Journal of Migration and Political Studies

e-ISSN : 3023-4328
Publisher : Sakarya University

Vol. 3, No. 2, 196-220, 2025
DOI: https://doi.org/10.69510/mipos.1684741

Review Article

Geo-Information for Humanitarian Mapping and Monitoring Crisis-Affected Regions: A Scoping Review

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Received: 26.04.2025
Accepted: 23.09.2025
Available Online: 29.09.2025

Abstract: The migration crisis is generated by mass movements of population within or outside the national borders of a country. Triggers to this phenomenon include either sudden events, such as natural catastrophes (floods, earthquakes) or gradual social pressure (wars and civil unrest). This paper aims to analyse the effective cartographic methods of mapping changing patterns of human movements. Replaced settlements are visible from space and can be mapped effectively using satellite images processed by Geo-Information Systems (GIS). This review study presents a thorough in-depth analysis of the significant role of the ML and GIS and their incorporating into crisis control and monitoring migration situations. Machine Learning (ML) hold a significant role in processing geospatial referenced data which is essential for mapping humanitarian crisis using Earth observation data. This review study presents a thorough in-depth analysis of the significant role of the ML and GIS and their incorporating into crisis control and monitoring migration situations. Understanding the reasons of migratory movements is supported by the interrogation of the trajectories which can be detected from space for mapping the ways of the migration's paths. A systematic literature review was performed, synthesizing findings from existing approaches, geospatial analysis and field observations related to humanitarian mapping. This study reveal that integrated use of ML, GIS and EO data can facilitate mapping the endangered areas for sustainable planning during crisis events across multiple spatiotemporal scales.

Keywords: Migration, Social Development, Disaster Mitigation, Data Analysis, Information

1. Introduction

Current debates surrounding the concept of environmental refugees focus on both past contributions and potential future contributions. In this context, the question of how to effectively map, visualize, track, and identify places affected by disasters is of utmost importance (Kostelnick and Hoeniges, 2018). These disputes could benefit from a geographic perspective on the refining of scale of mapping and the increasingly contested linkage between nature and society (Sheppard, 1995; Huber, 2010). Although the problem of the refugees have become widely monitored, there has still been debate over how much of the refugee movement can be attributed to the environmental and societal triggers.

Humanitarian mapping aims at accurate and rapid monitoring of crisis zones where people are forced to flee tdue to the climate effects or societal unrest (Ma et al., 2021). Its primary objective is to identify vulnerable areas affected by migration, for the purposes of monitoring, analysis, and forecasting possible developments in the situation developing countries that can be detected using Earth Observation (EO) data and Geographic Information Systems (GIS) technologies, as well as modern approaches of Machine Learning (ML) and Deep Learning (DL) to evaluate these data.

Hence, its major mission is to support the human response to natural and social disasters and economic development. It presents a combined effort between the reports from the communities on the ground and the cartographic activities which track 'places-at-risk' on a map using satellite imagery and other geospatial data. Zones at risk may include such target features as flooded areas (Chen, 2022), demolished buildings and destroyed districts after the earthquake, cracked roads and other damaged features of infrastructure caused by distractions or disasters. Humanitarian mapping is a crucial guide in optimizing social and natural development in the affected regions.

Cite as(APA 7): Lemenkova, P. (2025). Geo-information for humanitarian mapping and monitoring crisis-affected regions: A scoping review. *Journal of Migration and Political Studies*, *3*(2), 196-220. https://doi.org/10.69510/mipos.1684741

This article summarizes details of the state-of-the-art approaches to mapping people migrating in crisis situations. It additionally discusses the main migration triggers, preferred destinations, natural and social reasons for migration. The magnitude scales of natural hazards (floods, earthquakes) and social forces (civil wars, unrests, famine caused by droughts in developing countries) are assessed. The key objective of this study is to provide parameters affecting complex social-economic dynamics in

The present study aims to review the existing approaches to support the monitoring of affected regions during humanitarian crises. Novel technologies ensure the provision of operative data for monitoring refugee movements based on data-driven models and mapping methods in real time regime. The major applied models used for data processing as well as performance metrics, research gaps, limitations, and technical tools are assessed. The use of geoinformation technologies in Humanitarian Mapping domain is quite common and new technologies are often adopted quite rapidly, in operational applications/services as well as in volunteered geographic information related actions. This article focuses particularly on the use of EO technology and its critical role as a decision-supporting tool for humanitarian professionals.

2. Trigger Factors Forcing People to Flee: Background and Context

A distinction is made between forced and voluntary migration (Verkuyten et al., 2017). From a social psychological perspective, a strong distinction is being made in the society between forced migrants (Erdal & Oeppen, 2017; Bartram, 2015), i.e., people who have no choice but to migrate, and voluntary migrants (Scott, 2006), meaning those who migrate following their own free choice. While the first category is usually associated with asylum seekers – mostly poor people escaping from natural disasters, wars or civil unrest (Betts, 2016; Crawley & Jones, 2020), the second category is often constituted by educated middle social class who search for better places for living to apply their education, skills and knowledge (Liu, 2024; Adeyanju & Olatunji, 2022).

Many factors trigger local population to escape their places of living, which can be roughly divided into two categories, according to scholarly qualitative observations: social unrest (Hugo et al., 2012) and natural disasters (Conigliani et al., 2021; Lysaker, 2022). Spatial analysis supported by humanitarian mapping enables to analyse the extent of the areas influenced by the disasters and the degree of impact which helps, first, to mitigate the existing dangers, second, to minimize the potential losses, and third, to predict possible development of the situation in case of negative scenarios. In this regard, mainstreaming humanitarian mapping into regional planning is essential to effective risk management.

The migration governance crisis triggers diverse issues with security, economic and natural aspects within the countries accepting refugees. To house displaced people, refugee camps are constructed as the optimized solution governed by humanitarian agencies and governments. Selecting appropriate locations for these camps is a complex, logistically challenging, and multidisciplinary process that should consider many factors. Among them, land suitability, water availability and place security are the most important ones (Ayyildiz et al., 2021). This problem has a multi-criteria decision-making structure since there are numerous quantitative and qualitative elements that need to be considered while choosing the optimum location of refugee camps (Gutjahr & Nolz, 2016). Non-optimized solutions on camp constructions might result in further escape and displacement of refugees that involves long-term risks. The placement of refugee camps is a multifaceted and intricate process that can lead to additional displacement, long-term hazards, and issues for those affected. For instance, new refugees' settlements create effects on urbanization and rapidly change pattern of land use in the local landscapes. In this regard, EO data are useful source of information to detect areas from space to evaluate floods, stability of constructions and environmental safety (Islam et al., 2023; Lemenkova, 2025a; Sanyal, 2012).

