PANTHEON

Community-Based Smart City Digital Twin Platform for Optimised DRM operations and Enhanced Community Disaster Resilience

D6.3

RECOMMENDATIONS FOR COLLABORATIVE DATA DELIVERY

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TASK ABSTRACT

This task focuses on investigating and summarizing a number of recommendations for collaborative data delivery schemes in a Community-Based Disaster Risk Management system. The utilized technological frameworks, architectures and standards that are being used in the PANTHEON project are described and analysed. Technologies such as communication systems, cloud, Artificial Intelligence and Geographical Information Systems are exploited in order to provide an efficient way of information and data delivery and processing for an effective and robust decision-making.

[1] **Please indicate the type of the deliverable using one of the following codes**:
R = Document, report
DEM = Demonstrator, pilot, prototype, plan designs
DEC = Websites, patents filing, press & media actions, videos
DATA = data sets, microdata
DMP = Data Management Plan
ETHICS: Deliverables related to ethics issues.
OTHER: Software, technical diagram, algorithms, models, etc.

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EXECUTIVE SUMMARY

This document presents the results of the work performed in Task 6.4 – "Recommendations for Collaborative Data Delivery in a Community Based DRM System". This focuses on recommending methodologies and technologies for effective and efficient data delivery in DRM systems with a Community Based approach.

The deliverable describes basic technological approaches that are used for the implementation of Community Based Disaster Risk Management (DRM) systems, such as the PANTHEON one. It offers a general overview of the technologies and components and how these can be utilized/implemented/deployed in the framework of AI-assisted DRM.

1 INTRODUCTION

This section summarizes the fundamental elements of collaborative data delivery in DRM systems and operations, emphasizing on their usefulness and utilization.

Section 1 includes a general introduction about the main/fundamental components/technologies of such systems. **Section 2** gives an overview of cloud-based platforms and how are being used in DRM. **Section 3** talks about data standards and interoperability, which are important features for the collaboration of different and heterogeneous systems. Data collection and delivery methods are presented in **Section 4**. **Section 5** offers a description of geospatial data, which can be of major importance in cases of DRM, both pre- and post-disaster. Consequently, **Section 6** summarized the utilization of AI-supported analytics, which are being used in data processing and decision-making, assisting the main stakeholders, end-users and first responders. **Section 7** presents the notion of data visualization in decision-making, a feature that is fundamental to the end-users for timely and effective decisions and actions. Lastly, **Section 8** offers a short conclusion of the work.

1.1 CONSIDERATIONS ON COLLABORATIVE DATA DELIVERY IN DISASTER RISK MANAGEMENT

Collaborative data delivery is crucial for timely decision-making, coordinated response, and risk management and reduction in cases of community-affecting disasters. It may involve multiple stakeholders, such as government agencies and first responders, NGOs, local communities, scientists, and international partners. They must share and access data in real time or near real time to mitigate disaster impacts and/or prepare for the disaster, effectively and proactively.

Some of the aspects of collaborative data aggregation and delivery, can be summarized as follows:

1. Multi-Stakeholder Data Integration

Data that can be utilized and integrated include:

- Meteorological
- Geospatial
- Satellite
- Crowdsourced
- Local sensor data (e.g. traffic, local weather, seismic, etc.)

Data from heterogeneous sources must be synchronized and assimilated in order to provide a holistic picture of the situation.

2. Interoperability and Standardization

Interoperability of different datasets is another aspect to be addressed. Most datasets are provided in standardized formats, such as .json, GEOjson, .csv, netCDF, and more, but metadata are also useful to provide specific information about the datasets that are being utilized and processed.

Lastly, Application Programming Interfaces (APIs) are generally used for data acquisition from the various sources and/or for gathering them into one place for further analysis and processing.

3. Real-Time or Near Real-Time Delivery

Time is an important parameter of data delivery, especially for early warning and preparedness, but also for providing the stakeholders with accurate and timely information after the disaster.

In that sense, the various sources must be able to provide real or near real-time data, enabling thus effective responses and decision-making. Locally installed IoT-based sensors, satellite systems (such as Copernicus) and other third-party data sources offer the capability of real or near real-time data delivery.

4. Data Governance & Access Control

Data ownership has to be clearly defined, along with the relevant access policies/privileges for handling classified and/or sensitive data (personal, health, military, etc.).

5. Collaborative Platforms and Hubs

Collaborative platforms can provide the means for multi-actor and multi-stakeholder engagement and collaboration, especially when the disaster extends beyond the border of multiple countries.

Some of them are:

- ReliefWeb, HDX (Humanitarian Data Exchange) by UNOCHA[3]
- EM-DAT (Emergency Events Database)[4]
- Sahana EDEN[5] for disaster coordination

These allow sharing of updated maps, situation reports, needs assessments, and more.

6. Geospatial Information Systems (GIS)

Geospatial data are also of major importance for mapping hazard zones and affected areas, and evacuation routes. Collaborative web-based GIS such as ArcGIS Online[6] and QGIS[7] with cloud plugins are being widely utilized.

7. Community Data and Crowdsourcing

Community-generated data can provide insights and information about the disaster and the conditions on the affected area timely and earlier than any other source. This local knowledge can be provided by mobile apps, SMS or even drones flying over the affected area.

Tools like or OpenStreetMap[8] and Ushahidi[9] support crowdsourced disaster mapping.

8. Trust, Transparency & Validation

Data management and processing must integrate a shared responsibility for verifying and vetting the data, between the involved parties. Moreover, a chain for custody for data has to be included in the process. Version control and data lineage are key parameters that have to be taken into account and taken care of.

[3] https://reliefweb.int/organization/ocha
[4] https://www.emdat.be/
[5] https://eden.sahanafoundation.org/
[6] https://www.arcgis.com/index.html
[7] https://qgis.org/
[8] https://www.openstreetmap.org/#map=6/38.36/23.81
[9] https://www.ushahidi.com/

9. Communication & Decision Support

In order to uphold and enhance decision-making, communication means are important to be included. A user-friendly dashboard is the foundation of effective and efficient visualization, alerting and decision-making. It can be also tailored for different user groups, such as decision-makers, responders, public, etc. A Common Operating Picture (COP)[10] system provided the optimum effectiveness, as a single point of reference for all involved parties.

[10] https://www.jesip.org.uk/joint-doctrine/common-operating-picture/

2. CLOUD-BASED PLATFORMS

Cloud-based platforms play an important role in Disaster Risk Management (DRM) by enabling stakeholders to store, manage, and share large volumes of data from various sources—such as sensors, drones, satellites, or local communities—in real time. Their flexibility and scalability make them well suited to handle the dynamic and high-pressure nature of disasters, where the volume of data can increase rapidly and decisions must be made quickly.

These platforms allow multiple actors—such as emergency services, public authorities, researchers, NGOs, and citizens—to collaborate efficiently and securely, even when working remotely. They support essential DRM functions including real-time data integration, visualization, decision-making, and coordination.

In the PANTHEON project, cloud-based systems contribute to the development and operation of the Smart City Digital Twin (SCDT), ensuring that data from different sources is up to date, consistent, and accessible to all relevant stakeholders. This enables better situational awareness and more informed decisions before, during, and after disaster events.

2.1 COMMON CLOUD-BASED PLATFORMS USED IN DRM

Below is a list of cloud-based platforms that support collaborative data delivery in DRM settings. These platforms vary in scope, purpose, and audience, but they all enable organizations and communities to share, process, and visualize critical data in real time.

- The **Humanitarian Data Exchange (HDX)**[11], developed by the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA), is a widely used platform for sharing curated datasets related to humanitarian crises. It supports a wide range of data types, from health and population displacement statistics to risk maps, and offers built-in tools for visualization and analysis. Its open-data model and user-friendly interface make it a key tool for NGOs, UN agencies, and governments working in the field.
- **Google Earth Engine (GEE)**[12] is a powerful cloud-based platform that specializes in geospatial analysis using satellite imagery. It provides access to a vast archive of remotely sensed data, including Landsat and Sentinel missions, and enables users to perform advanced environmental analysis through JavaScript and Python APIs. GEE is frequently used in DRM to monitor floods, droughts, fires, and long-term climate changes, making it a valuable tool for researchers and technical experts.
- **Copernicus Emergency Management Service (EMS)**[13], operated by the European Union, offers rapid mapping capabilities based on satellite data. It supports civil protection authorities with up-to-date visual information before, during, and after major disasters such as floods, earthquakes, and forest fires. Its services are integrated into European response systems, making it a cornerstone in coordinated crisis mapping.

