow, ash, depth, damage proxy, land cover and vegetation change etc.) in disaster mapping promises to considerably improve the understanding and predicting processes. The increasing availability ofSAR data is also useful in crop type and flood mapping. During the last decades, an increasingamount of research has been undertaken to better exploit the potential of current and future satellite observations, from both government-funded and commercial missions, as wellas many datasets from airborne sensors carried on airplanes and drones. The scientific community has shown how remotely sensed variables can be used in real-time flood monitoring applications. With the proliferation of open and Earth observation data, this progress is expected to be on the rise. Increased and continued financial support for research and innovation on emergency impact assessments is recommended to get the most from state of the art technologies.

On the other hand, cloud computing platforms and data cubes are becoming common solutions to process petabytes of information at a much quicker rate compared to conventional desktop software. These platforms can be used to provide emergency disaster responses in a timely manner.

Participatory GIS (PGIS) can be an effective approach in the support of geospatial impact assessments, as well as validating the results from the geospatial assessment. PGIS also facilitates the collaboration among local communities.

5.2. Recommendations

Recommendations for the improvement of future impact assessments include developing and enhancing cooperation between international organizations and scientific research centers and academia to provide rapid progress on various disaster challenges. Governments can allocate/sustain/increase funds in the national budget for disaster risk management to improve resilient agriculture by strengthening international cooperation. It is beneficial for resource partners to support initiatives for the institutionalization of disaster assessment methodologies and management. Integration of remote sensing, field information (e.g., household surveys, damage and loss analyses), and models (e.g., food security projections), with advocacy and capacity enhancement processes at the technical and policy level are crucial for the improved impact assessments and to the delivery of relevant and actionable information to ends users.

To improve the results from impact assessments, appropriate field data collection following a suitable sampling scheme and method involving relevant national stakeholders should be adopted for validation and calibration. For example, the collection of field data to validate land cover and land use maps, or the collection of training points when cloud cover is a problem in EO data. Where possible, the workflow should include the crowdsourcing of emergency data (from e.g., smartphone applications, SMS, and social media) for the rapid collection of data.

The methodological approach can be further improved by combining various products and images for different time periods, as well as considering baseline data (e.g., last 10 years). Additionally, the combination of geospatial data products, including high resolution imagery, vegetation indices, agro-ecological zoning information by crop types, FAOSTAT, and other national agricultural statistics, must be employed to obtain robust national disaggregated crop statistics, consistent with the national datasets. These statistics can be used to assess crop damage caused by floods or other natural hazards.

Using higher spatial resolution satellite imagery for specific prioritized geographic areas is favorable; however, datasets with the highest resolution (e.g., GeoEye and WorldView, 0.4-0.5 m) are expensive. Moreover, crop calendars and market prices should be included in the assessment of economic impacts by crop type and triangulated with ancillary data (e.g., DIEM farmers' surveys) where available.

It is recommended to use different approaches and compare the results (e.g. triangulation) to identify the most likely impacted area, as the limitations tend to vary with product (e.g. cloud cover, temporal resolution, spatial resolution). For example, for flood impact assessments, the flow of water from a higher to lower elevation (derived from VHR DEMs) should be integrated as a crucial component along with flood extent. Furthermore, hydrodynamic models can be adopted to overcome limitations from EO data (e.g., cloud cover and unavailable data). It is recommended to establish early warning systems (EWS) and hydro meteorological stations using geospatial technologies. Country specific web platforms can be developed to quickly render maps, statistics and summary reports related to hazard impact, vulnerability of population, etc. at different levels as required.

It is recommended to develop and use standard operating procedures with national partners (with low-cost options for limited budgets) and enhance the collaboration with regional and national entities involved in land monitoring and disaster risk management. In particular, work should be done to standardize and automate the workflow for each disaster type (including data collection procedures and sources) to minimize the time spent on methodological decisions and maximize the time checking and delivery of the results. This requires teamwork and cooperation between relevant departments to maximize output.

Accordingly, Geospatial Unit in NSL-FAO is working closely to ensure cooperation and use of advanced technologies through integrated techniques and aiming to standardize the procedure for rapid impact assessments in countries and regions. Similarly, FAO DIEM hub is engaged in such a process whereby different data sources and associated workflows are integrated through use of Standard Operating Procedures to improve efficiency and improve timeliness and quality of products.