Another aspect of refugee camping concerns food security and availability (Lawlis et al., 2018). Resettled refugees have to fight for stability of access to food resources and secure their resources. As a result, proper camping management should consider natural resource management as a part of geospatial analysis intended for evaluation of suitable locations. In these aspects, humanitarian mapping proposes geospatial decision-making solutions that combine GIS technologies, analytical data processing and methods of satellite image analysis as tools to support the geospatial analysis for selecting places of camps (Younes et al., 2022; Al-haddad & Rakshit, 2023).

3. Civil Wars, Regional Conflicts and Unrest

Civil wars and social unrest such as the ongoing conflicts are responsible for the refugee mobilization, Figure 1. To control the situation, monitoring of such refugees' camps is required with much of the attention centered on mitigating the emergency or crisis events, helping population at such zones of crisis presents issues of national or international significance (Beck, 2003).

Figure 1

Refugees in a Camp Created by UNHCR (left); People Collecting Water in a Refugee Camps in Africa (right)

Note: Médecins Sans Frontières (MSF), https://www.msf.org/

Nevertheless, despite the continuous agreements to repatriate refugees and the significance of ecosystem services for the survival of the communities, there has been a paucity of quantification of the harm caused by the conflict and the appropriateness of human resettlement. To monitor the endangered areas and zones of conflict, GIS-based cartographic support and geo-information management are highly important (Aung, 2021). Humanitarian mapping and monitoring such areas include diversified stages of actions.

First, the preliminary evaluation of situation, assessment and analysis are required for outlining the sketch of the event and the level of disaster (Foster, 1986). The response planning is then organized for strategic development which requires inventory of the available resources and mobilization of volunteers (Hamilton, 2005; Haworth, 2017). The implementation of monitoring and humanitarian mapping is then based on geospatial resources that include GIS, RS and geospatial data, statistical information and descriptive analysis (Ren et al., 2021; Diehr et al., 2025). The presented maps are evaluated for accuracy which is performed through the operational review and real-time quality control (He & Hu, 2025; Cho et al., 2025; Safabakhshpachehkenari et al., 2025). Such multiphase workflow supports real-time mapping which is necessary for immediate humanitarian interventions to meet the needs during crisis events or emergency situations such as wars or civil unrest.

4. Natural Hazards Affecting People: Real-Time Monitoring and Mapping

Understanding the role of natural disasters in the socio-economic balance is crucial for preventive risk assessment and support of population at risk. In this section we provide a brief review of the natural hazards, and approaches to operative monitoring in real-time regime to prevent losses of human lifes.

4.1. Climate-related events: Floods, tropical cyclones, droughts

Many existing studies suggest (Hirsch et al., 2024; Wen et al., 2025; Liu et al., 2025; Mihai et al., 2025) that climate-related events, such as floods, tropical cyclones and droughts, have mainly effect on the environmental balance of the affected regions, having a considerable influence on vegetation growth. Availability of water enables the possibility of agriculture crop system and favours the economic well-being. Response to floods (Ahmad, 2003; Mirza, 2011; Lemenkova, 2024a; Quader et al., 2021) and wildfires (Amos et al., 2019; Pultar et al., 2009) can be effectively mapped using the approaches of humanitarian mapping. For instance, GIS-based monitoring osing space-born satellite images enable to track refugee campfire and evaluate the severity of impacts using spectral indices (Hassan et al., 2022).

Climate disasters include weather-related events (Brown, 2007). This mostly involves the increase of temperature and decrease of precipitation as two major climatic parameters. Besides, density of river network create another important factor for habitats. Hydrological river network supports natural ecosystems which creates valuable resources for local population. For instance, dense plant canopy enhance crown water storage and maintain temperature balance. In contrast, deforestation affects soil and local microclimate setting and drastically reduces environmental potential for living. Therefore, climate effects on vegetation cycle and ecosystems are crucial for population living in rural areas. Such processes result in regional desertification and aridification, which severely affected agriculture and crop harvest (Blaikie et al., 2014). In arid regions, droughts become a direct consequence of such events and as a result, people flee from such areas searching for places with more favorable environmental conditions and stable access to available food.

Examples of other climate-related hazards include floods (Atmaja et al., 2024), tropical cyclones (Hassan et al., 2024), tsunami (Nieto et al., 2023), local inundations and droughts (Zhu et al., 2024). Regional effects of climate processes are especially notable in coastal area. As reported recently, determining the areas at risk of flood in coastal countries, such as Bangladesh (Figure 2) is essential. GIS-based analysis enables to facilitate a prompt response of local government aimed at mitigation of consequences for areas affected by major disasters. For example, moons and tidal fluctuations along the coastal regions contribute to local flooding which increases in submerged vegetation such as mangroves (Sumarga et al., 2023).

Figure 2

Damaged Urban Settlement and Destroyed Coastal Landscapes as a Result of Climate Disasters (left). Photo Credit: MSF. Floods in Bangladesh Caused by Seasonal Rainfalls Leaving People Displaced

Note: Earth.org. (https://earth.org/)

African countries with tropical climate often experience contrasting seasons and climatic extremes that affect people's well-being: a dry season with dusty winds, hot and humid period rainless weather, and a wet monsoon season with heavy rains and harsh conditions. Coastal regions in West Africa also experience the influence of the salt water of the ocean, affected by tides typical of the Atlantic coast and the riverine estuaries which affect the vegetation in the lagoons and possibility of fishing during these periods (Lemenkova & Debeir, 2023). Such processes affect agricultural development by local farmers. For instance, in Guinea-Bissau, temperature fluctuations and alternating monsoon-type rainy seasons, alternated with periods of hot, dry winds blowing from the Sahara, affect the possibility of agricultural activities (Lemenkova, 2024f). Related processes affect ecological vulnerability in coastal regions of tropical regions and agricultural activities of locals in Africa.