[11] https://data.humdata.org/
[12] https://earthengine.google.com/
[13] https://emergency.copernicus.eu/

- **ArcGIS Online**[14], developed by Esri, is one of the most widely adopted commercial platforms for geographic information systems (GIS) in the cloud. It allows for the creation of interactive maps, real-time dashboards, and shared geospatial data layers. This makes it particularly useful for emergency services and municipal authorities seeking to maintain situational awareness and coordinate field operations during crises.
- **OpenAerialMap**[15] **& OpenStreetMap**[16] **(OSM)** represent community-driven approaches to mapping and geospatial data collection. These platforms rely on crowdsourced information and freely available aerial imagery, which can be particularly valuable in the immediate aftermath of disasters. Volunteers and organizations around the world have used OSM and OpenAerialMap during major events like the Haiti and Nepal earthquakes, creating detailed maps where no official ones existed.
- **Sahana Eden**[17] is an open-source information management system designed specifically for disaster response. It can be deployed in the cloud or on local servers and includes modules for situation reporting, resource tracking, shelter management, and volunteer coordination. It has been implemented by both NGOs and governments to support DRM planning and operations, especially in low-resource settings.
- Platforms such as **UN OpenGIS**[18] and **GeoNode**[19] enable the sharing and visualization of geospatial data in ways that support collaboration across agencies and countries. They offer cloud-hosted options and support the publication of maps and early warning information. These platforms are often used by national disaster agencies and regional authorities to build geospatial portals that integrate various data sources in one place.

Together, these platforms demonstrate the diversity and richness of tools available for cloud-based collaboration in DRM. Their complementary features, ranging from citizen-sourced mapping to satellite-based monitoring, highlight the importance of choosing the right platform(s) depending on the data types, stakeholders involved, and operational needs.

To help compare these platforms and understand their specific strengths, **Table 1** summarizes their key features, typical use cases, and platform types.

Table 1: Cloud-based platforms commonly used for Collaborative Data Delivery in DRM

Platform	Key Features	Common Use Cases	Type
Humanitarian Data Exchange	Curated humanitarian datasets, APIs, dashboards	Conflict zones, pandemics, displacement tracking	Open data platform

[14] https://www.arcgis.com/index.html
[15] https://openaerialmap.org/
[16] https://www.openstreetmap.org/
[17] https://sahanafoundation.org/eden/
[18] https://www.un-spider.org/advisory-support/space-based-information-management
[19] https://geonode.org/

Google Earth Engine	Satellite imagery, geospatial analysis, Python/JS APIs	Flood/drought mapping, deforestation, fire detection	Cloud + scripting API
Copernicus Emergency Management Service	Rapid satellite mapping, risk assessment	Earthquakes, wildfires, refugee camps	Operational service
ArcGIS Online	Real-time GIS, dashboards, web maps	Emergency operations, spatial planning	Commercial SaaS
OpenAerialMap & OpenStreetMap	Crowdsourced mapping, drone image integration	Damage assessment, infrastructure mapping	Open source
Sahana Eden	Situation reports, resource/ shelter/volunteer management	National/local DRM programs	Open source
UN OpenGIS / GeoNode	Geospatial layers, access control, metadata handling	Early warning systems, public data portals	Open source/cloud

2.2 KEY CAPABILITIES ACROSS THESE PLATFORMS

Cloud-based platforms used in DRM share several important capabilities that make them effective tools for collaborative data delivery and decision-making during emergencies. Understanding these key features helps clarify why these platforms are essential and how they support different stakeholders in DRM processes.

- **Real-time data integration**: These platforms can collect and integrate data from a wide variety of sources, including ground sensors, satellite imagery, weather stations, drones, and field reports. The ability to process incoming data in real time ensures that users have the most current information available to assess risks, monitor ongoing events, and respond quickly as situations evolve.
- **Role-based access**: To maintain data security and ensure that sensitive information is only available to authorized users, cloud platforms implement role-based access controls. This means different stakeholders—such as emergency responders, government officials, researchers, and community members—can access data according to their roles and responsibilities. Controlled access helps protect privacy, prevent data misuse, and streamline collaboration.
- **Dashboards and alerts**: Interactive dashboards provide visual summaries of complex data through maps, charts, and status indicators, offering an at-a-glance view of the situation. Many platforms also support alert systems that notify users of significant changes or emerging risks, enabling faster operational decisions and proactive management during crises.
- **Mobile access**: Mobile-friendly interfaces and apps allow field personnel and community volunteers to update information directly from disaster sites using smartphones or tablets. This capability supports two-way communication: field data is quickly shared with command centres, and instructions or alerts can be sent to teams on the ground, improving coordination and response effectiveness.
- **Interoperability**: These platforms are designed to work well with other systems by supporting open standards and APIs (Application Programming Interfaces). Common formats such as GeoJSON, WMS (Web Map Service), and others allow different tools and datasets to connect and exchange

information smoothly. Interoperability ensures that data from multiple sources and platforms can be combined, analysed, and used seamlessly, reducing technical barriers to collaboration.

All the cloud-based platforms described above meet these key capabilities, though the exact features and their depth can vary depending on the platform's focus and design. **Table 2** gives a brief overview of how each platform align with these requirements.

Table 2: Key capabilities supported by common cloud-based platforms in DRM

Platform	Real-time Data Integration	Role-based Access	Dashboards & Alerts	Mobile Access	Interoperability (Open APIs / Standards)
Humanitarian Data Exchange	Yes	Yes	Yes	Limited	Yes
Google Earth Engine	Yes	Yes	Yes	Limited	Yes
Copernicus Emergency Management Service	Yes	Yes	Yes	Limited	Yes
ArcGIS Online	Yes	Advanced	Advanced	Yes	Yes
OpenAerialMap & OpenStreetMap	Yes	Limited	Limited	Yes	Yes
Sahana Eden	Yes	Yes	Yes	Yes	Yes
UN OpenGIS / GeoNode	Yes	Yes	Yes	Limited	Yes

It can be seen that most platforms like Google Earth Engine, Copernicus EMS, and ArcGIS Online excel at ingesting and processing real-time data from satellites, sensors, and field reports. Platforms like HDX and Sahana Eden also support timely updates from multiple data sources.

Role-based access varies from advanced controls (ArcGIS) to simpler or community-driven models (OSM). Commercial platforms such as ArcGIS Online provide advanced role-based access controls to manage data privacy and sharing among users. Open-source platforms like Sahana Eden and GeoNode also offer configurable access levels, though implementations can differ in complexity.

Platforms focused on operational decision-making tend to have richer dashboards and alert systems. Platforms such as ArcGIS Online and Copernicus EMS feature rich dashboards and alert mechanisms to support decision-making. HDX offers dashboards and visualizations, while platforms like OpenStreetMap focus more on data sharing than alerting.

Mobile access support varies; platforms designed for fieldwork and community involvement tend to have better mobile support. Many platforms support mobile data entry and updates, either through dedicated apps (e.g., Sahana Eden) or mobile-friendly web interfaces (e.g., ArcGIS Online, OpenStreetMap). This is essential for capturing field data and reports in disaster zones.

All platforms emphasize open standards and APIs, enabling integration with external tools and datasets. Open standards and APIs are a priority for all these platforms to varying degrees. Google Earth Engine, GeoNode, and UN OpenGIS emphasize open data formats and interoperability, enabling integration with external systems and data sources.

In summary, while each platform may emphasize certain capabilities more strongly depending on its purpose, together they cover the full range of key features necessary for effective collaborative data delivery in DRM systems. When choosing a platform, stakeholders should consider which capabilities are most critical for their specific use cases and operational context.

2.3 FINAL RECOMMENDATIONS

Cloud-based platforms are key tools for collaborative data delivery in DRM, but choosing the right one depends on the specific needs and capacities of each project. For open and community-based collaboration, platforms like HDX, OpenAerialMap, and OpenStreetMap are good choices, especially when transparency and accessibility are important. In contrast, platforms such as ArcGIS Online and Google Earth Engine offer more advanced features for geospatial analysis and are better suited for institutions with technical expertise.

In the context of the PANTHEON project, platforms that enable Smart City Digital Twins, real-time data integration, and multi-stakeholder collaboration, such as ArcGIS Online, GeoNode, or Google Earth Engine, are especially relevant. At the same time, using open platforms like HDX and OSM helps ensure broader participation and inclusion of community data sources.

3. DATA STANDARDS AND INTEROPERABILITY

In DRM, effective coordination between stakeholders, ranging from government agencies and NGOs to research institutions and international organizations, requires more than access to data. It demands that this data be structured, shared, and interpreted in consistent ways. This is where data standards and interoperability become essential.

Without common standards and interoperable systems, efforts to share information may result in misunderstandings, delays, or data silos, all of which can seriously compromise disaster preparedness, response, and recovery. For projects like PANTHEON, which aim to create integrated and community-based digital ecosystems for disaster resilience, the ability to exchange data seamlessly across systems, institutions, and jurisdictions is a critical requirement.

