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Review

Model Driven Approach for Efficient Flood Disaster Management with Meta Model Support

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Abstract: Society and the environment are severely impacted by catastrophic events, specifically floods. Inadequate emergency preparedness and response are frequently the result of the absence of a comprehensive plan for flood management. This article proposes a novel flood disaster management (FDM) system using the full lifecycle disaster event model (FLCNDEM), an abstract model based on the function super object. The proposed FDM system integrates data from existing flood protocols, languages, and patterns and analyzes viewing requests at various phases of an event to enhance preparedness and response. The construction of a task library and knowledge base to initialize FLCNDEM results in FLCDEM flooding response. The proposed FDM system improves the emergency response by offering a comprehensive framework for flood management, including pre-disaster planning, real-time monitoring, and post-disaster evaluation. The proposed system can be modified to accommodate various flood scenarios and enhance global flood management.

Keywords: floods; disaster management system; natural disaster management system; model-driven approach

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Citation: Khan, S.M.; Shafi, I.; Butt, W.H.; Díez, I.d.l.T.; Flores, M.A.L.; Galvlán, J.C.; Ashraf, I. Model Driven Approach for Efficient Flood Disaster Management with Meta Model Support. *Land* **2023**, *12*, 1538. https://doi.org/10.3390/land12081538

Academic Editor: Romulus Costache

Received: 3 July 2023
Revised: 30 July 2023
Accepted: 31 July 2023
Published: 3 August 2023

1. Introduction

Natural catastrophes such as earthquakes, tsunamis, floods, forest fires, plane crashes, and viruses are becoming more common, posing major challenges not just for the public but also for government organizations in charge of disaster management and preparedness. Modeling languages are widely utilized in many other disciplines, including business process modeling, systems engineering, information management, and computer science. We intend to develop a meta-model for flood and disaster management (FDM) in this study, which focuses on disaster management as a specific field. The meta-model is utilized to precisely define the necessary constructs and norms for the development of semantic models in the field of crisis management. It is anticipated that the meta-model will be beneficial to a wide variety of users, such as computer-aided software engineering (CASE) tool suppliers, method engineers, modeling tool providers, repository providers, system integrators, researchers, and end-users such as emergency responders, coordinators, and managers. Natural catastrophes such as earthquakes, tsunamis, floods, forest fires, plane crashes, and viruses are becoming more common, posing major challenges not just for the public but also for government organizations in charge of disaster management and preparedness. Recent failings to respond to Natural disasters such as the H1N1 pandemic and the earthquake in Haiti have sparked concern.

In Victoria, Australia, bushfires are frequently attributed to a lack of timely availability of skills, which is sometimes associated with particular categories of events [1]. Frequently, the potential for skill reuse is neglected, with disastrous consequences. Therefore, utilizing the FDM meta-model, this work suggests a method for integrating disaster management (DM) information to develop a flood support system that incorporates several DM operations to tailor them to a particular disaster. This strategy is inspired by method engineering, a knowledge management practice in software engineering.

There are different kinds of disasters, as shown in Figure 1, including natural disasters, technological/industrial disasters, environmental disasters, and complex humanitarian emergencies. These disaster groups are further categorized into sub-groups. For example, natural disasters include earthquakes, floods, wildfires, etc. To handle such disasters, a variety of approaches can be adopted like machine learning, geographic information systems, the Internet of Things (IoT), etc; we select a model-driven engineering approach to manage natural disasters.