Finally, wildfires with related air pollution are caused by the increase of temperature. Australian wildfires can be mentioned as an example of such disasters. Forest fires lead to land degradation and trigger other environmental problems, such as soil erosion, desertification, decreased water runoff and reduced water storage, the drying of springs, and biodiversity loss. All these and similar events have severe impacts on livelihoods or even cause human deaths. Social aspects of disaster vulnerability can be evaluated using spatial analysis as a part of humanitarian mapping (Morrow, 1999). For example, using social data containing registrar of population, mapping correlation of most affected areas can be correlated with maps of social vulnerability and exposure to disasters for endangered groups of society such as poor, elderly, women and children. GIS-based mapping urban distribution can assist in identification of buildings located within the area at risk, Figure 3. However, there are still gaps in the understanding of social vulnerability with regard to natural hazards and its consequences for land-use management, post-disaster restoration policies, and the recovering of societal system after the hazard event. The use of IT and GIS can be employed to facilitate our understanding in such complex processes and support decision-making processes at local government level.

In such and similar cases, remote sensing (RS) data are useful for demonstration of the pre- and post-flooding inundated areas or former forests, destroyed by fire. Both a post-fire damage assessment and the prompt and efficient implementation of emergency measures depend on timely information regarding the location of the fire-impacted areas and the extent of the fire. Such monitoring can effectively be done using satellite time series analysis in real time regime (Alonso-Canas & Chuvieco, 2015). Communities, governments, and scientists can use the benefits of operative mapping to pay close attention to fire disasters because of the wide-ranging effects that wildfires have on the environment and society. In this regards, data obtained from spatial analysis have a high capacity to influence decision making by revealing areas at risk and identifying vulnerable regions on maps.

Figure 3

Refugee Camp of Zaatari in Jordan in a VHR Optical Image (left); Map Source: Z_GIS. A Radar Image (right)

Note: ESA imagery https://earth.esa.int/eogateway

4.2. Geological disasters: Earthquakes, landslides, tsunamis

Worldwide, geological disasters such as earthquakes and associated tsunamis or volcanic eruptions have had severe negative impacts on human livelihoods for centuries. Less dangerous yet still devastating events include landslides or soil erosion (Hossain et al., 2023). The major reason for earthquake occurrence is caused by the active movement of the tectonic plates and associated high seismicity in the zones of lithosphere friction (Dou et al., 2024; Lemenkova, 2022a). Despite the continuous efforts to predict earthquakes, this task remains a challenge in the geophysical domain, as well as evaluating stability of buildings during the construction and their resistance to natural and environmental effects (Lindh S Lemenkova, 2023a, 2023b). Measurements of the geologic risks and possible prediction of hazrads (earthquakes or landslides) are usually surrounded by considerable uncertainties. In decision making, recommendation are widely accepted on simplifications and modelling. Therefore, predicting earthquakes requires knowledge of the exact computed time, location and magnitude. Forecasting such events can still be made only with a certain degree of probability and using data integration (Nyimbili et al., 2018; Lemenkova, 2024b). In GIS-based geological risk assessment, predictive modelling is overcome by separating geological and social mapping (distribution of houses within the zone of risk).

5. Epidemic and Pandemic: Mapping Spread of Diseases

One of the most important applications of the humanitarian mapping refers to public health emergencies (Dermatis et al., 2024). For instance, recent pandemic diseases Ebola, or the outbreaks of such diseases as Avian influenza, malaria, cholera, yellow fever, are all examples of the events where medical monitoring is essential to prevent the distribution of the disease as much as possible (Tzavella et al., 2022; Li et al., 2019). In these and similar cases, maps provided by humanitarian activities assisted security medical intervention (Lee et al., 2011). Preparedness and responses to such infectious diseases, including epidemics and pandemics requires operative monitoring and mapping (McMichael, 2018). This is especially actual for monitoring the health situation of people in crowded camps where actual and precise information can support mitigation and ensure fast changing situations. Long term impacts of the health monitoring are mainly intended for population estimation in refugee or camps of internally displaced persons. Nevertheless, it is increasingly including informal settlements within fast growing cities where monitoring refugee camps has many recent research cases (Giada et al., 2003).

6. Geospatial Data and Technologies: Tools for Humanitarian Mapping

The international refugee monitoring is based on quantitative geospatial data. Apart from the computational aspect of data processing used by the GIS analysts, the capacity of the GIS methods to act as a robust approaches in societal studies and regulating migration governance crisis is methodologically relevant. The issues with coordinated refugee data that reveal vulnerabilities and current pattern of locations have been brought to the attention of international organizations and academic researchers. Despite these initiatives, the limitations of quantitative refugee data still exist. In this regard, increasing the availability of data on migration and refugee's is of crucial importance. The fundamental advantages of geospatial data for migration mapping include the following aspects:

1. aggregation of georeferenced locations showing the paths and ways of migration;
2. cross-evaluation to optimize and harmonize datasets with existing data;
3. continuous coverage and frequent updates: monitoring by EO data in real time regime;
4. exposure to natural risks and disasters as indicators of survivor bias.

The role of geospatial data (satellite images) and GIS methods is mainly to sustain this positive feedback between crisis situations (both natural and social ones) and analysis of the data for decision making. This especially concerns refugee vulnerabilities and exposure to natural and climate risks which can be monitored in real regime time using satellite data. Hence, the primary objective of the humanitarian mapping is supporting social geographic analysis through production of new geospatial data (maps) and using existing ones (e.g., maps showing previous situation before crisis, to analyse extent and dynamics of the event). The use of satellite images and maps in humanitarian contexts favor accurate identification of the areas affected by crisis and directions of the migrating population.

6.1. Methodological approaches of humanitarian mapping

For humanitarian mapping, integrated information plays an important role, especially in cases where the situation on the ground is very complex or the quality of available EO data is limited. Volunteered geographic information-based initiatives like the humanitarian OpenStreetMap (OSM) team follows the mission of creating maps for humanitarian response (Westrope et al., 2014; Yang et al., 2024). To this end, it incorporates a global community within the map-making process, based on modern distributed geo-spatial technologies (Wu et al., Liu et al., 2024). Such data may be complementary to the proper EO data and used for verification of real-time situation. Nevertheless, while more and more elements in this process (including quality assurance, task distribution, analysis of the mapped results) are automated, the mapping itself still relies mainly on the manual mapping work of thousands of volunteers (Luo et al., 2024; Fang et al., 2019; Gao S Klein, 201). In such cases, the use of machine-based methods of data processing for automation is essential.