This section outlines key data standards used in DRM, explains the main types of interoperability, presents challenges commonly encountered, and highlights good practices that can help strengthen data interoperability in multi-stakeholder environments.

3.1 KEY DATA STANDARDS IN DRM

A number of international data standards have been developed to support structured, timely, and meaningful information exchange during emergencies. These standards cover a wide range of data types, including geospatial data, statistical indicators, emergency alerts, and situation reports.

Data standards provide a shared framework for how information is structured, described, and exchanged. In DRM, using well-established standards ensures that data can be easily understood, processed, and combined across systems and organizations. Below are some of the most commonly used standards that support collaborative data delivery in DRM settings.

- **ISO 19115** is a widely adopted standard for describing geospatial datasets. It defines how to document metadata, such as the origin, purpose, scale, and structure of spatial data, so that it can be properly discovered and reused. This standard is foundational in GIS environments and is commonly used by UN agencies and national mapping authorities to ensure consistent metadata practices across platforms.
- **The Common Alerting Protocol (CAP)** is an international XML-based standard for sharing emergency alerts and public warnings. It is designed to support multi-channel delivery, enabling the same alert message to be sent via SMS, TV, sirens, mobile apps, and other systems. CAP ensures that warnings are clear, timely, and machine-readable. It is used by organizations such as the World Meteorological Organization (WMO), FEMA, and national disaster management authorities worldwide.
- **Situation Reports (SITREPs)** provide a structured format for reporting developments during emergencies. These reports often include data on affected populations, response activities, needs assessments, and logistics. While not a technical data standard, SITREP templates promote consistency and comparability. They are widely used by agencies like UNOCHA and the World Health Organization (WHO) to coordinate humanitarian response efforts.

- **GeoJSON**, **GML** (Geography Markup Language), and **KML** (Keyhole Markup Language) are standard formats for encoding geographic data. These formats are supported by most GIS and web mapping tools, including Google Earth, OpenStreetMap, and ArcGIS. They allow for the easy exchange of spatial features such as points, lines, and polygons, and are often used in DRM for map overlays, risk zones, and damage assessments.
- **HXL (Humanitarian Exchange Language)** is a lightweight standard designed for use in spreadsheet-based data. It uses simple hashtags to tag data columns (e.g., #sector, #org, #affected) and enables automatic cleaning and merging of datasets. HXL is supported by the Humanitarian Data Exchange (HDX) and is widely used by NGOs and UN agencies to make humanitarian data more interoperable and easier to process.
- **WMS (Web Map Service)** and **WFS (Web Feature Service)** are standards developed by the Open Geospatial Consortium (OGC) for sharing spatial data over the web. WMS delivers rendered map images, while WFS provides access to vector features. These services are used by platforms like ArcGIS, GeoServer, and GeoNode to publish and consume geospatial data in real time.
- **SDMX (Statistical Data and Metadata eXchange)** is an international standard for exchanging structured statistical data, often used in reporting on social and economic indicators such as population, health outcomes, and disaster impact metrics. It is promoted by organizations like the UN Statistics Division, the OECD, and the World Bank, and is useful in DRM contexts that involve tracking and comparing key indicators across countries and regions.

Table 3 provides a summary of these key data standards, including their main purposes and examples of use in the DRM context.

Table 3: Key data standards in DRM Collaborative Data Delivery

Standard	Purpose	Used By
ISO 19115	Metadata for geospatial datasets	UN agencies, GIS systems
CAP (Common Alerting Protocol)	Standard format for emergency alerts	WMO, FEMA, IPAWS
SITREP (Situation Reports)	Structured reports during emergencies	UNOCHA, WHO
GeoJSON / GML / KML	Geospatial data formats for maps and layers	OpenStreetMap, Google Earth, GIS platforms
HXL (Humanitarian Exchange Language)	Lightweight standard for spreadsheet-based data	HDX, NGOs
WMS/WFS (OGC Web Services)	Map and feature access over the web	ArcGIS, GeoServer
SDMX (Statistical Data and Metadata eXchange)	For statistical indicators (e.g., population, mortality)	UN, World Bank

These standards help ensure that data can be automatically processed, correctly interpreted, and integrated into operational platforms, even when shared between systems built by different organizations or countries.

3.2 CORE INTEROPERABILITY PRINCIPLES

Achieving interoperability in DRM systems involves more than just using shared formats. It requires a multi-layered approach that includes technical, semantic, syntactic, and organizational dimensions.

- **Semantic interoperability:** This ensures that data exchanged between systems is understood in the same way by all parties, even when it comes from different institutional or national contexts. It involves the use of shared vocabularies, taxonomies, and ontologies, such as the UN-SPIDER disaster type classification or humanitarian response categories (e.g., shelter, WASH, health).
- **Technical interoperability:** Refers to the ability of systems and software to connect and exchange data automatically, regardless of the underlying technologies. This typically involves using RESTful APIs, middleware, and data adapters. For example, ArcGIS Online and Google Earth Engine can both be integrated with other platforms through standardized web APIs.
- **Syntactic interoperability:** This deals with the structure and format of data. Interoperability at this level means that the data conforms to recognized schemas and data formats, so it can be automatically parsed and used by other systems. Examples include emergency alert messages structured in XML using the Common Alerting Protocol (CAP) and geospatial layers published in formats like GeoJSON or KML, which can be directly interpreted by mapping platforms, web services, and GIS tools.
- **Organizational interoperability:** Often the most challenging aspect, this refers to the policies, agreements, and institutional arrangements that allow for cross-organizational collaboration. Memoranda of Understanding (MOUs), common data-sharing protocols, and coordination mechanisms (e.g., those established by UN OCHA or national disaster agencies) all fall under this category.

3.3 CHALLENGES AND BEST PRACTICES

Despite the availability of open standards and modern technical tools, achieving true interoperability remains a complex task in practice. Some of the common barriers include:

- **Inconsistent data models and classifications**, such as differing definitions of hazard categories or impact indicators across countries or sectors.
- **Language and localization issues**, which can complicate the use of shared taxonomies or multilingual data exchange.
- **Data sovereignty and access restrictions**, particularly when sensitive information is involved or when national policies limit data sharing.
- **Limited digital infrastructure**, especially in regions that are most vulnerable to disasters, making real-time data exchange technically difficult.

To address these challenges and promote effective data interoperability, the following practices are recommended, both within the PANTHEON project and in wider DRM initiatives:

- **Adopt open standards whenever possible**, and encourage their use in procurement, platform development, and data exchange agreements.
- **Use data catalogs and metadata registries** that conform to standards like ISO 19115 or DCAT. Platforms such as GeoNode or CKAN support standardized metadata publication and discovery.

- **Design systems using modular and API-first architecture**s, enabling different components to communicate through well-documented interfaces.
- **Invest in training and capacity-building** to ensure that technical staff and local stakeholders are familiar with the standards and tools being used.
- **Foster institutional collaboration**, including cross-border coordination and joint protocol development, to support organizational interoperability.

Addressing these challenges is key to building disaster management systems that work well across different organizations and regions. By following best practices and using open standards, projects like PANTHEON can help make sure that data is shared smoothly and used effectively. This improves decision-making during emergencies and supports better coordination and resilience in the long term.

4. DATA COLLECTION AND DELIVERY

In DRM, the ability to collect, manage, and disseminate data effectively is fundamental to enhancing preparedness, enabling timely response, supporting recovery efforts, and implementing long-term mitigation strategies. This section explores the critical components of data management in DRM, including the types of data involved, methods of acquisition and communication of the data, and best practices for both collection and delivery.