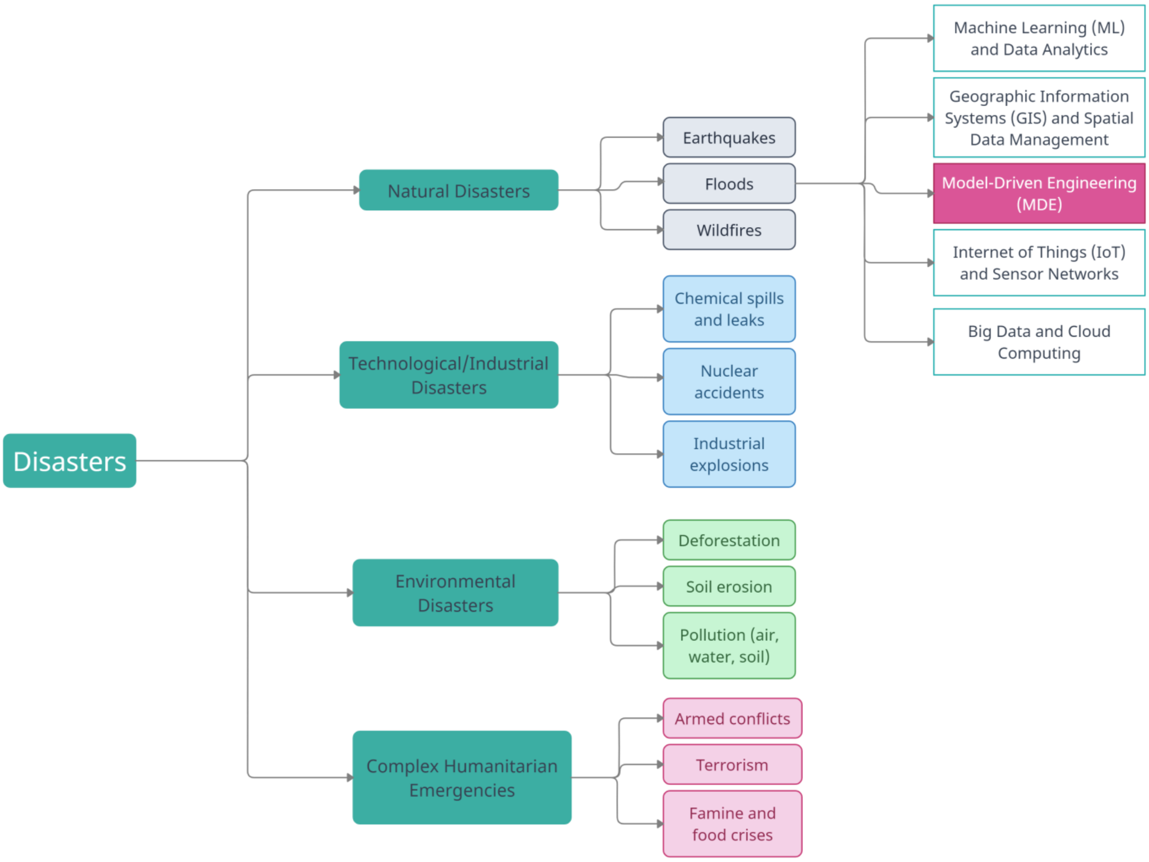

Figure 1. Block diagram of the flow of the work.

DM manages and resolves disaster risks and effects. It covers mitigation, readiness, response, and recovery [2]. DM involves organizing, directing, and using counter-disaster resources [3]. The practitioners from this domain attempt to decrease or prevent hazards, assist disaster victims, and recover quickly. Operationalizing this domain involves many difficult activities. Inclusions include risk assessments, preparedness, emergency responses, rescue, relief distribution, and reconstruction. Modeling and communicating DM data is challenging. Also, it needs to evolve to incorporate changing demands.

Instead of pursuing a comprehensive model, this paper proposes a meta-model that can connect diverse and incomplete models that attempt to express DM knowledge systematically. They can organize the theory of generic concepts that influence our perception of reality [4]. Models should influence reality [5]. They must be true or faithful representations so that the model can be used to answer queries about the world or predictably alter the world. Meta modeling produces a meta-model that describes what can be expressed in valid knowledge domain models; it is a model about models. In this context, a model refers to the DM solution model that depicts the coordination of DM activity and its elements (e.g., people, resources, and plans) and how these should be arranged for a specific disaster. Failures in DM frequently result from the accumulation of a complex sequence of events and are frequently accompanied by changes in environmental factors [6].