6. Conclusion

This report highlights the role of geospatial tools and technologies in the impact assessment of emergency crises and shocks. Examples of in-country applications, cross-cutting challenges, and recommendations were presented to support efficient responses. We focus on the use and integration of geospatial data, tools and applications during impact assessments, particularly concerning the agriculture sector, using several national case studies on flood impact assessments, volcanic eruptions, pest and disease, and conflict. Numerous challenges were highlighted related to capacitation, technology, data, and innovation. The following improvements were put forward for future disaster risk assessments: (1) prepare national data (geospatial and tabular); (2) collect field data; (3) combine remote sensing, GIS and statistical products (e.g. high resolution imagery, vegetation indices, agro-ecological zoning information by crop type, FAOSTAT and other national agricultural statistics) to improve methodological approaches; (4) consider crop calendars and market prices to assess the economic impact by crop type; (5) compare results from different methodological approaches and sources; (6) establish early warning systems (EWS) and hydrometeorological stations using geospatial technologies to increase food production and to improve resilience of targeted smallholder farmers and food insecure households in affected areas; and (7) enhance the collaboration with regional and national entities. The last point is particularly important to ensure all efforts are focused on maximizing the quality of results.

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Appendix

Appendix 1: Impact assessment data integration and dissemination through the FAO Data in Emergencies Hub

A recurring theme in this report concerns the challenges presented by data fragmentation, speed of analysis and synthesis of information and rapid visualization and dissemination of results. The FAO Data in Emergencies (DIEM) (Geospatial hub[1] (Figure A1) represents an attempt to address all of these challenges in one platform and set of associated processes.

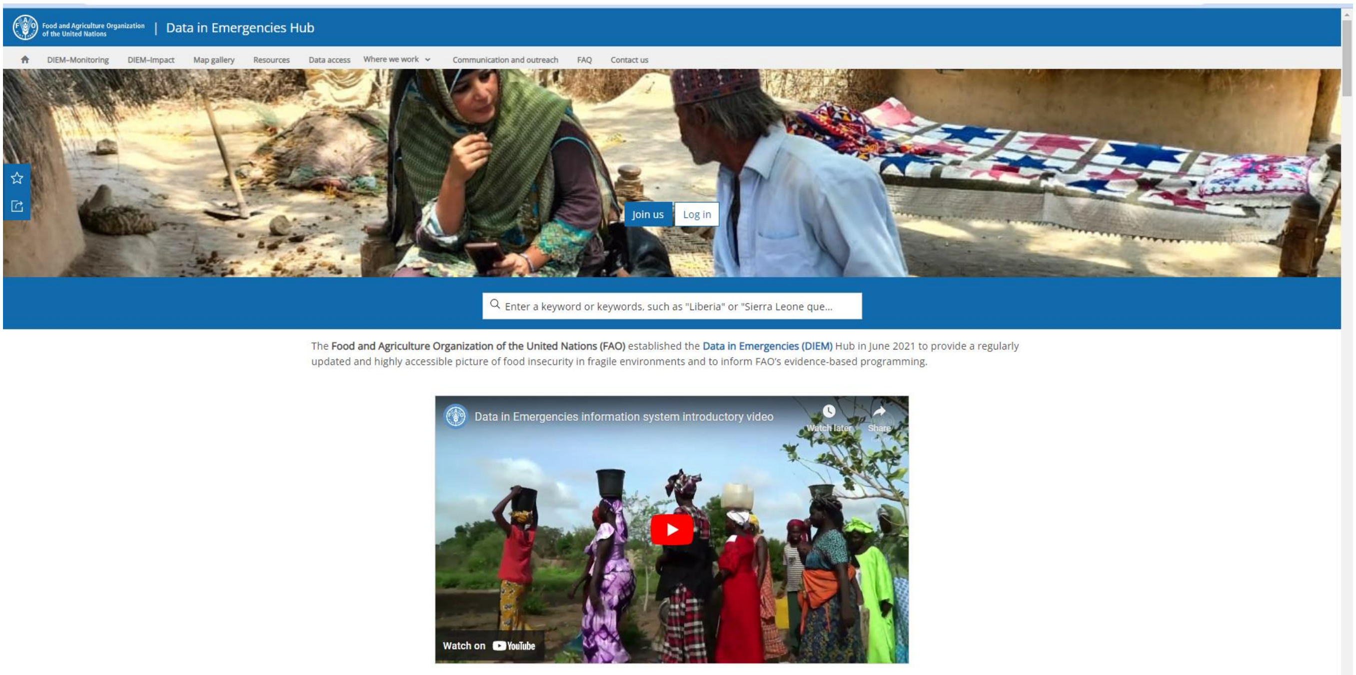

Figure A1 – DIEM hub interface

DIEM focuses on the relationship between shocks, agricultural livelihoods, and food security outcomes over time at the level of rural and agricultural households. This is illustrated in the following figure.