4.1 TYPES OF DATA COLLECTED

DRM relies on a wide array of data types to assess risks and coordinate actions. These include:

- **Geospatial data** that helps us understand the physical features of the land and how they are connected. This includes satellite images that show detailed, real-time views of the Earth's surface and help track changes over time, which is useful for spotting areas at risk. Other geospatial data, like Digital Elevation Models (DEMs), show elevation, slope, and land shapes. This information is important for predicting floods, assessing landslide risks, and planning safe infrastructure in areas that face natural hazards.
- **Meteorological and hydrological data** are fundamental for the forecasting, monitoring, and management of natural hazards such as floods, droughts, storms, and heatwaves. Temperature data is particularly important for identifying heatwaves, drought conditions, and the potential for wildfires. Additionally, wind speed and direction are critical for storm tracking, modelling wildfire behavior, and ensuring aviation safety during emergency situations. Tide and sea level data also play a key role in coastal hazard management, supporting storm surge forecasting and tsunami early warning systems.
- **Demographic and socio-economic data** are particularly important, as they help identify populations that are most vulnerable to hazards. This includes information on age, income levels, education, housing conditions, and access to essential services. By analyzing these factors, decision-makers can better understand the potential impacts of disasters on different communities and prioritize resources and interventions to protect those at greatest risk.
- **Infrastructure and asset data** are indispensable to evaluate exposure of critical facilities such as hospitals, schools, transportation networks, and utilities—to potential hazards and plan logistics during emergencies, ensuring that resources can be deployed efficiently and that essential services remain operational or are quickly restored in the aftermath of a disaster.
- **Historical disaster data** provides a record of past events and their impacts. This data is essential for identifying patterns, understanding vulnerabilities, and improving the accuracy of predictive models. Moreover, this data plays a key role in guiding infrastructure planning. For instance, in the context of flood resilience, it can help to determine optimal sites for flood retention basins and supports the elevation of essential infrastructure such as roads and buildings.
- **Real-time sensor data** from IoT devices, drones, and mobile apps for situational awareness during emergencies. These technologies provide immediate, on-the-ground insights that are critical for informed decision-making and rapid response. For example: IoT sensors installed in rivers, dams, or urban drainage systems can detect rising water levels or structural stress, triggering early flood warnings. Drones equipped with cameras and thermal sensors can quickly survey disaster-affected

areas, assess damage, locate survivors, and identify inaccessible zones. Mobile apps allow citizens to report incidents, share geotagged photos, and receive real-time alerts, creating a two-way flow of information between the public and emergency services. By integrating these data streams into centralized platforms, emergency managers can monitor evolving conditions in real time, allocate resources more effectively, and coordinate response efforts with greater precision

4.2 DATA ACQUISITION

Data acquisition in DRM involves a combination of traditional and modern technologies, including:

- **Remote sensing** via satellites and drones/aircrafts for environmental monitoring. Acquiring this data involves accessing various sources and platforms that provide satellite and aerial imagery, as well as processed geospatial datasets. Here are some sources:
  - **Government and International Agencies** demonstrate their engagement by providing open, authoritative and actionable information through many platforms (**Table 4**):

Table 4: Remote sensing platforms provided by government and international agencies

Platform	Proprietary	Technology	Description	Link
Earthdata	NASA National Aeronautics and Space Administration	Satellite	Earthdata provides near real-time satellite data to detect and track disasters like wildfires, floods, and hurricanes, to identify affected areas and guide emergency response.	https://www.earthdata.nasa.gov/
MODIS	NASA National Aeronautics and Space Administration	Satellite - Terra and Aqua satellites	MODIS instruments capture data across 36 spectral bands. These bands are optimized for observing: • Clouds and aerosols • Land surface (vegetation, snow, fires) • Ocean color and temperature • Atmospheric water vapor and temperature.	https://modis.gsfc.nasa.gov/about/
Copernicus Space Component Data Access	ESA European Space Agency	Satellite - Sentinels satellites	Copernicus through its Emergency Management Service (CEMS) provides continuous global monitoring for hazards such as: • Floods • Droughts • Wildfires	https://dataspace.copernicus.eu/ https://emergency.copernicus.eu/
EarthExplorer	USGS United States Geological Survey	Satellite	EarthExplorer offers imagery from missions like Landsat, Sentinel, and ASTER, which are crucial for: • Monitoring land changes before and after disasters • Assessing flood extents, wildfire burn scars, and landslide zones	https://earthexplorer.usgs.gov/

			• Supporting long-term hazard mapping and risk modeling	
UN-SPIDER	UN United Nations	Satellite	UN-SPIDER enables countries especially developing nations to access and use space-based technologies to monitor hazards, assess risks, and support emergency response.	https://www.un-spider.org/

- **Commercial providers** like Maxar Technologies[20], Planet Labs[21], and Airbus Defence and Space[22] etc. offer high-resolution, timely satellite imagery and customizable analytics. For aerial data, which is ideal for localized damage and infrastructure assessments, we quote GarudaUAV[23], Nearmap[24], EagleView[25], Vexcel Data[26] and DroneDeploy[27] as examples.
- **Humanitarian and open-source platforms** supporting DRM include Google Earth Engine[28], OpenStreetMap[29] (OSM), ReliefWeb[30], and Humanitarian Data Exchange[31] (HDX) for satellite data. For platforms supporting drone imagery we quote OpenAerialMap[32] and HOT[33] (Humanitarian OpenStreetMap Team).
- **In-house drone operations** for DRM can involve deploying drones with mission planning apps like Pix4Dcapture[34], or DJI GS Pro[35], and processing imagery using tools such as Pix4D[36], Agisoft Metashape[37], or ArcGIS Drone2Map[38].

- **Ground-based sensors** —such as seismographs, weather stations, and flood gauges—provide essential data for monitoring seismic activity, atmospheric conditions, water levels etc. Below are some key providers and platforms, that offer access to this type of sensor data, organized by category:
  - Government and Public Agencies: Several national and international agencies provide access to sensor-based environmental data.

20 https://www.maxar.com/
21 https://www.planet.com/
22 https://space-solutions.airbus.com/industries/
23 https://garudauav.com/disaster-management/
24 https://www.nearmap.com/solutions/state-government/
25 https://www.eagleview.com/government/public-safety/
26 https://vexceldata.com/industries/aerial-images-government/public-safety/
27 https://www.dronedeploy.com/
28 https://earthengine.google.com/case_studies/
29 https://www.openstreetmap.org/about
30 https://reliefweb.int/disasters
31 https://data.humdata.org/dataset
32 https://openaerialmap.org/about/
33 https://www.hotosm.org/
34 https://www.pix4d.com/product/pix4dcapture/
35 https://www.dji.com/fr/ground-station-pro
36 https://www.pix4d.com/product/pix4dmapper-photogrammetry-software/
37 https://www.agisoft.com/
38 https://www.esri.com/fr-fr/arcgis/products/arcgis-reality/products/arcgis-drone2map

For instance, organizations like Météo-France[39], the National Oceanic and Atmospheric Administration[40] (NOAA), and the Indian Meteorological Department[41] (IMD) offer data from weather stations, including metrics such as rainfall, wind speed, temperature, and humidity.

Hydrological services monitor river and groundwater levels to support flood and drought assessments.

Seismological institutes, such as the United States Geological Survey[42] (USGS) and the European-Mediterranean Seismological Centre[43] (EMSC), supply earthquake data collected from seismographs and accelerometers.

Additionally, environmental agencies use ground-based sensors to monitor air and water quality, providing critical data for environmental health and policy:

- **U.S. Environmental Protection Agency[44] (EPA)** operates a nationwide network of air quality monitoring stations and supports innovations in low-cost, portable sensors for community-based monitoring. Their platforms include the **Air Sensor Toolbox** and various open-access data portals.
- **European Environment Agency[45] (EEA)** coordinates air and water quality monitoring across EU member states through networks like **AirBase** and **WISE (Water Information System for Europe)**. These systems collect data from ground-based sensors and make it publicly available.
- **National Oceanic and Atmospheric Administration[46] (NOAA)** – USA monitors atmospheric and water conditions using both ground-based and satellite sensors. Their **National Water Model** and **Air Resources Laboratory** provide real-time data for environmental and disaster risk management.
- **Environment and Climate Change Canada[47] (ECCC)** operates extensive networks for air and water quality monitoring, including the **National Air Pollution Surveillance (NAPS)** program and **Real-Time Hydrometric Data** services.
- **Japan Meteorological Agency[48] (JMA)** uses ground-based sensors to monitor air pollutants and water levels, supporting early warning systems for floods, typhoons, and other hazards.
    - Academic and research institutions, including universities and specialized research centers, frequently deploy sensor networks to support environmental monitoring and hazard-related studies. The data collected through these networks is often made available to the public via open-access repositories, promoting transparency and enabling further scientific analysis and collaboration.
    - IoT and Smart City Platforms: In urban areas, smart city infrastructure often includes IoT-based sensors. Accessing their data may be available through partnerships or open data initiatives. An example from Japan demonstrates how disaster risk management (DRM) can

[39] https://meteofrance.com/
[40] https://www.noaa.gov/
[41] https://mausam.imd.gov.in/
[42] https://www.usgs.gov/
[43] https://www.emsc-csem.org/
[44] https://www.epa.gov/
[45] https://www.eea.europa.eu/en
[46] https://www.noaa.gov/
[47] https://www.canada.ca/en/environment-climate-change.html
[48] https://www.data.jma.go.jp/multi/index.html?lang=en

benefit from integrating smart city data with an IoT platform like FIWARE[49]. This technology enables real-time monitoring and delivers timely insights that support early warning systems, enhance emergency response coordination, and strengthen resilience planning.