The increase of the available pool of the RS data necessarily raises the problem of processing these data effectively, rapidly yet accurately. This is possible through the selective machine-based approaches. For instance, novel methods include the object-based change analysis for the automatic detection of destructed dwellings and land cover patterns (Knoth & Pebesma, 2017; Lemenkova, 2024c, 2025c) advanced spatial statistics and modelling (Nelson et al., 2020), machine learning algorithms for the RS data processing (Asadollah et al., 2024; Lemenkova, 2024d), to mention a few. Such methods present optimal solutions for information extraction and mapping through automated interpretation of EO data.

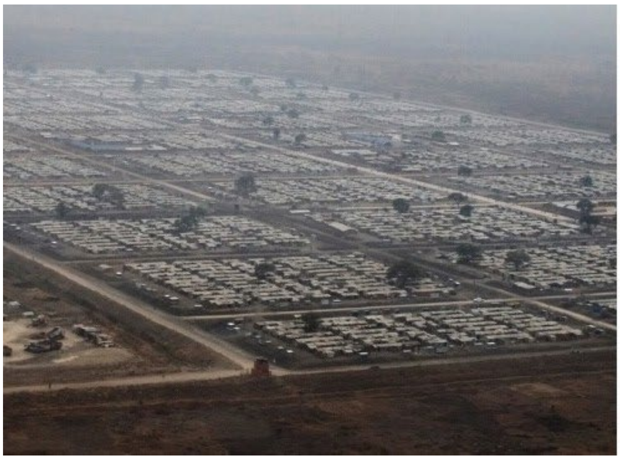
6.2. Remote sensing data: Sources of geo-information for monitoring crisis

Remote sensing (RS) data are a valuable source of information that ensures operative monitoring and mapping Earth's surface as visible from space. Many cases exist in contemporary literature on environmental monitoring that use the RS data as a backbone for spatial analysis (Imtiaz et al., 2025; Chen et al., 2024; Lemenkova, 2024; Chen et al 2025; Lemenkova, 2022b; Zheng et al., 2024). Specifically for the purposes of the humanitarian mapping, diverse RS data can be used due to the differences spatial extent of the mapped area, actual needs of mapping, access to data, regional aspects of territory, data availability, among the few parameters (Bennett et al., 2024; Crooks S Wise, 2013; Cinnamon, 2020; Lemenkova, 2022c). The type of organized assistance by humanitarian mapping might require various types of data which may include the high-resolution, moderate resolution or even course resolution RS data for humanitarian monitoring and mapping.

Among the diverse types of RS data, the role of Very High Resolution (VHR) satellite images is of utmost importance for remotely located (or highly unsecured) regions where access is physically restricted for humanitarians and volunteers (Killeen et al., 2022). The use of VHR optical satellite imagery for humanitarian purposes started in parallel with their employment for commercial purposes around the year 2000 (Bjorgo, 2000). The advantages of an independent information source offering information, especially for remote and insecure areas, were rapidly adopted. Besides satellite images, other types of data that might be used for humanitarian mapping include UAV, and other types of RS data such as optical of radar imagery, as shown on Figure 4.

Figure 4

Pre-Processed Imagery Service as Oblique Aerial Image (left); Bentiu Displacement (South Sudan) Protection of Civilians Site (PoC) Camp (right)




Note: MSF, https://www.msf.org/

6.3. GIS and AI technologies for mitigation and solving humanitarian crisis

Nowadays, geoinformatics has experienced rapid growth, with scripting and programming-based novel methods of mapping at the forefront of progress. Such methods necessarily require to be integrated into the modern approaches to humanitarian mapping to assess migration paths and evaluate complex links between the social, climate, environmental and economic factors affecting people's migration. GIS and RS data enable to effectively predict and prognosis the consequences of climate change and hazards. On the other side, the RS-based mapping refers to the use of satellite images to address a specific need of cartography that uses satellite images for interpretation of complex process on the face of the Earth: changes in land cover types, prognosis of natural hazards (floods or droughts) and using the condition of the advanced statistical data analysis by processing the results of geospatial modelling for evaluation of quality of these data. In view of this, the most challenging issues that one might face using geoinformatics methods in social mapping is the ever-increasing multi-disciplinary profile of data related to the migration governance crisis.

As a response to the more and more increasing role of geoinformatics, the trajectory of GIS data science and cartographic applications promises track of ways of people migrations and reshaping landscapes of current directions of humans (Dun & Gemenne, 2008). For accurate mapping, a comprehensive understanding of the application of geospatial data science and geoinformatics to the novel mapping approach is essential. Crisis mapping is effective and able to quickly ascertain the spatial variety and intensity of refugee migration routes and expansion of affected areas. To this end, automatic image processing techniques enable us to quickly and accurately identify refugee tents and their spatial extent. In this way, it presents an essential segment of the larger domain of the activities run by humanitarian agencies and organizations such as humanitarian information management, support people at risk, etc. Beyond regular mapping, the satellite images can identify the hotspot and areas at risk or heterogeneity of migration zones at a smaller spatial scales to highlight these situations.

7. Boost of Programming: New Era of Big Data Processing in Real-Time Regime

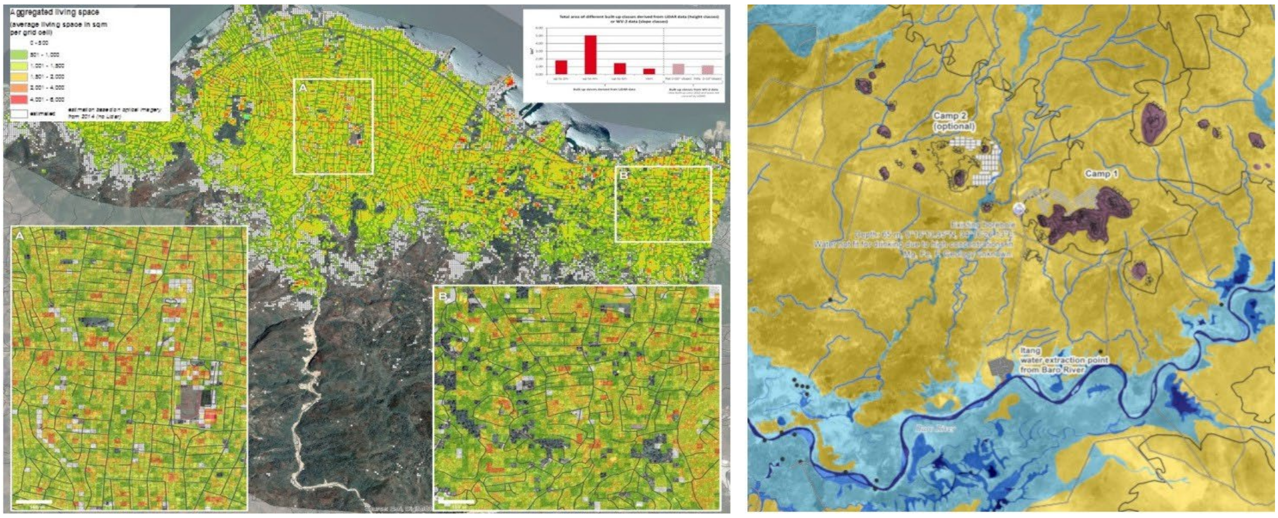
7.1. IT for monitoring natural hazards and social crisis