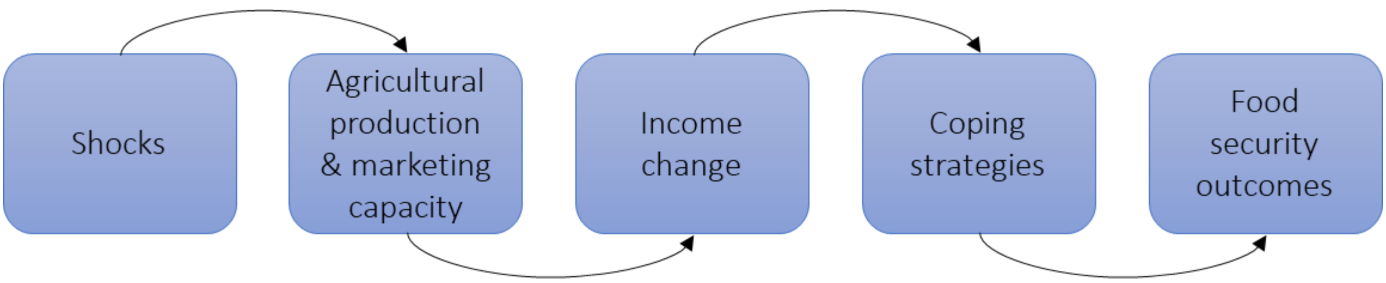

Figure A2 – Simplified DIEM conceptual framework

[1]https://data-in-emergencies.fao.org/

DIEM is comprised of three pillars:

DIEM-Monitoring: Through this pillar, FAO collects, analyses and disseminates data on shocks and livelihoods in countries prone to multiple shocks. DIEM-Monitoring aims to inform decision-making by providing regularly (28 countries for 2-3 rounds per year) updated information on how different shocks are affecting the livelihoods and food security of agricultural populations.
DIEM-Impact: In order to understand the impact of large-scale hazards - sudden-onset, slow-onset, natural and manmade - DIEM-Impact conducts assessments to provide a granular and rapid understanding of the impact on agriculture and agricultural livelihoods. DIEM-Impact also seeks to provide an estimate of damage and losses to the agricultural sector.
DIEM-Risk: DIEM-Risk seeks to provide agricultural livelihood risk profiles derived from geographic baselines of past events and their impacts on agricultural livelihoods.
In line with the focus of this publication on emergency impact assessment, the remainder of this annex focuses on the DIEM Impact pillar.

As noted earlier on in this publication, in the area of post-disaster impact assessments, satellite imagery is critical to provide early information on the scope and severity of effects of cyclones, floods and volcanic eruptions among others, at a time when representative field data is not yet available, and to complement field data collected in the later stages (Figure A3).

The DIEM-Impact pillar follows a phased approach in which each phase following a sudden-onset disaster brings specific objectives, constraints and assessment approaches tailored to these.