  - Commercial Sensor Networks: Private companies like Libelium[50], Bosch[51], and Davis Instruments[52] offer sensor deployment and data services for DRM, including Custom sensor installations for critical infrastructure, Early warning systems for floods, landslides, and industrial hazards, and Real-time monitoring platforms with dashboards and alerts.
  - Community-Based Monitoring: In some regions, especially where formal networks are limited, community-installed sensors (e.g., low-cost rain gauges, river level sensors) are used. And their data is often shared via mobile apps or SMS-based systems.

- **Crowdsourcing and mobile apps** allow citizens to report incidents and conditions in real time and directly from the field, providing first-hand, geo-tagged information that can be used by emergency services and decision-makers.
  - Examples of Mobile Data Collection Apps: KoboToolbox[53], Open Data Kit[54] (ODK), ArcGIS Survey123[55] (Esri).
  - Examples of Crowdsourcing Platforms: Ushahidi[56] is a crowdsourcing platform used globally for crisis mapping. It allows users to submit reports via SMS, email, or web forms, which are then visualized on interactive maps. HOT[57] from OpenStreetMap where volunteers contribute to mapping disaster-prone or affected areas, which is crucial for logistics and planning during emergencies.
- **Government and institutional databases** provide census data, land use records, and emergency response plans. Like Eurostat[58]: The statistical office of the European Union provides detailed population and housing census data for EU member states or CORINE Land Cover[59] that Offers detailed land cover maps and datasets for Europe, updated regularly.
- **Social media monitoring tools** to detect emerging threats and public sentiment. Example: AIDR[60] (Artificial Intelligence for Disaster Response), developed by Qatar Computing Research Institute (QCRI) that uses machine learning to classify tweets during disasters (e.g., requests for help, infrastructure damage).

[49] https://www.fiware.org/2020/12/01/collaborating-municipalities-for-disaster-resiliency-and-sustainable-growth/
[50] https://www.libelium.com/
[51] https://bosch-iot-suite.com/
[52] https://www.davisinstruments.com/
[53] https://www.kobotoolbox.org/
[54] https://getodk.org/
[55] https://survey123.arcgis.com/
[56] https://www.ushahidi.com/
[57] https://www.hotosm.org/
[58] https://ec.europa.eu/eurostat/fr/data/database
[59] https://land.copernicus.eu/en/products/corine-land-cover
[60] https://aidr.qcri.org/

4.3 KEY CONSIDERATIONS FOR DATA COLLECTION

To ensure the effectiveness, integrity, and ethical use of data in DRM, it is essential to consider several key factors that influence the quality and usability of the information collected and analyzed:

- **Purpose-Driven and Hazard-Specific Data Collection**

  Effective data collection in DRM must be guided by clear objectives. It should be strategically aligned with the specific goals of the DRM initiative—whether focused on preparedness, emergency response, recovery, or long-term mitigation. This ensures that the data gathered is not only relevant and actionable but also supports efficient use of time and resources.

  Equally important is tailoring data collection to the nature of the hazard. Different types of disasters demand different types of information. For instance, managing wildfires requires data on vegetation density, wind patterns, humidity levels, and fire spread models. By customizing data collection to the specific characteristics of each hazard, organizations can significantly enhance the accuracy, relevance, and operational value of the information they gather.

- **Accuracy and Reliability**

  Data must be rigorously validated and verified to prevent the spread of misinformation, which can lead to misguided decisions and resource misallocation. This includes cross-checking sources, using calibrated sensors, applying quality control protocols and ensure data collectors are trained in standardized methods and tools.

  It is equally important to ensure that baseline data—such as population distribution, infrastructure assets, land use, and environmental conditions—is regularly maintained. These datasets form the foundation for risk assessments, early warning systems, and emergency planning. However, they can quickly become outdated due to factors like rapid urbanization, demographic shifts, infrastructure expansion, and evolving climate conditions.

- **Timeliness**

  In emergency situations, the speed at which data is collected, processed, and disseminated is critical. Real-time or near-real-time data enables rapid situational awareness, supports timely decision-making, and enhances the effectiveness of response efforts. These can be achieved through automating data pipelines that use IoT sensors, mobile apps, and APIs to stream data in real time or establishing early warning systems that integrate real-time monitoring with alert systems (e.g., SMS, sirens, apps).

- **Standardization**

  Adopting common data formats (e.g., GeoJSON), metadata standards, and communication protocols ensures interoperability between systems and organizations. Standardization facilitates seamless data integration, sharing, and comparison across different platforms and jurisdictions.

- **Privacy and Ethics**

  The collection and use of sensitive data—such as personal identifiers, health information, or geolocation—must be masked or removed before sharing or analysis to adhere to strict privacy standards. Ethical considerations include obtaining informed consent where applicable, anonymizing datasets, and implementing secure data storage.

- **Inclusivity**

  Data collection efforts must be designed to capture the experiences and needs of all population groups, including marginalized, vulnerable, and at-risk communities. Inclusive data practices help avoid systemic biases and ensure that disaster response strategies are equitable and just.

4.4 DATA DELIVERY MECHANISMS

Once data is collected, its value lies in how effectively it is communicated to diverse stakeholders—including emergency responders, government agencies, humanitarian organizations, and the general public. Timely and accessible delivery of information is critical for informed decision-making, rapid response, and community preparedness. The following are key mechanisms used to disseminate DRM data:

- **Dashboards and GIS platforms**: Interactive dashboards and Geographic Information Systems (GIS) provide real-time visualization of disaster data, such as hazard zones, population exposure, and infrastructure impact. These platforms allow users to filter, analyze, and interpret complex datasets through maps, graphs, and timelines. **Example**: Esri's Disaster Response Program[61].
- **Early warning systems**: These systems are designed to alert populations and authorities before or during a disaster. They use multiple communication channels—such as SMS, radio broadcasts, television, sirens, and mobile notifications—to ensure wide reach, especially in vulnerable or remote areas. Example: The Common Alerting Protocol[62] (CAP) standard used by national meteorological and emergency services.
- **Mobile applications**: Mobile apps provide real-time updates, safety instructions, evacuation routes, and shelter locations. They also enable two-way communication, allowing users to report incidents or request help. Example: The FEMA[63] app in the U.S. or the GDACS[64] app for global disaster alerts.
- **Reports and briefings**: Tailored situation reports, policy briefs, and operational updates are essential for decision-makers and field teams. These documents synthesize key insights, forecasts, and recommendations in a concise format to support strategic planning and coordination. Example: Situation Reports[65] (SitReps) issued by the UN, Red Cross, or national disaster agencies.
- **Open data portals**: Publicly accessible platforms promote transparency, collaboration, and innovation. These portals host non-sensitive datasets that can be used by researchers, journalists, developers, and civil society to analyze risks, track responses, and build local resilience tools. Example: Data.gov (USA), Copernicus Emergency Management Service (EU), and OpenAerialMap.

4.5 KEY CONSIDERATIONS FOR DATA DELIVERY

Delivering data effectively during disasters is not just about speed—it's about ensuring that the right information reaches the right people in the right way. To maximize impact and usability, several critical factors must be addressed:

[61] https://www.esri.com/en-us/disaster-response/overview
[62] https://en.wikipedia.org/wiki/Common_Alerting_Protocol
[63] https://www.fema.gov/about/news-multimedia/mobile-products
[64] https://www.gdacs.org/About/app.aspx
[65] https://huntbook.predefender.com/part-1/delivieries/sitrep/index.html

- **Timeliness**

  Information must be disseminated as quickly as possible to support real-time decision-making and emergency response. Delays in data delivery can result in missed opportunities to save lives or mitigate damage. Automated alerts, live dashboards, and pre-configured communication protocols can help ensure rapid dissemination.

- **Accessibility**

  Data should be provided in formats and languages that are accessible and understandable to a wide range of users, including local communities, emergency responders, and policymakers. This involves offering multilingual support, mobile-friendly formats, offline accessibility for areas with limited connectivity, and visual aids tailored for users with low literacy levels.

- **Security**

  Sensitive data must be rigorously protected from unauthorized access, tampering, or misuse. To ensure secure handling, it is essential to use platforms that support secure file sharing, version control, and access restrictions. Additionally, all data dissemination practices should comply with relevant local and international data protection laws, safeguarding both privacy and trust.

- **Clarity and usability**

  Data should be presented in a clear, concise, and actionable manner to support effective decision-making. Overly technical or cluttered information can create confusion and delay critical responses. To enhance usability, best practices include using visualizations such as maps, charts, and infographics; emphasizing key takeaways; and providing context and interpretation alongside raw data to ensure clarity and relevance for diverse audiences.