Rapid growth of Information Technologies (IT), increasing pool of the RS and Earth Observation (EO) data along with active development of Geographic Information Systems (GIS) paved the way to the development of more and more advanced tools in geoinformatics for operative monitoring of crisis events (Fatah et al., 2024; Lemenkova, 2022d). At the same time, we are now facing a rapid growth of data that leads to the 'big data' era with needs of their automatic, rapid and accurate processing. As response to these needs the use of IT in processing large volumes of Earth observation datasets represents a critical element for monitoring crisis situation. This refers both to the cartography in general and humanitarian mapping in particular as its thematic part. This evidence is in line with recent studies indicating the capacity of IT to handle large RS datasets for operative monitoring in real-time regime (Chen et al., 2023; Mattas et al., 2023; Xiahou et al., 2025). Thus, recent development of online technologies, Internet platform and mobile technologies have triggered the distribution of the humanitarian mapping practices which include digital mapping platforms and data sharing (Qin & Ye, 2025; Kemarau et al., 2025). This is actual for areas at risk where rapid distribution of trustful information is essential for monitoring and controlling by locals.

The access to the reliable data provided by local population is essential (Tzavella et al., 2018). For example, real-time data which includes geospatial information recorded through precise geolocation such as Global Positioning System (GPS) can effectively support accurate geospatial positioning of the endangered places. They can ensure the distribution of the up-to-date data displaying of current situation is valuable for humanitarian mapping. Moreover, digital technologies are used by humanitarian actors and affected populations as a support to monitor health and well-being as data collection (Mesmar et al., 2016).

Figure 5

Geospatial Data Processed by GIS for Humanitarian Mapping. Estimated Living Space, Haiti (left). Map Source: Z_GIS. Hydrogeological Analysis, Ethiopia (right)



Note: ESA

7.2. Machine learning in mapping: New possibilities of research

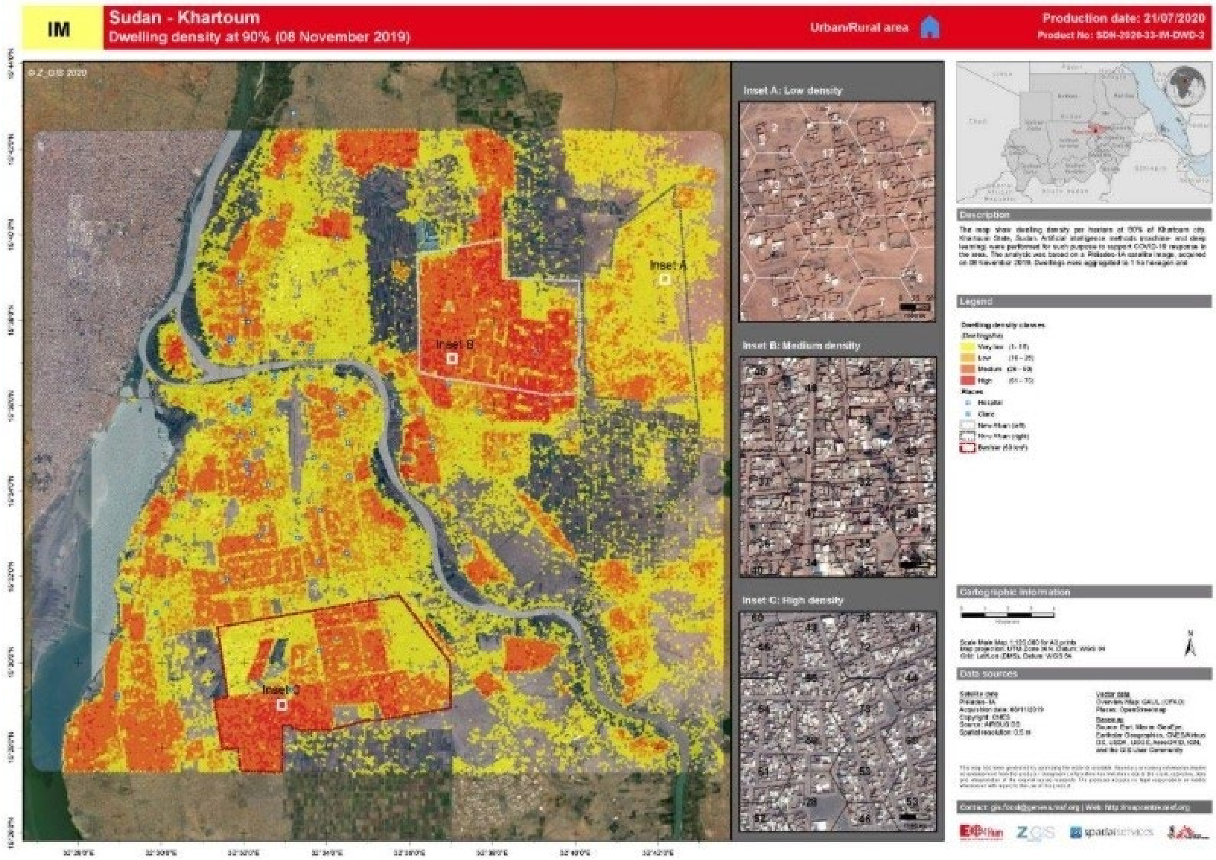
Machine learning (ML) in disaster, migration and crisis management is crucial for addressing challenges of operative monitoring. Effective use of ML supports automation in disaster management through methods of artificial intelligence (AI) that facilitate monitoring of refugees's campuses and enables to prognosis, mitigate and prevent risky situations. Programming tools that ensure ML present effective methods for data processing, data modelling and data management. This supports crisis monitoring through data analysis and visualization in real-time regime and big volumes of datasets. The use of ML algorithms, such as artificial neural networks (ANN), random forest (RF), decision trees, K-means and others, has been essential for satellite image analysis (Lu et al., 2021; Lemenkova, 2025b). Such methods present a novel interdisciplinary approach to processing Earth observation data with aim to reveal spots of migration from space, Figure 6.