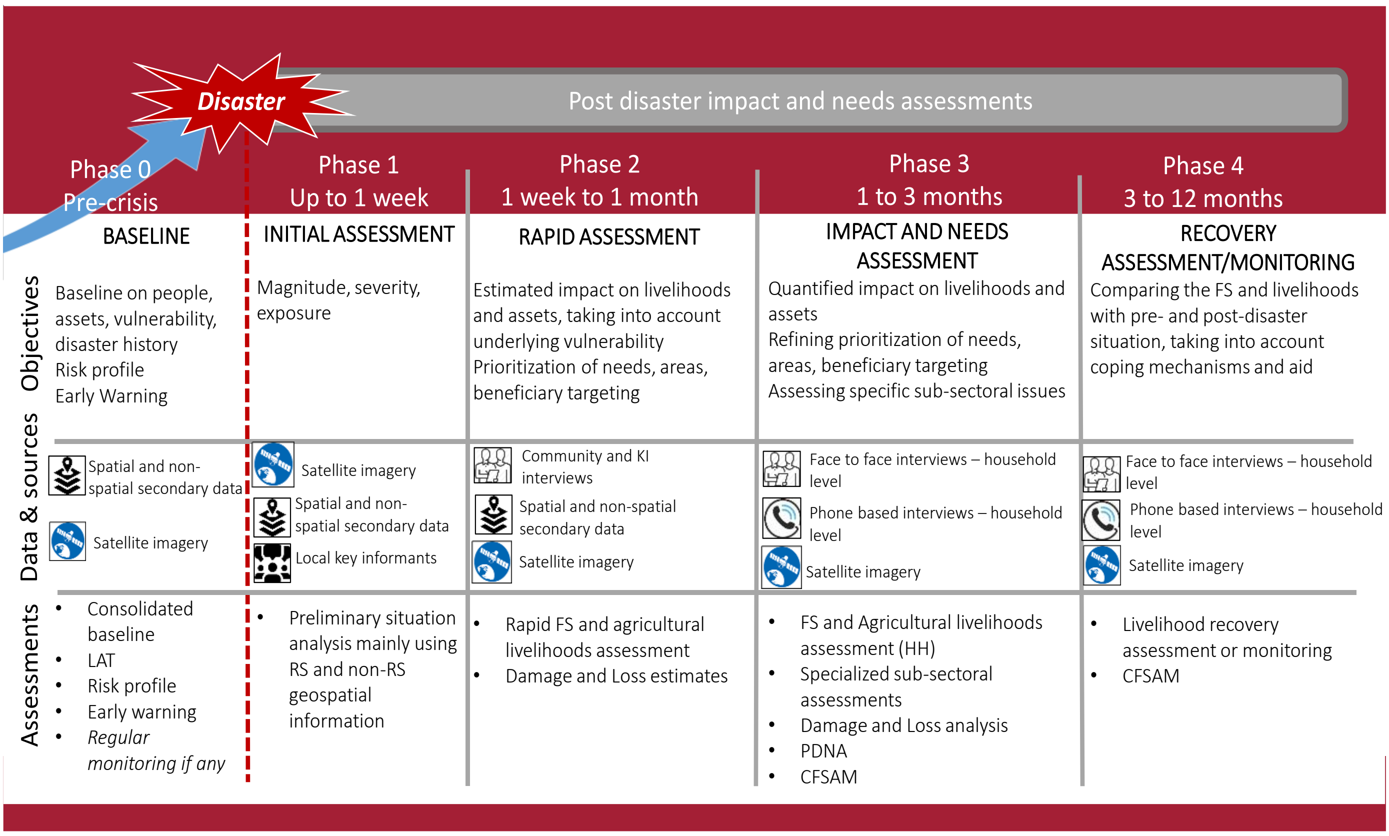

Figure A3 - DIEM Phased Impact Assessment Framework

The underlying conceptual and analytical framework for DIEM Impact is as shown below:

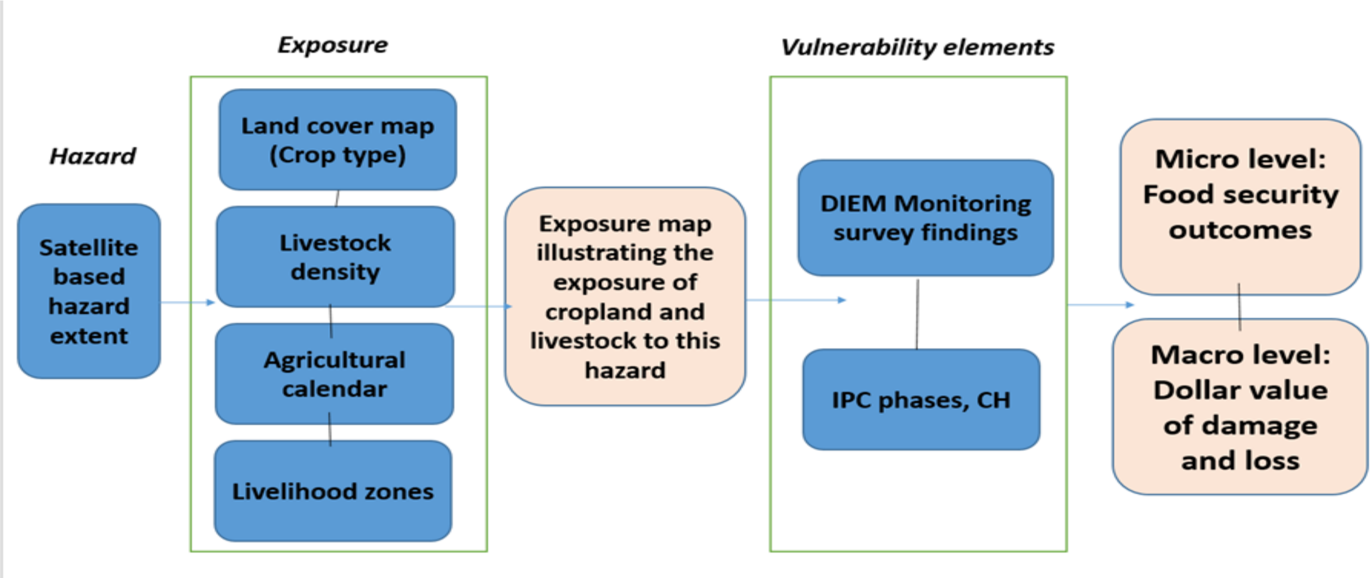

Figure A4 – DIEM Impact assessment workflow

Geospatial technologies can contribute to all phases:

1. In the *pre-disaster phase*, geospatial technologies focus on building the baseline data that will be needed to estimate the impact once a disaster hits, in particular with the development of detailed land cover maps and the development of risk profiles.
2. In *Phase 1*, the first 48 hours to one week following the disaster, while often no or very limited information is available from the ground, geospatial technologies can provide a first estimate of the scope and severity of the disaster effects, and exposure of people and key agricultural assets. The main goal here is to capture the actual or predicted change in livelihoods and food insecurity of *agricultural households* due to the impact of a given hazard or combination of hazards. This is a function of exposure to and vulnerability to the hazard or hazards. Exposure information potentially consists of flood masks (sourced from WFP ADAM (2023) and updated on a daily basis), precipitation anomalies (NASA, 2023), or NDVI. This information can be combined with open source spatial information on land cover (using global land cover (ESA, 2021)), livestock density (based on Gridded Livestock of the World, GLW 1 km (Gilbert et al., 2010), livelihood zones (from FEWS NET (2023)), food security phases (from IPC[2] or CH), agriculture and markets infrastructure (from various sources, such as HDX[3]), and demographics (from WorldPop[4]). For example, after a 5.9 earthquake that struck the central region of Afghanistan on 22 June 2022, layering the areas affected with human and livestock population density allowed for the identification of the likely effects on livelihoods (such as in Figure A5).
3. In *Phase 2*, the first month following the disaster, depending on logistical constraints some information comes from the field, but usually more qualitative and limited in scope. Geospatial assessments conducted in Phase 1 can help identify the most affected areas to be visited if a Rapid assessment is conducted face to face with key informants or communities. Geospatial technologies can also be used to extrapolate the results from the data collected in the field (e.g. level of crop losses in areas affected by the

[2]https://www.ipcinfo.org/ipcinfo-website/ipc-overview-and-classification-system/ipc-acute-food-insecurity-classification/en/
[3]https://data.humdata.org/
[4]https://hub.worldpop.org/

disaster at different levels) over the full scale of the disaster and provide a picture of the total extent of disaster effects, contributing in particular to initial Damage and Loss estimates. After the Cyclone Mocha that made landfall in Myanmar on 13 May 2023, satellite images for this period not only permitted an estimation of flooded cropland (Figure A6), but also pointed at the most affected areas that were immediately targeted by a rapid KII assessment to understand the impact. These estimates, analysed in light of the vulnerability of affected populations, socioeconomic context and seasonality, inform the prioritization of needs, areas and beneficiary profiles.

4. In *Phase 3*, in the following two months, field access or telecommunications are usually sufficient or restored to allow for quantitative assessments, wither face-to-face or through phone interviews, to collect representative information on the impact of the disaster on agricultural populations (micro level) as well as on the overall sector including with final calculations of damages and losses (macro). The field information collected in phases 2 and 3 can be used as ground-truthing of the geospatial results, and to identify specific issues to be further investigated, often requiring more precise baseline information, such as impact on mangroves and coastlines, or landslides. In addition, the complementarity of the different tools can extend to the analysis of resilience: as exposure (provided by remote sensing and GIS analysis), which refers to the duration and magnitude of a shock, is coupled with vulnerability (provided by a follow up households' surveys), response actions can target not only the most affected areas but also the interventions that build resilience. For example, between December 2022 and January 2023 Afghanistan experienced an extreme cold snap, with the central region of Ghor recording the lowest reading of -33°C. By layering the temperatures estimated for different areas with animal density, an exposure map (Figure A7) could be used in relation to the data collected by the households' survey in those areas and address questions such as 'how had preparedness mechanism mitigated losses?', 'what were the characteristics making households more vulnerable to cold temperatures?' and 'what interventions are necessary to rehabilitate livelihoods sustainably?' (Figure A8).
5. In Phase 4, beyond the first three months after the disaster, the focus moves on to monitoring the situation and assessing the recovery of the affected populations and the agriculture sector. Geospatial technologies can help in particular monitor the recovery of the vegetation and performance of the cropping season, in addition to measuring the effects of any after-shock in case of an earthquake or a volcanic eruption for example. The Phased approach is also a continuum in which post-disaster assessments feed into the revision of baselines in preparedness for any future disaster.