- **Feedback mechanisms**

  Establishing two-way communication channels is essential for enhancing data quality and fostering trust and collaboration among users. These channels enable individuals to report errors, share updates, or seek clarification, ensuring that information remains accurate and relevant. Effective examples include in-app feedback forms, community hotlines, and social media integration, which allow for real-time interaction and responsiveness.

5. GEOSPATIAL DATA

5.1 INTRODUCTION

Disasters, both natural and anthropogenic, continue to affect millions of people globally each year, causing loss of life, displacing communities, and disrupting economies. Climate change, rapid urbanization, and environmental degradation have intensified the frequency and severity of these disasters. Consequently, there is a growing demand for more effective, data-driven approaches to Disaster Risk Management (DRM). Among the most promising tools in this field is geospatial data, which plays a critical role in all phases of disaster management—preparedness, response, recovery, and mitigation.

Geospatial data, derived from sources such as satellites, aerial imagery, remote sensors, and geographic information systems (GIS), provides spatial and temporal insights that are essential for assessing risk, monitoring hazards, and informing strategic decisions. This chapter explores the applications, benefits, limitations, and future potential of geospatial data in DRM.

5.2 UNDERSTANDING GEOSPATIAL DATA

Geospatial data refers to any data that includes a geographic component. It can be broadly categorized into:

- **Spatial Data**: Refers to the specific location of objects or features (e.g., latitude and longitude coordinates, shapefiles).
- **Attribute Data**: Describes characteristics of spatial features (e.g., population density, building types).
- **Temporal Data**: Provides information about when an event or change occurred.

Common sources of geospatial data include:

- **Satellite Imagery**: From platforms such as Sentinel-2, Landsat, MODIS.
- **Remote Sensing**: Includes radar, LiDAR, and thermal sensors.
- **Unmanned Aerial Vehicles (UAVs)**: Drones that provide high-resolution, real-time imagery.
- **Crowdsourced and Volunteered Geographic Information (VGI)**: Platforms like OpenStreetMap and Ushahidi.
- **Global Positioning Systems (GPS)** and **mobile-based tracking**.

These sources allow for dynamic monitoring of landscapes, population movement, infrastructure, and environmental changes—all critical in the context of DRM.

5.2 APPLICATIONS IN DISASTER RISK MANAGEMENT

5.2.1 RISK ASSESSMENT AND HAZARD MAPPING

One of the foundational uses of geospatial data in DRM is the identification and mapping of hazard-prone areas. Through historical data analysis, topographic studies, and climate modeling, geospatial tools can generate detailed hazard maps for floods, earthquakes, landslides, and storms.

For example, Digital Elevation Models (DEMs) combined with rainfall data can simulate flood extents, while remote sensing data can identify landslide-prone zones by analyzing slope stability, vegetation cover, and soil moisture. Vulnerability assessments integrate social and economic data—such as population density, poverty indices, and building material types—allowing planners to identify communities most at risk.

5.2.2 EARLY WARNING AND REAL-TIME MONITORING

Early warning systems rely heavily on geospatial data to detect hazards in real time and communicate risks effectively. For instance:

- **Flood forecasting models** use real-time precipitation data, river gauge information, and topographic mapping to issue alerts.
- **Volcano and earthquake monitoring** incorporates satellite thermal imaging, deformation mapping, and seismic data.
- **Cyclone tracking systems** use satellite imagery and atmospheric modeling to predict storm paths and intensities.

GIS platforms also enable the integration and visualization of these datasets to produce intuitive dashboards and alerts for emergency managers.

5.2.3 DISASTER RESPONSE AND EMERGENCY MANAGEMENT

During the response phase, timely and accurate geospatial data is critical for coordinating rescue and relief operations. High-resolution satellite images can identify damaged infrastructure, flooded zones, blocked roads, and affected populations. This information supports:

- **Search and rescue operations**: By identifying the most severely affected areas and mapping access routes.
- **Humanitarian logistics**: By planning the distribution of aid, food, medical supplies, and shelter.
- **Command and control centers**: Through live GIS dashboards and crisis maps that guide decision-making.

An example is the use of UAVs in the aftermath of the 2015 Nepal earthquake, which provided detailed imagery of collapsed buildings and inaccessible regions, facilitating targeted relief efforts.

5.2.4 RECOVERY AND RECONSTRUCTION

Post-disaster recovery benefits from continuous geospatial monitoring to track reconstruction progress, evaluate land use changes, and assess long-term impacts. Urban planners can use geospatial tools to update zoning regulations, identify safe relocation sites, and build resilience into infrastructure. Comparative analysis of pre- and post-disaster imagery helps in damage quantification and insurance assessments.

In many developing countries, this process is supported by international platforms such as the Global Facility for Disaster Reduction and Recovery (GFDRR), which integrates satellite data into post-disaster needs assessments.

5.2.5 CLIMATE ADAPTATION AND LONG-TERM RESILIENCE

Geospatial data is also crucial in developing strategies for long-term climate adaptation. Models that simulate sea-level rise, temperature anomalies, and extreme weather patterns help governments and stakeholders plan for future scenarios. Coastal cities, for instance, use geospatial risk maps to guide land-use planning and infrastructure investment, ensuring that future development avoids high-risk areas.

5.3 TECHNOLOGICAL TOOLS AND PLATFORMS

Several tools and platforms have emerged to support geospatial applications in DRM:

- **GIS Software**: ArcGIS, QGIS, and GRASS GIS for spatial analysis and visualization.
- **Remote Sensing Platforms**: Sentinel Hub, Google Earth Engine, and NASA's FIRMS for real-time monitoring.
- **Open Data Initiatives**: Humanitarian Data Exchange (HDX), Copernicus Emergency Management Service, and Global Disaster Alert and Coordination System (GDACS).
- **Mobile and Drone Technologies**: For rapid on-the-ground assessments.
- **Machine Learning and AI**: For pattern recognition in satellite imagery and predictive modeling of hazards.

These technologies are increasingly interoperable, enabling integrated workflows and collaborative analysis.

5.4 CHALLENGES AND LIMITATIONS

Despite the transformative potential of geospatial data, several barriers limit its widespread use in DRM:

- **Data Accessibility**: Proprietary data, licensing restrictions, and inconsistent formats can hinder timely access.
- **Technical Expertise**: Many developing countries lack skilled personnel to analyze and interpret geospatial data effectively.
- **Infrastructure Gaps**: Limited internet access, computing resources, and outdated equipment constrain data usage.
- **Data Integration Issues**: Combining datasets from different sources with varying resolutions and standards remains challenging.
- **Privacy and Ethics**: The use of personal location data, particularly during crises, raises ethical concerns around surveillance and consent.

Addressing these challenges requires investment in digital infrastructure, capacity building, and international cooperation.

5.5 POLICY RECOMMENDATIONS

For geospatial data to fully support DRM, several policy actions are recommended:

- **Develop National Spatial Data Infrastructures (NSDI)** to ensure coordinated data collection, sharing, and governance.
- **Promote Open Data Policies** to enhance accessibility for all stakeholders.
- **Invest in Training and Education** programs to build local technical capacity.
- **Foster Public-Private Partnerships** with satellite companies, cloud computing platforms, and NGOs.
- **Encourage Community Participation** in data collection and risk mapping to enhance local relevance and ownership.

5.6 CONCLUSION

Geospatial data has become an indispensable tool in modern disaster risk management. Its ability to provide real-time, location-specific insights enhances decision-making, increases operational efficiency, and ultimately saves lives. From hazard mapping to early warning and post-disaster recovery, geospatial technologies empower governments, humanitarian organizations, and communities to prepare for and respond to disasters more effectively. As data and technology become more accessible, the integration of geospatial intelligence into DRM systems will be critical to building resilience in an increasingly risk-prone world.

6. AI-SUPPORTED ANALYTICS

6.1 INTRODUCTION

The increasing frequency and severity of natural and human-induced disasters—exacerbated by climate change, urbanization, and socio-political vulnerabilities—has elevated the importance of timely, accurate, and scalable decision-making in **Disaster Risk Management (DRM)**. Traditional decision-making frameworks often fall short in managing the complexity and velocity of disaster data. This has led to the integration of **Artificial Intelligence (AI) analytics** and **Decision Support Systems (DSS)** into the core of disaster preparedness, response, and recovery operations.

AI analytics enables machines to learn from vast data inputs—ranging from satellite imagery to social media—and identify patterns, make predictions, and suggest actionable insights. When embedded within DSS platforms, these insights support decision-makers in identifying high-risk zones, optimizing emergency responses, allocating resources, and planning long-term resilience strategies. This chapter provides an analytical overview of how AI analytics and decision support systems are transforming DRM by enhancing predictive capabilities, operational efficiency, and strategic coordination.