Modeling languages are widely utilized in many other disciplines, including business process modeling, systems engineering, information management, and computer science [7]. We intend to develop a meta-model for flood and disaster management (FDM) in this study, which focuses on disaster management as a specific field. The meta-model is utilized to precisely define the necessary constructs and norms for the development of semantic models in the field of crisis management. It is anticipated that the meta-model will be beneficial to a wide variety of users, such as CASE tool suppliers, method engineers, modeling tool providers, repository providers, system integrators, researchers, and end users such as emergency responders, coordinators, and managers.

Moreover, this study investigates and assesses the efficacy of existing flood disaster management systems, such as early warning systems, risk assessment strategies, and emergency response plans. In addition, the research examines the obstacles to the establishment of efficient flood risk management methods, such as resource limitations, inadequate infrastructure, and low public awareness. Ultimately, this study seeks to provide insights and recommendations for developing a more comprehensive and effective flood disaster management system by identifying the challenges and gaps in the existing system. There is a block diagram that displays how We worked for this Research.

The rest of this paper is divided into sections. Much important research works related to the current study are discussed in Section 2. Section 3 presents the background of the problem, the need for a model-driven approach, as well as, the importance of the problem at hand. The proposed system is discussed in Section 5 while its implementation, and validation are given in Section 6. Finally, Section 7 concludes this study.

2. Literature Review

DM is a complicated and multidimensional discipline that includes disaster prevention and management, as well as limiting their impact on human life and business activities. Complex chains of events and shifts in external circumstances typically lead to failed crisis management rather than any one specific cause [6]. Consequently, it is widely acknowledged that no two catastrophes are identical and that each disaster requires its own management strategy. However, responses to comparable catastrophes can frequently be transferred from one circumstance to another, such as the widespread evacuation of personnel. This literature review emphasizes developing a unified understanding of common concepts and methods applicable to various disasters to improve disaster management. The authors suggest employing a generic representation layer or meta-model to accomplish this by utilizing current crisis management and security models [8]. The proposed technique is based on method development and meta-modeling to generate interoperable, reusable, and transportable software assets and components.

Method engineering is the application of knowledge-based technology based on the outcomes of software development to complete knowledge representation and capture, whereas meta-modeling aims to generate interoperable, portable, and reusable software components and assets. In the context of disaster management, the meta-model is the fundamental building element that provides statements about the possible structure of models without necessarily specifying the exact syntax of the language [8]. The authors employ meta-modeling to create initial attempts to describe disaster management information in a reusable format based on an intelligent decision support system. By establishing a centralized entry point with the proposed method, the authors intend to facilitate the formulation of disaster management strategies as new situations arise. To demonstrate the methodology, the author provides a basic meta-model that generalizes most of the features found in existing crisis management models.

A domain-based meta-model can model its language effectively. Meta models are designed to automate the production and maintenance of variant archetypal software products. The study [9] extended meta-modeling from software engineering to DM to facilitate the reuse of knowledge. The authors incorporate the previous application into the organization of DM domain knowledge to facilitate process engineering for unforeseen requirements. Knowledge of an organization can be developed both internally and externally. The research work [10] aims to establish a DM language that can be used to construct repositories for enterprise-wide DM data sharing. Knowledge transfer would then likely be effective. Successful knowledge sharing depends on knowledge contributors populating the knowledge management system with content and knowledge searchers retrieving content for reuse; the same individual can act as both a contributor and a seeker at different times [11]. This can facilitate the strategic administration of organizational knowledge to help DM organizations operate effectively in volatile environments [12].