Algorithms of ML, including deep learning (DL) exhibit unique methodologies which enable automation of data processing which is possible through scripting and programming languages. For real-time mapping, the integrated use of such technologies and robust VHR data is a critical solution that enables to monitor the strength and dynamics of crisis. For example, ML-based image processing facilitates flood control, a significant and recurrent category of natural disasters. It also accurately identifies the directions of migration paths, the potential distribution of diseases and possible ways of human movement. M L algorithms enable decision planners and policy makers to interact with data in operative way through image classification, mapping and geospatial analysis. This can either facilitate or reveal the areas at risks, the exposure at hazards and the migration of population.

The use of ML decreases complexities in data processing that beyond conventional models typically used to predict processes using semi-automated ways of modelling and simulation. For instance, the algorithms of RF, SVM and DT can enhance the accuracy of image treatment otherwise difficult to achieve using traditional GIS software. Moreover, cutting-edge technologies like cloud computing and big data analysis improve the precision and accuracy of cartographic workflow that is essential for spatial planning of migrating routes, planning refugees campuses, environmental policy making and social control. Large datasets can be processed using advanced Python or R programming tools to base research on script-based techniques which is needed in the personalized research tasks: processing data in big volumes, effective use of ML methods for RS data processing, etc.

Figure 6

Mapping Dwelling Density in Context Of Monitoring Urban Dynamics Using EO Data



Note: European Space Agency (ESA)

Computational reproducibility of geospatial data processing is a principle difficult to achieve in practice. The five pillars of reproducibility in general, computational research serves as a solid guideline in ensuring that computational research work is reproducible quickly and easily. These include literate programming, code version control and persistent sharing, computer environment control, data sharing and documentation. Apart from pure computing, reproducible principle is important for GIS and satellite image processing, Figure 7. Literate programming, introduced by Donald E. Knuth, is the idea of writing the logic behind a program in the form of a text easily understandable for humans. This is then combined with code snippets resulting in the output containing the code together with computational results such as figures and tables. The aim is to make the presented approach more understandable and the flow of the instructions more logical. This principle is then transferred and adopted in ML ideas and fundamentals. This approach is now widely used in spatial analysis and mapping of increase automation, accuracy and speed of mapping.

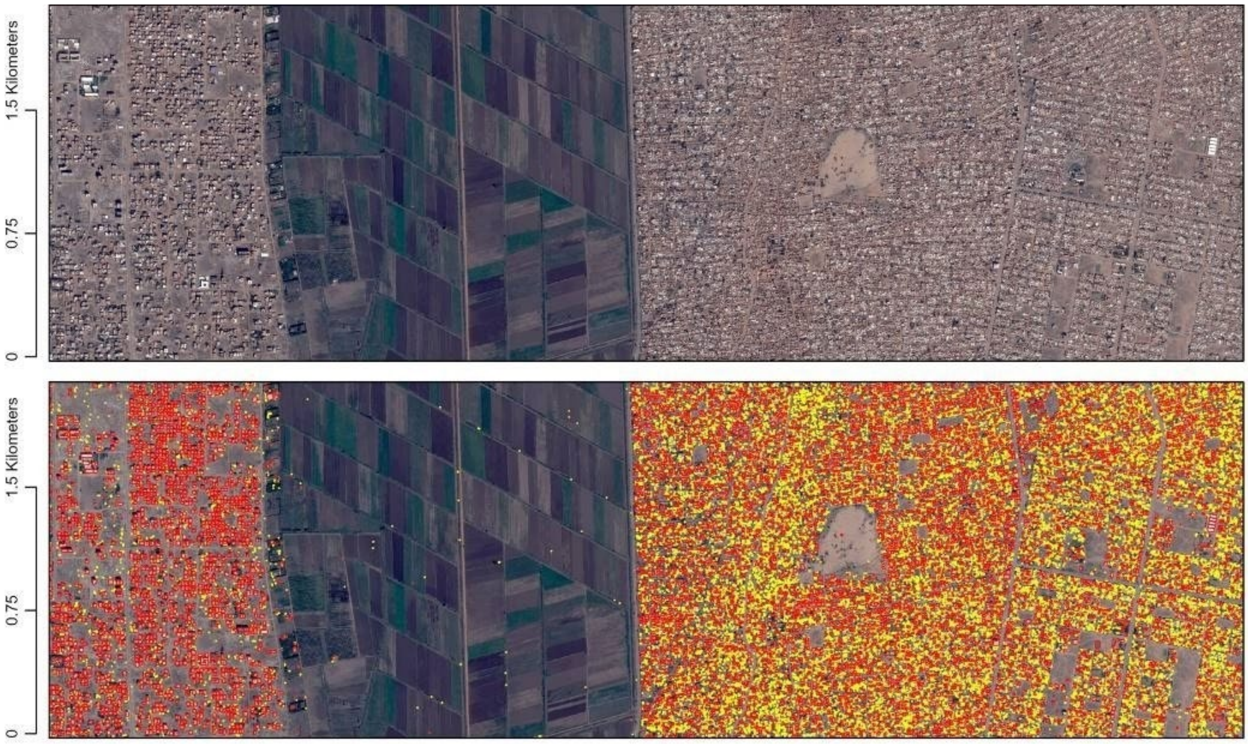
When discussing integration of geo-information, ML and GIS for monitoring humanitarian crisis, there is a difference between expanding the body of knowledge as a subfield, and practical applications of EO data observation for local policy makers. The governmental organization that support and monitor refugees can effectively use geospatial data and GIS for taking decisions on optimization of migration or hazard assessment in climate-affected regions (flooded areas or crop areas affected by drought). For example, finding an application for mapping software program or algorithm of EO data processing contributes to the humanitarian mapping as well as land cover agricultural mapping. The core idea of the flexibility of ML and GIS consists in the fact that the algorithm can be adapted and extended to fit the needs of region affected by crisis through EO data and geospatial solutions.