6.2 CONCEPTUAL FRAMEWORK

6.2.1 AI ANALYTICS IN THE CONTEXT OF DRM

AI analytics encompasses techniques from **machine learning (ML)**, **deep learning (DL)**, **natural language processing (NLP)**, and **computer vision**. These methods are applied to structured and unstructured datasets to forecast hazards, classify risk levels, detect anomalies, and optimize decisions.

Core capabilities include:

- **Predictive Analytics**: Forecasting events like floods, earthquakes, and disease outbreaks.
- **Prescriptive Analytics**: Recommending actions based on simulations and optimization models.
- **Real-Time Analytics**: Monitoring data streams from satellites, sensors, and social media for early warnings.

6.2.1 DECISION SUPPORT SYSTEMS (DSS)

A DSS is an interactive software-based system that supports decision-making activities by integrating data, models, and user-friendly interfaces. In DRM, AI-enhanced DSS platforms provide:

- **Risk visualization tools** (e.g., hazard maps, scenario models)
- **Alert systems** for early warnings and public notifications
- **Resource allocation optimizers** for logistics and personnel deployment
- **Policy simulation environments** for long-term planning

Together, AI analytics and DSS tools form the backbone of intelligent disaster governance.

6.3 APPLICATIONS OF AI-DRIVEN DECISION SUPPORT IN DRM

6.3.1 EARLY WARNING AND FORECASTING SYSTEMS

AI-powered DSS platforms improve the **accuracy and lead time** of early warning systems. By learning from historical data, meteorological inputs, and real-time sensor feeds, AI models can predict hazard onset with higher confidence.

- **Flood Forecasting**: Neural networks and decision trees are trained on river gauge readings, rainfall, and topography to predict flood zones. These predictions are fed into DSS interfaces that visualize high-risk areas and send alerts.
- **Tsunami Detection**: Machine learning algorithms analyze seismic data and ocean buoy readings to predict tsunami generation and arrival times more quickly than traditional methods.
- **Cyclone Tracking**: AI integrates satellite wind data, sea surface temperatures, and historical tracks to estimate storm paths, helping authorities prepare evacuation strategies.

6.3.2 DYNAMIC RISK MAPPING AND VULNERABILITY ASSESSMENT

AI-DSS platforms are instrumental in **spatial risk modeling**:

- **Computer Vision** techniques automatically classify land cover, infrastructure types, and vegetation from satellite imagery.
- **NLP tools** extract vulnerability indicators from textual reports, surveys, and social media posts.
- **Clustering algorithms** group populations based on exposure, socio-economic vulnerability, and access to services.

These outputs feed into interactive risk maps that allow planners to simulate scenarios such as dam failures or urban fires and assess community-level impacts.

6.3.3 REAL-TIME EMERGENCY RESPONSE OPTIMIZATION

When disasters strike, real-time decision support is critical. AI-enhanced DSS platforms help:

- **Prioritize Search and Rescue (SAR)** operations based on predicted casualty densities.
- **Optimize evacuation routes** using real-time traffic data, road blockages, and hazard spread models.
- **Coordinate logistics** by forecasting the demand for shelter, water, and medical supplies based on affected population estimates.

For example, reinforcement learning algorithms can help continuously update optimal aid delivery routes as road conditions evolve during a crisis.

6.3.4 POST DISASTER DAMAGE ASSESSMENT

AI analytics enables fast, scalable post-disaster assessments. DSS platforms use:

- **Satellite image comparison** powered by deep learning (e.g., CNNs) to detect damaged buildings and infrastructure.

- **Drone footage analysis** for hard-to-reach zones.
- **Automated report synthesis**, integrating crowdsourced damage reports, geotagged images, and field surveys.

These assessments help inform insurance payouts, recovery investments, and reconstruction priorities, especially in data-scarce environments.

6.3.5 LONG-TERM STRATEGIC PLANNING AND RESILIENCE BUILDING

AI models integrated into DSS platforms support long-term policy formulation by simulating complex risk environments:

- **Climate scenario modeling**: AI predicts the impacts of 1.5°C or 2°C warming on flood frequency, agricultural productivity, and migration patterns.
- **Urban expansion models**: Predict where informal settlements may grow and what infrastructure investments are needed.
- **Cost-benefit simulations**: Help governments weigh investments in flood barriers, early warning systems, or social protection schemes.

By turning data into foresight, AI-driven DSSs empower policymakers to build resilience over decades, not just days.

6.4 ARCHITECTURE OF AI-ENABLED DECISION SUPPORT SYSTEMS

AI-enabled DSS platforms typically involve the following architecture:

1. **Data Ingestion Layer**: Collects real-time and historical data from satellites, IoT devices, mobile phones, social media, and public databases.
2. **Data Processing Layer**: Preprocesses, cleans, and harmonizes multi-format data, often using big data tools such as Apache Spark.
3. **AI Engine**: Applies machine learning models to identify trends, forecast hazards, or recommend decisions. May involve supervised or unsupervised learning, and increasingly uses **transfer learning** to adapt models to local contexts.
4. **Decision Logic Layer**: Encodes domain-specific rules, optimization algorithms, and expert systems to evaluate AI outputs.
5. **User Interface**: Dashboards, mobile apps, and GIS visualizations enable human decision-makers to interpret AI insights and take action.

Examples include the **Google Flood Forecasting System**, the **RiskScape DSS** from New Zealand, and **UNDRR's INFORM Risk Index platform**.

6.5 BENEFITS OF AI ANALYTICS AND DECISION SUPPORT IN DRM

The benefits of AI analysis and decision support are summarized in **Table 5**.

Table 5: AI Analytics and Decision Support benefits in DRM

Benefit	Description
Speed and Scalability	AI can analyze vast, diverse datasets faster than human teams, providing timely insights for large-scale disasters.
Predictive Power	Models can forecast hazard probabilities, exposure, and recovery times with increasing precision.
Scenario Flexibility	DSS platforms allow simulation of “what-if” scenarios to prepare for multiple risk pathways.
Resource Optimization	Reduces wastage by directing resources to where they are needed most.
Evidence-Based Policy	Enhances long-term resilience planning with data-driven foresight.

6.6 CHALLENGES AND ETHICAL CONSIDERATIONS

Despite its advantages, AI-DSS integration in DRM raises critical concerns:

- **Data Quality and Bias:** AI models can reinforce inequalities if trained on biased or incomplete datasets. For example, informal settlements may be underrepresented in satellite imagery, leading to risk underestimation.
- **6.2 Algorithm Transparency:** “Black-box” AI models, particularly deep neural networks, lack explainability, making it difficult for officials to trust or act on outputs without understanding the rationale.
- **6.3 Accessibility and Digital Divide:** Many low-income and hazard-prone countries lack the infrastructure or technical capacity to deploy AI-DSS tools effectively, exacerbating global risk disparities.
- **6.4 Ethical Use of Personal Data:** Mobile phone location tracking and social media mining for early warnings may infringe on privacy. Robust governance frameworks are essential to protect rights during emergencies.
- **6.5 Overreliance and Human Oversight:** Decision-makers may defer excessively to AI-generated recommendations. Human judgment, domain expertise, and local context must remain central.

6.7 RECOMMENDATIONS AND FUTURE DIRECTIONS

To harness the full potential of AI and decision support for DRM, stakeholders should:

- **Invest in Localized, High-Quality Data**: Build geospatial and socio-economic datasets that reflect community-level realities.
- **Develop Transparent, Explainable Models**: Focus on interpretable AI that can justify its recommendations to decision-makers.

- **Strengthen Institutional Capacity**: Equip national disaster agencies with AI training, infrastructure, and partnerships.
- **Promote Ethical AI Use**

7. DATA VISUALIZATION AND DECISION SUPPORT

7.1 INTRODUCTION

Effective disaster risk management (DRM) relies on timely, accurate, and actionable information. As the volume and complexity of disaster-related data continue to increase—with inputs from satellites, sensor networks, simulations, and social media—the need to synthesize this information for decision-makers has become more critical. **Data visualization** and **decision support systems (DSS)** play a central role in transforming raw data into meaningful insights, enabling governments, humanitarian agencies, and first responders to act quickly and strategically.

This chapter explores the synergy between data visualization and decision support in DRM. It outlines the principles of effective visualization, the architecture of DSS platforms, key applications, technical tools, and the challenges of integrating these technologies in diverse operational environments.

7.2 THE ROLE OF DATA VISUALIZATION IN DRM

Data visualization refers to the graphical representation of information and data, enabling users to see trends, patterns, and anomalies that might be missed in tabular formats. In DRM, visualization facilitates:

- **Risk communication**: Translating technical risk assessments into comprehensible visuals for policy makers and communities.
- **Situational awareness**: Mapping hazards, infrastructure, and population exposure in real-time.
- **Resource allocation**: Highlighting priority zones for emergency response or long-term investment.
- **Scenario simulation**: Helping planners and stakeholders explore the impacts of different interventions.