Structuring and preserving content take time and requires quality control [13] that commonly uses metadata. Metadata is the foundation of information infrastructures since it semantically describes content and services [14]. Management of crisis concepts for information repositories increases organizations' and communities' resilience [8,15]. Such frameworks must be empirically validated by specialists. Meta models provide metadata, data linkages, and a comprehensive abstract picture of the domain with recommendations for specialization into specific contexts. They can verify the exhaustiveness of knowledge repositories. During development, the DM meta-model generalizes all viable DM model concepts. This collection of concepts and their relationships can be used to validate the completeness of concepts in a particular DM conceptual framework (model).

The meta-model presented in [16] may serve as a benchmark for DM knowledge modeling. Knowledge system models define the system and its environment for a particular purpose. The most important aspect of developing this specification is collecting all concepts necessary for system organization [17]. The DM meta-model permits DM users to derive the optimal disaster solution model from a description of the context. If a regional authority wishes to develop an effective flood evacuation strategy, all DM components must be specified in detail. Evacuation processes can be modeled. The processes may include

i. Evacuating at-risk individuals from disaster-affected areas,
ii. Emergency services team coordination of evacuees,
iii. Establishment of evacuating operation centers, and
iv. Organization of evacuation facilities and other evacuation processes.

Finding sub-processes, identifying sub-problems, finding solutions to those problems, and then combining the results of those efforts constitute the core components of a solution model for particular disaster-related issues [16]. This requires knowledge of DM methodologies, protocols, and strategies [18]. The study [16] provides DM users with structured constructs and principles of DM knowledge (for example, concepts, actions, stakeholders, and resources). A DM meta-model exposes and clarifies DM processes, structure, and resources. The meta-model explicitly identifies reusable domain components including users, resources, procedures, and plans.

According to [19], lacking domain knowledge might slow, error-prone, and expensively analyze data. It can also cause domain stakeholders to be overused. Meta models help DM practitioners communicate and reduce analysis time. It will accelerate DM requirement analysis. Traditional repositories only store and search components, ignoring process evaluation essential to reuse [19]. Repositories contain process domain information, therefore [19] suggests using them to speed up domain analysis and understanding. DM meta-models facilitate faster analysis. Meta models have been utilized to simplify and validate a model against a significant portion of its domain [20]. Meta models must satisfy six criteria:

i. Purpose,
ii. User,
iii. Scope–what constructions (or entities) are addressed,
iv. Formality–can computers interpret it,
v. Independence–is it independent of system implementation, and
vi. Understand ability–can a professional comprehend it [21].

Table 1 provides DM concepts used in existing models on DM. The identification of the task's scope, or the general concepts used in all phases of DM, proved to be the most challenging aspect of developing the DM meta-model. By recognizing DM concepts, the meta-model will break down all DM challenges into sub-DM issues. After figuring out what the idea is, you have to find out who does it, how, when, and what the prerequisites are. Reconciliation promotes globalization and DM's domain operations contain numerous components. Included are DM duties, activities, responsibilities, resources, decisions, users, and tools, as well as unanticipated environmental events. Developing future DM models to facilitate an efficient DM meta-model ensures correctness. This will generate good DM organization models for real-world domain applications. The authors used an iterative meta-modeling approach to analyze the DM domain [22]. This procedure yielded the DM meta-model.

Table 1. Demonstration of the DM concepts used to portray various DM actions in existing disaster models.

Ref.	Model	Mitigation	Preparedness	Response	Recovery
[23]	Circular model for disaster	Disaster mitigation	Disaster prevention, Disaster preparedness	Warning, disaster, emergency response	Rehabilitation, reconstruction, development
[24]	Disaster phase and time period model	Hazard vulnerability, hazard mitigation	Emergency preparedness	Emergency response	Disaster Recovery
[25]	Integrated disaster management model	Hazard assessment, strategic plan, mitigation	Risk management, preparedness	Response	Monitoring and evaluation
[11]	An emergency management model for home health care organizations	Mitigation	Preparedness	Response	Recovery
[12]	Expand contract model	Prevention and mitigation strand	Prepared strand	Relief and response strand	Recovery and rehabilitation strand
[8]	A comprehensive conceptual model for disaster management	Hazard assessment, strategic planning, mitigation	Risk management, preparedness	Response	Recovery, monitoring and evaluation
[26]	Ibrahim-Razi model	Inception of errors, accumulation of errors	Warning, disaster impending stage, triggering event	Emergency state, disaster	Normal state
[27]	Traditional DM cycle model	Mitigation	Preparedness	Disaster Impact	Reconstruction, rehabilitation