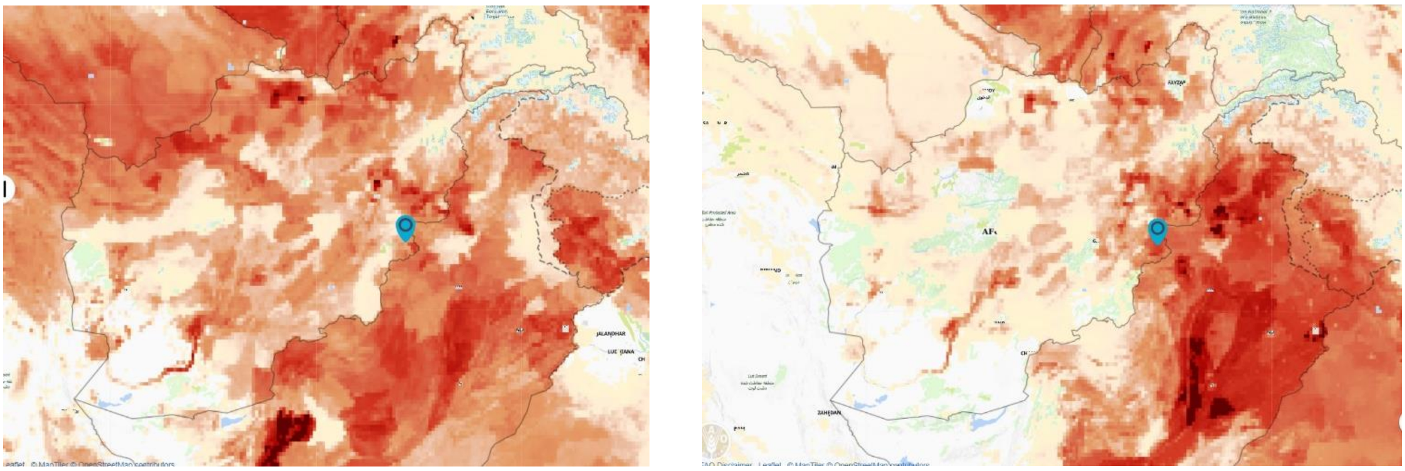

Figure A5 – Cattle and Sheep density in the area affected by the earthquake, using the Gridded Livestock of the World (GLW) (Afghanistan, June 2022). Source: Afghanistan Earthquake: The impact of the earthquake on agricultural livelihoods and food security, January 4, 2023 (https://storymaps.arcgis.com/stories/baaa1f02a22e467dafc612d3bfb83af4

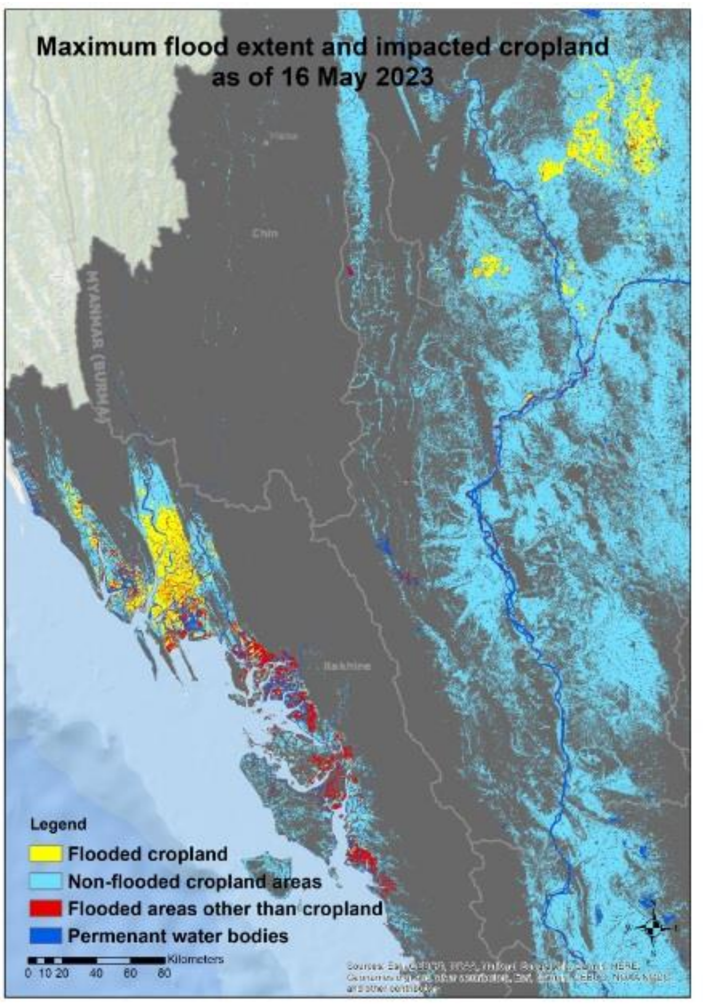

Figure A6 – Overlay of the cropland and maximum flood extents by cyclone Mocha (Myanmar, May 2023). Source: Tropical cyclone Mocha, Myanmar: The impact of tropical cyclone Mocha on agriculture and livelihoods (https://storymaps.arcgis.com/stories/a97314f4fec34a448721f320829acfbe)