Key types of visualizations include:

- **Geospatial maps** (e.g., hazard zones, evacuation routes)
- **Time series charts** (e.g., rainfall intensity, aftershock frequency)
- **Dashboards** (e.g., real-time case numbers, affected populations)
- **Network diagrams** (e.g., logistics chains, communication networks)

7.3 DECISION SUPPORT SYSTEMS IN DRM

A **Decision Support System (DSS)** is a computer-based tool that helps decision-makers analyze data, evaluate alternatives, and make informed choices. In the context of DRM, DSS platforms integrate data streams, analytical models, and user interfaces to support activities such as:

- **Early warning and alerts**
- **Evacuation planning**
- **Impact forecasting**
- **Emergency logistics**
- **Post-disaster recovery prioritization**

DSS platforms can range from simple interactive maps to sophisticated multi-layered systems that incorporate machine learning and simulation engines.

7.4 INTEGRATION OF VISUALIZATION AND DSS IN DRM

The integration of data visualization into DSS platforms enhances their usability and effectiveness by:

1. **Enhancing Understanding**
    - Visual summaries help decision-makers interpret complex datasets quickly.
    - Dashboards and interactive maps allow users to drill down into layers of information, from macro (country-level) to micro (neighborhood-level) views.
2. **Improving Speed and Accuracy**
    - Real-time visualizations can highlight emerging threats (e.g., rising river levels, spreading wildfires) and prompt faster responses.
    - Visual anomaly detection (e.g., radar signatures, sensor malfunctions) can trigger automated or human-verified alerts.
3. **Supporting Scenario Analysis**
    - Planners can simulate "what-if" conditions (e.g., Category 5 hurricane landfall) and visualize potential impacts on infrastructure and populations.
    - Visualizations help communicate model outputs to stakeholders who may not be technical experts.

7.5 TECHNICAL ARCHITECTURE OVERVIEW

A robust visualization and DSS system for DRM typically includes:

1. **Data Sources**
    - **Remote sensing** (satellite, UAV)
    - **Ground sensors** (weather stations, seismic detectors)
    - **Crowdsourced data** (social media, SMS reports)
2. **Historical and forecast models** (e.g., hydrological models, climate projections)
3. **Data Management and Integration**
    - Use of data warehouses, cloud platforms, and APIs for seamless integration.
    - Geospatial Information Systems (GIS) provide spatial analytics capabilities.
4. **Analytical Engine**
    - Incorporates statistical models, AI/ML algorithms, and rule-based logic to process and interpret data.
5. **Visualization Layer**
    - Built using web-based libraries (e.g., D3.js, Leaflet, Mapbox), commercial platforms (e.g., ArcGIS, Tableau), or custom dashboards.
    - Responsive interfaces allow filtering, zooming, and layer toggling.
6. **Decision Logic and User Interface**
    - User-facing components include dashboards, mobile apps, and alert systems.
    - Interfaces allow input from decision-makers, including scenario selection and priority weighting.

7.6 KEY APPLICATIONS

Key applications of DSS include:

- **Early Warning Systems:** Visualization dashboards consolidate weather forecasts, sensor readings, and risk indices to issue early warnings. Example: flood alert systems that color-code river basins based on water level thresholds.
- **Evacuation Planning:** Interactive maps highlight safe zones, shelters, road accessibility, and estimated population densities. DSS tools optimize evacuation routes based on real-time traffic and hazard data.
- **Damage and Impact Assessment:** Post-disaster visualizations include satellite imagery overlays, damage heatmaps, and affected infrastructure layers. These tools support needs assessments and appeals for aid.
- **Multi-Hazard Risk Mapping:** Layered risk maps integrate data on floods, earthquakes, landslides, and fires to prioritize resilience investments. DSS platforms can recommend policies based on exposure, vulnerability, and coping capacity.
- **Logistics and Supply Chain Management:** DSS systems visualize warehouse stock levels, transport routes, and distribution schedules to support humanitarian logistics. Scenario modeling helps prepare for supply chain disruptions.

7.7 TOOLS AND TECHNOLOGIES

Table 6 summarizes the main technological tools that can assist in the integration of visualization and DSS for DRM.

Table 6: Tools providing geospatial and DSS capabilities in DRM

Tool/Technology	**Use Case**
ArcGIS	Advanced geospatial analysis and map creation
QGIS	Open-source GIS tool for community-driven risk mapping
Power BI / Tableau	Dashboard creation with data visualization capabilities
Leaflet / Mapbox / D3.js	Custom web-based interactive maps
OpenStreetMap (OSM)	Community-sourced base maps for disaster zones
Sahana Eden	Open-source DSS platform for humanitarian response

7.8 CHALLENGES AND CONSIDERATIONS

- **Data Gaps and Inconsistencies:** Visualization and DSS are only as good as the data fed into them. In many regions, data is outdated, sparse, or of poor quality.

- **Technical Complexity:** Sophisticated systems may be difficult to maintain or use without technical capacity-building, especially in low-resource settings.
- **Interoperability:** Systems must be designed to integrate diverse data types and comply with standards for sharing across agencies.
- **Cognitive Overload:** Too much information or overly complex visualizations can overwhelm decision-makers. Simplicity and clarity are critical in high-pressure situations.
- **Accessibility:** Tools should be usable in low-bandwidth environments and by non-technical users, including community leaders and frontline responders.

7.9 FUTURE DIRECTIONS

- **AI-Driven Visualizations**: Integration with large language models and computer vision to automatically generate annotated maps and decision summaries.
- **Multimodal Dashboards**: Combining maps, charts, text, and video to support different decision-making styles.
- **User-Centered Design**: Co-developing visualization platforms with end-users to ensure relevance and usability.
- **Decentralized Data Systems**: Use of blockchain or distributed ledgers for real-time, tamper-proof data integration across agencies.
- **Augmented Reality (AR)**: Field-based AR tools to visualize invisible risks (e.g., radiation, plume dispersion) in real time.

7.10 CONCLUSION

Data visualization and decision support systems are indispensable components of modern disaster risk management. By enabling timely, informed, and coordinated action, they enhance the capacity of stakeholders to save lives, reduce losses, and build long-term resilience. As technologies evolve, the focus must remain on human-centered design, equity in access, and ethical integration of emerging tools.

8. CONCLUSIONS

This deliverable provided all the basic information about the technologies, tools and methodologies that can enhance and support DRM in Community-based decision making systems/platforms. Some of them have been selected as constituent parts of the PANTHEON system/project. In general, there is an abundance of technological developments that are both needed and can be utilized in DRM, due to the complexity and number of activities involved. The document can be a useful foundation for future DRM system implementations.

9. LIST OF ABBREVIATIONS

Abbreviation	Meaning
AI	Artificial Intelligence
AIDR	Artificial Intelligence for Disaster Response
API	Application Programming Interface
CAP	Common Alerting Protocol
CEMS	Copernicus Emergency Management Service
COP	Common Operating Picture
DEM	Digital Elevation Model
DL	Deep Learning
DRM	Disaster Risk Management
DSS	Decision Support System
ECCC	Environment and Climate Change Canada
EEA	European Environment Agency
EM-DAT	Emergency Events Database
EPA	Environmental Protection Agency
GDACS	Global Disaster Alert and Coordination System
GEE	Google Earth Engine
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Geospatial Information System
GPS	Global Positioning System
HDX	Humanitarian Data Exchange
HOT	Humanitarian OpenStreetMap Team
HXL	Humanitarian Exchange Language
JMA	Japan Meteorological Agency

KML	Keyhole Markup Language
ML	Machine Learning
MOU	Memorandum of Understanding
NAPS	National Air Pollution Surveillance
NGO	Non-Governmental Organization
NLP	Natural Language Processing
NOAA	National Oceanic and Atmospheric Administration
NSDI	National Spatial Data Infrastructures
ODK	Open Data Kit
OGC	Open Geospatial Consortium
OSM	OpenStreetMap
QCRI	Qatar Computing Research Institute
SAR	Synthetic Aperture Radar
SCDT	Smart City Digital Twin
SDMX	Statistical Data and Metadata eXchange
SITREP	Situation Report
UAV	Unmanned Aerial Vehicle
UNOCHA	United Nations Office for the Coordination of Humanitarian Affairs
USGS	United States Geological Survey
VGI	Volunteered Geographic Information
WFS	Web Feature Service
WHO	World Health Organization
WISE	Water Information System for Europe
WMS	Web Map Service