3. Background

3.1. Problem Statement

Intense precipitation events and subsequent river floods have the potential to cause serious property damage and loss of life, emphasizing the necessity for FDM techniques that can mitigate risk and prevent crises. Access to precise on-site information, trustworthy forecasting, and appropriate reaction methods and procedures that can be implemented successfully are essential for achieving this. Some major challenges related to the FDM system can be seen in Figure 2.

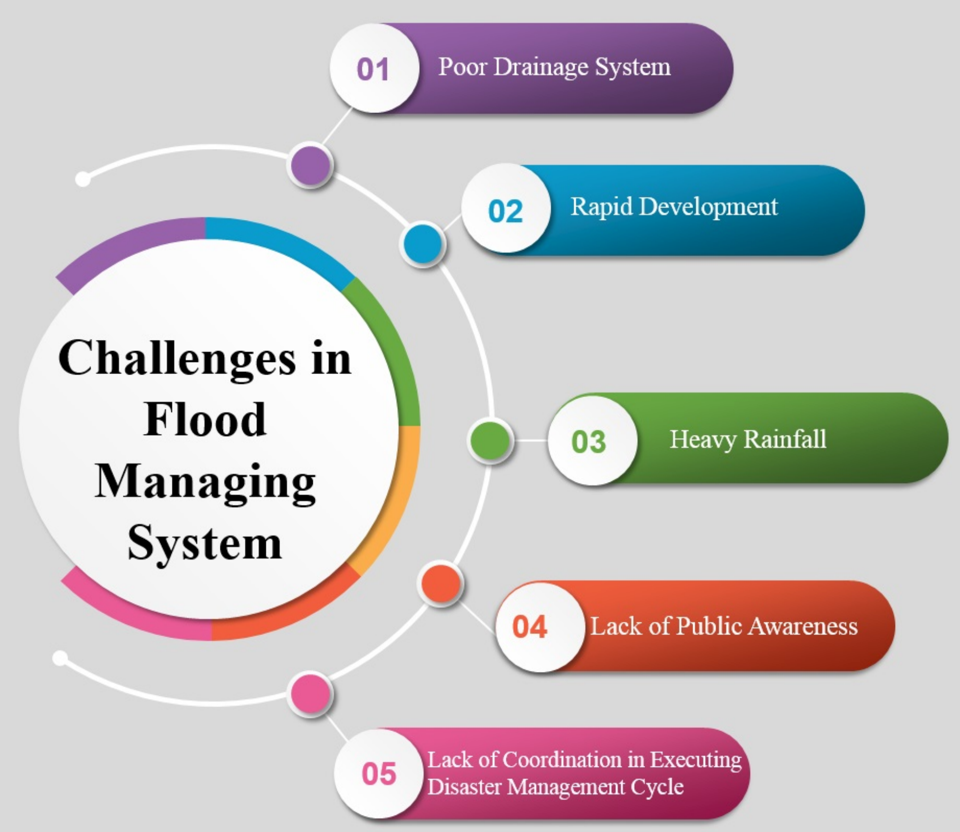

Figure 2. Challenges related to the flood management system.