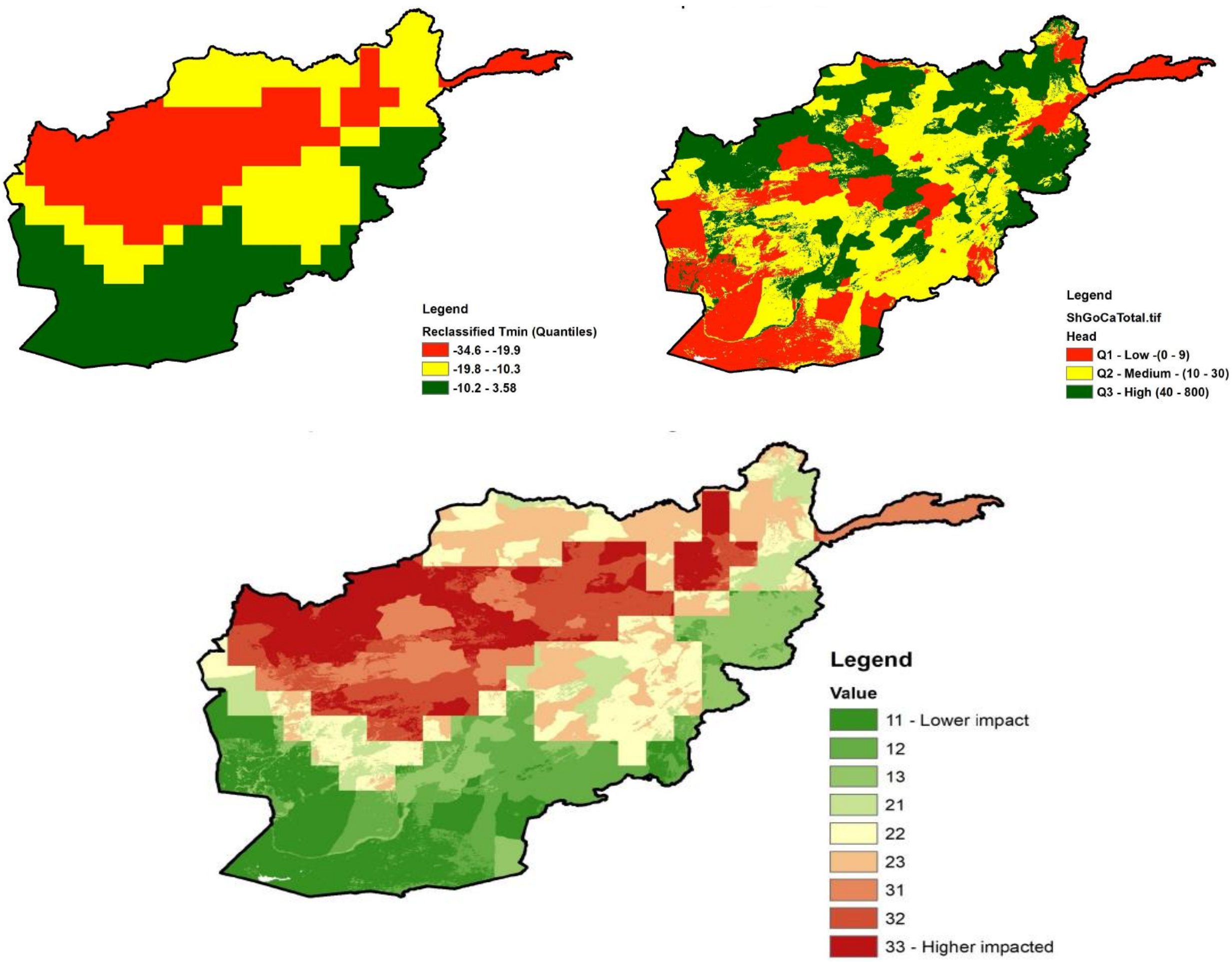

Figure A7 – The map on the top left (classes of exposures to extreme temperatures) has been overlaid with the map on the right (cattle, goats and sheep density classes), resulting in the map at the bottom, showing the different potential losses (Afghanistan, cold wave 2023). Source: DIEM Impact Assessment of the cold wave in Afghanistan (in publication)