7.3. Data sharing for operative processing and common access

An important aspect of data processing and sharing in real-time crisis mapping is code version control. It enables persistent sharing of data and mapping methods for visualizing crisis situations in the operative mode. Sharing code is becoming a standard practice for reproducibility of geospatial data. A version control system can track changes made to files while repositories represent sets of files under version control for a project with shared exact coordinates of target areas as dataset. An example of a widely used version control system is Github, subject to regular updates, bug fixing, and adding new features. As changes can potentially affect the results of computational work, computer environment control is of increasing importance. Hence, reporting the exact version of all programs, libraries or frameworks used is essential in allowing others to reproduce the achieved results.

Figure 7

Satellite Data Processing for Mapping Land Cover Changes Using Convolutional Neural Network (CNN)



Note: Z_GIS.

The lack of persistent data sharing is one of the main reasons why research results based on ML are irreproducible. If data were created synthetically, explaining the creation process and linking the tools used to create the data is highly advisable. Data reuse increases efficiency and prevents redundant research as well as facilitating new research. Comprehensive documentation significantly simplifies the reproduction of a setup. Published documents in shared repositories (Github) are central pieces that outline a research project and link to supporting materials for operative humanitarian mapping. The repository should have a detailed "readme" file, and the paper explain in detail and link to other software or data that was used for the project which together results in a critical role for reproducibility to ensure quick access for participatory users that evaluate crisis in real-time regime.

Another aspect to consider when talking about the integrative aspects of EO data processing is the contribution is generalization. If practical results of monitoring human movements and resettlements can be generalized to a certain point, the extent of flexibility of scale (local, regional of global) may describe the scope of data adjustability. Another ongoing discussion about data integration is about in which field of humanitarian mapping a contribution was made: it is monitoring of floods, mapping cyclone directions, droughts or hot spots of civil unrest? A result shown in a GIS-based work in one domain can contain a contribution to the mitigation of crisis through cartographic tools.

7.4. Integrating approaches for tracking migration

Unlike the traditional methods that can be used in humanitarian mapping (for example, such software as ArcGIS, QGIS, Erdas Imagine for RS data analysis, Idrisi GIS for advanced image processing), the integrated approaches which combine programming, RS and cartography pave way to the more advanced ways of handling Earth observation data for social services and visualization of people's migration. Specifically, this is useful for mapping highly heterogeneous landscapes in such regions as tropics, and areas affected by wildfires and floods (Lu et al., 2024). Furthermore, the advanced methods enable us to process data for visualization of mosaic vegetation biomes of west Africa and evaluate the probability of droughts and possible famine. Hence, integrated approach enriches modern challenges of the humanitarian mapping. Using technologies of satellite image processing, statistical GIS analysis and programming plays a primary role in driving humanitarian mapping.

Such data can be useful to assess the contrast from the savannah or dense tropical forests or agricultural areas. Complex and highly fragmented patches that are related to the low fertility of lands and might be factors of famine. Processing these data requires special skills of using advanced methods of RS data processing, the use of big data in geospatial analysis, detecting dynamics of vegetation types using a series of satellite images. For instance, it can be achieved using scripting techniques that ensure sophisticated cartographic design and spatial analysis. As a response to these needs, modern GIS approaches to the humanitarian mapping may consider such advanced tools as GRASS GIS or GMT. Multi-disciplinary approaches that are used in these tools ensure more insightful analysis of the interrelated processed that are affected both by climate impacts, social wars and environmental factors which lead to the migration crisis and force people to flee.

8. Data-Driven Solutions for Mapping

8.1. Satellite images as source of information for controlling humanitarian crisis

For satellite image-based mapping to reveal hazards, crisis-affected regions and areas-at-risk on the Earth, numerous data analysis approaches have been carried out and targeted GIS functionality as a fundamental technology for RS-based mapping. As a consequence, using EO data enables us to deepen the analysis of social-environmental changes in diverse aspects using advanced tools. For instance, RS data can be applied based on their physical fundamentals of spectral reflectance, orbit characteristics that differ various satellite missions (SPOT, Landsat, Sentinel and many more). The variety of such data can help to identify spots of crisis, both of natural character (fires, floods, earthquakes) and social (detect camping of migrants of destroyed buildings during the civil war).

Understanding technical characteristics of spatial data is essential for correct handling of information obtained from these sources. Hence, we can use the RS data as a source of multi-faceted information which enables us to highlight diverse aspects of the Earth's landscapes for migration crisis related to climate, environmental and economic reasons (famine, war, social unrests). Hence, mapping becomes more intelligent than their mechanical reuse for data visualization. Geoinformation approaches can be used to derive information from multiple types of satellite imagery and in this way may contribute to deepening the understanding of people's migration. Thus, the integration of data and methods increases the multidisciplinary of the humanitarian mapping using geoinformation tools and applicability of its technical methods.

8.2. Integrative data management for operative crisis monitoring

Apart from the methodological aspect, the production of geospatial data and maps in humanitarian context strongly depends on data management. This is because it aims at such crucial parameters as identifying the exact location, dynamics of distribution and the scale of disasters (from low to the highest level) in risk issues (Alam et al., 2020; Bethel et al., 2011). These include identifying the emergency cases and situations cause by wars and civil unrest (Buhaug S Lujala, 2005; Gizelis et al., 2021; Gorsevski et al., 2013), health risk hazards (Mori et al., 2007; Shube et al., 2024), or monitoring geographic disasters (Chen et al., 2025; Lemenkova, 2025b; Ali et al., 2024). With this regard, the continued development of the digital data sharing has accelerated the speed of responses to this technological advancement, enabling involved members of the public and agencies to produce geospatial data and support maps through participated mapping aimed at remotely located areas. Advances in networking, computing and interpersonal communications facilitate quick exchange of data sources which is operatively used.

Another important aspect of the use of RS data for humanitarian mapping consists in the long-term history of satellite images which has provided deep insights into modelling and prognosis of environmental and climate-related processes. For example, using time series analysis of satellite images for modelling landscape dynamics enables us to reveal trends in floods, to highlight the intensity of hazards, to forecast possible hazards and to evaluate potential risks for people. This provides the crucial link between geoinformation per se (as a theoretical branch of cartographic domains for spatial data processing) with social aspects and the well-being of human society.

9. Phases of Policy Making and Inter-Governmental Cooperation Supported by EO Data

Geo-information resources, satellite imagery and maps are a primary requirement in visualizing data in humanitarian situations. Therefore, the use of spatial data is crucial for critical reassessment of data (Purwanto et al., 2024). The most valuable resource is presented by open data without restrictions of limitations. The information obtained from such data can be reused for updated mapping and operative monitoring. The decisions made based on the spatial data include cost-benefit analyses, transport analysis, and hazard risk assessment. Proper use of data ensures effective management of crisis situations and helps to mitigate negative implications for affected people (Logar et al., 2020).