3.2. Why Using Model-Driven Approach

A modern strategy can assist flood management systems for a variety of reasons. Real-time monitoring, made possible by technologies such as sensors, drones, and satellite imaging, allows for the early detection of potential flood hazards and the speedy reaction to an impending disaster. Data-driven decision-making is also possible when data from real-time monitoring is used. This information can be used to forecast the possibility of floods and create evacuation preparations. Modern technology facilitates immediate communication by allowing for the rapid transmission of flood information and the coordination of relief activities. Cooperation among the numerous authorities and groups involved in flood management can also be improved with contemporary technology, allowing for a more coordinated response. Finally, flood management systems can respond faster and more efficiently by harnessing contemporary technology and data, decreasing the impact of floods on the impacted population, and potentially saving lives. The diagram given in Figure 3 can help to understand how problem-solving is completed by using a model-driven approach.

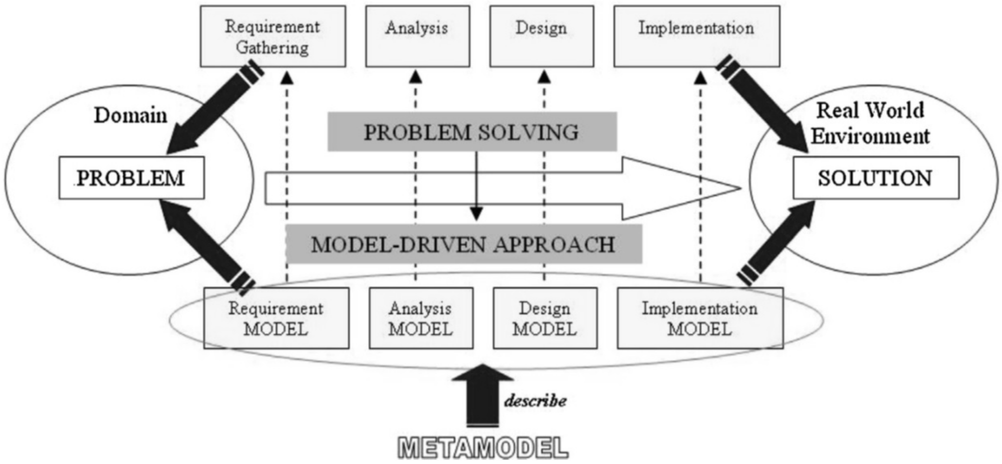

Figure 3. Problem-solving through the model-driven approach.

3.3. Importance of the Domain

It is possible to emphasize the importance and relevance of studying and putting in place an FDM system, particularly in the case of developing countries like Pakistan, where the nation has frequently faced severe floods. It is even more important to address the issues and build successful FDM techniques. The following section seeks to summarize the significance of the study.

3.3.1. Humanitarian Impact

Floods have serious negative effects on human welfare because they result in deaths, displaced populations, and the destruction of livelihoods, infrastructure, and crops. The study acknowledges the enormous significance of reducing the negative effects of floods on the afflicted population, their safety, and their well-being by concentrating on flood-stricken areas in Pakistan.

3.3.2. Economic Losses

Numerous economic sectors, including agriculture, industry, and commerce, are negatively impacted by flooding. By examining flood disaster management in Pakistan, the study acknowledges the economic importance of devising robust strategies to minimize damage, enhance resilience, and facilitate timely recovery, thereby reducing the economic burden of flood events. During floods, various strategies can be used to reduce the damage, make the area more resistant, and help people get back on their feet quickly. While specific will vary depending on geography, flood severity, and local conditions, the following are some standard steps to consider

- **Flood Risk Assessment and Early Warning Systems**: Creating early warning systems can help anticipate possible flood events. This lets the government warn people and businesses in vulnerable places sooner, giving them more time to get ready and leave if they need to.
- **Infrastructure and Land Use Planning**: Strict land use regulations and zoning laws can stop construction in flood-prone areas or urge people to build structures that can withstand flooding. Also, investing in strong infrastructure like flood barriers, levees, and stormwater management systems can help redirect or limit floodwaters.
- **Natural Flood Control Methods**: Putting into practice natural flood control methods, such as rehabilitating wetlands, building human-made ponds, and developing green spaces, can assist absorb surplus water and lessen the severity of floods.
- **Flood Insurance and Financial Protection**: Encouraging or mandating flood insurance for properties in flood-prone areas can provide financial protection to property owners and companies. This can help make up for some of the money that floods cost.