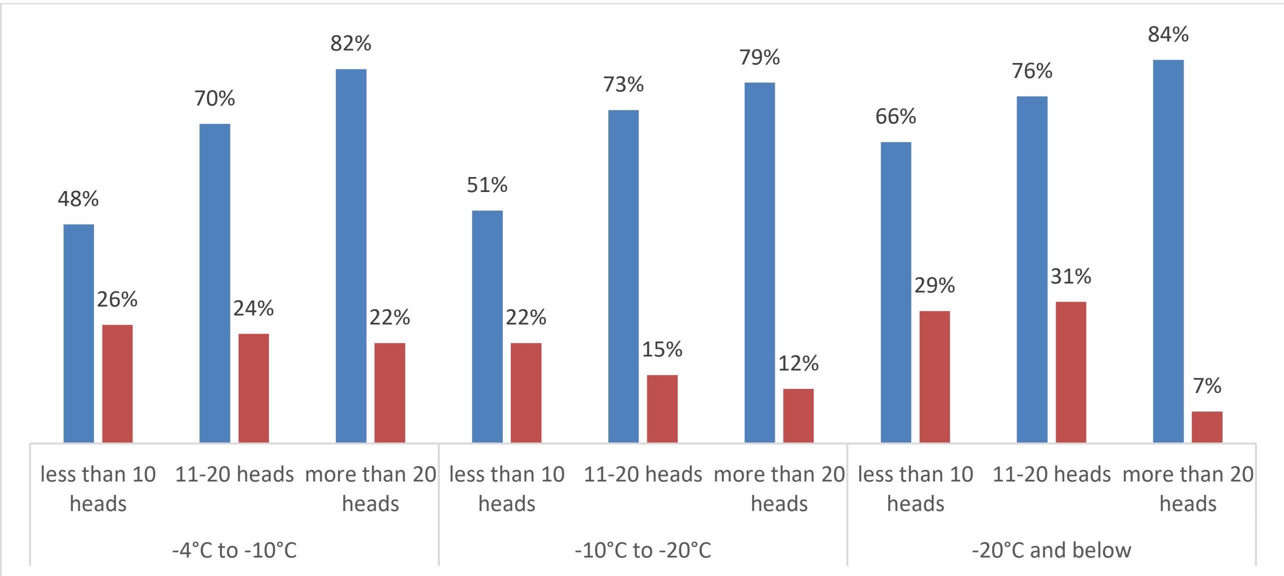

Figure A8 – Losses of cattle by herd size and exposure (Afghanistan, cold wave 2022, household survey). Source: DIEM Impact Assessment of the cold wave in Afghanistan (in publication)

The geospatial assessments therefore feed into a larger assessment framework, designed and coordinated by the FAO DIEM team, in which they complement different data collection methodologies and modalities used through the different phases of the disaster impact assessment.
Overall, the FAO DIEM system offers practical and accessible solutions to some of the challenges highlighted in the main text of this publication through:

- Leveraging readily available data and information from partners and open sources to conduct rapid *ex-post* impact assessments (within 48 hours to 5 days). This may be with or without pre-existing baselines. This approach benefits from some preparatory work ahead of major events in terms of baseline data compilation, geo-referencing, and frequent update. One constraint with such approaches can be the lack of accurate seasonal information on different crops. DIEM is now tackling this by mapping crop calendars, integrating space and time dimensions, in order to capture crop vulnerability to hazards depending on species and development stage at the time of the event.

- Using geospatial technologies to bring together different kinds of data in later phases of the overall post hazard assessment process. Various geospatial and non-geospatial data on hazard, exposure, vulnerability and livelihood outcomes are repeatedly brought together to create an evolving and integrated picture of impact on agricultural households. All of this is accessible online through interactive maps, dashboards, and tools such as StoryMaps[5]. Through the DIEM hub all of this can be visualized.

[5]StoryMaps are user-friendly tools that can be used in a collaborative manner by different subject matter experts (e.g. remote-sensing, damage and loss, household survey). StoryMaps unfold a story structured around a narrative and illustrations, essentially maps, in a way that can meet the needs of various users such as analysts, programming experts, and communication specialists. Interactive maps embedded within StoryMaps draw on other sources and platforms. In this regard, StoryMaps are a powerful opportunity to harness existing data-rich platforms, such as FAO's Hand in Hand platform and DIEM hub, for a specific purpose. The possibility to update StoryMaps with new insights makes that container particularly relevant to post-disaster situations that require fine-tuning of preliminary estimates and monitoring over time.

The report emphasizes the role of geospatial data and tools in assessing the impacts of both natural and human-induced hazards on agriculture. Its primary goal is to assist stakeholders in facilitating informed disaster risk reduction initiatives within the agriculture sector. The document showcases a diverse array of case studies, offering practical insights into the application of geospatial data and tools. In addition to scientific analyses, it sheds light on the challenges, opportunities, and insights crucial for stakeholders and technical partners involved in hazard impact assessment employing geospatial data/tools. Drawing from lessons learned, the report also provides recommendations regarding methodological approaches, particularly highlighting the importance of capacity building at local to national levels, efficient data management, and the integration of technological innovations within the broader framework of disaster risk reduction.

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