Actions and future trends would include developing policy frameworks that support displaced people using advanced technologies and datasets of Earth observation for effective crisis monitoring. Responsible organizations support displaced people aim at ethical support of human welfare through policy frameworks using available datasets on refugees. Such agencies and NGOs actively use geospatial information and maps for taking actions to improve the living conditions of the endangered people. For instance, these include such organizations as International Red Cross, UN, International Rescue Committee, UNOSAT, UNO for the Coordination of Humanitarian Affairs, Women's Refugee Commission, UN’s Inter-Agency Humanitarian Program Cycle, Emergency Rescue Committee, etc.

More exactly, supporting humanitarian action through cartographic assistance and maps helps these agencies to specify directions of their actions and identify target regions of humans in times of need. Moreover, humanitarian mapping supports charity and assistant organizations through providing contemporary data on the disaster distribution and placement of refugees within the organized system, such as refugee camps (Kemper et al., 2011). Humanitarian mapping is based on a variety of ethical principles as well as global-level agreements between the organizations in time of disasters that have no political borders, such as earthquakes or floods. The organized response of locals to the impacts of natural disasters and social wars can be predicted as possible development of situation in subsequent years using data obtained in previous period of observations.

10. Conclusion: Integrating Data and Technologies as the Future of Mapping Crisis Regions

This review presented the comprehensive assessment of an in-depth methods of social disaster management systems, including IT-based solutions, ML and GIS-based identification of crisis situation, migration paths and refugees campuses. Specifically, we highlighted the essential role that IT and computer science play in the advanced methods of humanitarian mapping. Key findings indicate that

ML can automate the workflow of data processing and adjust parameters of image classification in the optimal way. Detecting natural disasters, such as floods, wildfires, droughts, cyclones, earthquakes benefits from the exploring of satellite data. We discussed the possibilities of RS data for tracking natural catastrophes on times series images and spaceborne Earth observation data. Furthermore, processing images in big data volumes can reveal the dynamics of crisis, support monitoring and prognosis. Use of such data delves into the different domains that collectively contribute to effective management of crisis situation where people are forced to flee in order to escape from hazards and areas at risk. Integration of geospatial data and modern programming technologies form effective complexes that can improve crisis mitigation and control endangered regions.

Maps play essential role in solving crisis situations through organized monitoring of refugees' camps and support for humanitarian information management. The essential advantage of cartographic data visualization consists in spatial aspect of geospatial data location. This primarily supports the analysis of the extent of affected areas, ways of migration and location of refugee camps. Besides, maps created within the framework of humanitarian monitoring support decision making process and policy making through analysis of geospatial information. Visual forms of representation such as images, graphs, statistical charts, infographics and maps excellently summarize information and present it in an effective form which enables to highlight zones of the endangered regions.

The study investigates the potential of the IT and GIS functionality that modern tools offer to gather real-time Earth observation data on crisis-affected areas. This review highlighted that enhancing awareness in hazardous situation through geo-information enables taking prompt and reasonable actions, which is essential for local governments. Visualization and mapping the areas affected by natural hazards and social crisis pose significant challenges for environmental management and analysis of social sustainability. Computer-assisted technologies and advanced GIS-based modelling facilitates data handling for complex decision making in crisis situations, because EO data-driven spatial engineering enables modelling scenarios, aiding in preparation and response planning.. Climate-related processes such as droughts, floods, cyclones, earthquakes on the other hand, and social unrest and civil wars on the other, introduce various challenges in location and placement of population. Understanding the mechanisms governing human migration is crucial for assessing possible social risks, developing mitigation strategies, and ensuring the safety support for migrants. A critical but often overlooked factor influencing the accuracy of mapping critical zones is the role of computer science which presents powerful tools, data and approaches to monitoring hazard areas.

Despite the recognized importance of the integration of computer-based technologies for EO data processing, significant knowledge gaps remain in our understanding of how geospatial data can be treated in the optimized way for humanitarian mapping across various spatiotemporal scales. Addressing these gaps is essential, given the increasing reliance on knowledge extraction methods that support the effective use of EO data for controlling humanitarian crisis. To this end, we discussed remote sensing advantages for monitoring migration routes from space, which is undoubtedly a valuable tool for disaster and crisis management. For example, using time-series analysis based on the satellite images taken before, during and after flood event can introduce new data on the degree and magnitude of the hazardous event with enhanced potential for long-range prognosis and mitigation of flood-affected areas. This can support in warranty of population especially in the agricultural areas and facilitating informed decision-making and resource allocation during crisis based on analysis of spatial data. Thus, the long-term analysis of a series of satellite images and climate data using ML methods ensures prognosis of droughts in the arid areas. In turn, correct prognosis can significantly decrease risks of losses through optimized solutions. Processing EO data necessitates a thorough understanding of information extracted from geospatial data, which requires the use of the advanced computer-based modelling tools for correct and accurate data handling and geo-information analysis.

This research complements, in a humanitarian perspective, recent evidence that indicates that the integration of the IT methods, RS data and GIS tools play a key role in identifying areas affected by crisis and mitigating possible consequences from nature hazards and social unrest through mapping (Chatziparaschis et al., 2020; Plank, 2014). It also attributes to reflecting the role of linkage in the technical methods of advanced geospatial data procesisng and societal feedback between the environmental challenges and computer-based models.

Here we provided a focused synthesis of recent advancements in humanitarian mapping. Specifically, we discussed on current understanding of triggering factors that lead to the migration crisis in climate- or disaster-affected regions. More specifically, we introduced the principal advantages of the computer technologies such as ML, DL and programming algorithms to geospatial data processing; we discussed the properties of prevalent geospatial data types (RS, VHR imagery, maps) and elucidate the approaches to their processing. We also described the pathways through which geospatial data can be processed effectively including a brief review of the existing advanced software, image classification techniques and cartographic visualization; we analyzed how sharing geospatial data through interactions (data sharing system such as GitHub) impact real-time mapping which is crucial for humanitarian mapping. We also identified gaps in current knowledge that need to be addressed in the future for development of methods of humanitarian mapping and areas in crisis.

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Article Information Form

Conflict of Interest Disclosure: No potential conflict of interest was declared by the author.

Artificial Intelligence Statement: No artificial intelligence tools were used while writing this article.

Plagiarism Statement: This article has been scanned by iThenticate.