- **Community Awareness and Education**: It is essential to inform the people of the dangers of flooding, the precautions to take, and the best way to evacuate. When floods happen, well-informed communities are more likely to react well and limit the damage.
- **Emergency Response and Relief Planning**: Making detailed emergency response plans and relief strategies can help make sure that flood disasters are dealt with quickly and efficiently. This includes planning evacuation routes, constructing temporary shelters, and organizing aid to help the impacted communities.
- **Investment in Resilient Infrastructure**: Upgrading the infrastructure we already must make it more flood-resistant can help reduce harm. This could mean raising important infrastructure, making buildings stronger, and making sure that important services are safe from floodwaters.
- **Sustainable Urban Design**: Promoting sustainable urban design practices, like permeable pavements and green roofs, can help cut down on surface run-off and stop floods in cities.
- **International Cooperation**: Since some floods can happen across national borders, countries can work together to better prepare for and respond to transboundary flood events by sharing data and working together on flood control.
- **Climate Change Mitigation and Adaptation**: Addressing the underlying causes of climate change and implementing adaptation measures to shifting weather patterns are essential. Reducing greenhouse gas emissions and putting in place policies that are adaptable to climate change can help reduce the number and harshness of extreme weather events like floods.

It is important to remember that he risk of flooding cannot be totally eliminated, no matter what measures are taken. But a combination of these measures, tailored to the specifics of each area, can make floods much less expensive and make communities more resilient. Collaboration between government departments, communities, and experts is the key to successfully putting these strategies into place.

3.3.3. Environmental Concerns

Floods can have devastating ecological effects, such as soil erosion, water contamination, and habitat devastation. By addressing flood management in Pakistan, the study acknowledges the significance of preserving the environment, safeguarding natural resources, and promoting sustainable practices to minimize the long-term ecological effects of floods.

3.3.4. Climate Change Adaptation

As climate change and unpredictability become worse, floods are likely to happen more often and be stronger in many places, including Pakistan. The study emphasizes the need to comprehend the interplay between climate change and flood disasters. It seeks to contribute to the development of adaptive measures and resilience-building strategies that can assist Pakistan and other flood-prone regions around the globe in preparing for future challenges. These strategies might include:

i. Developing Early Warning Systems.
ii. Identification of food-prone areas and make regulations and guidelines for using Land and development.
iii. Develop climate-resilient infrastructure such as buildings, roads, bridges, etc. that can withstand flooding and quickly be restored after a flood event.
iv. Involving local communities in the planning and decision-making process to ensure that adaptation measures consider their needs, knowledge, and experiences.
v. Developing comprehensive plans that outline actions to be taken before, during, and after a flood event to minimize damage and enhance recovery.
vi. Establishing support systems, such as insurance programs and financial assistance, to help affected individuals and communities recover after a flood.

vii. Facilitating knowledge exchange and collaboration between flood-prone regions globally to learn from each other's experiences and develop effective strategies

3.3.5. Policy and Governance

Effective flood disaster management calls for well-defined policies, governance frameworks, and coordination among government departments, non-profit organizations (NGOs), and local populations. By analyzing flood management systems in the context of Pakistan, this study seeks to identify policy gaps, recommend improvements, and contribute to the improvement of governance mechanisms, thereby bolstering flood preparedness and response efforts.

3.3.6. Knowledge and Research Gap

The study acknowledges the need for extensive research on flood disaster management systems, with a particular emphasis on Pakistan. This study aims to fill the existing knowledge vacuum and provide valuable insights, lessons learned, and best practices that can be used to develop more effective flood management strategies in Pakistan and other flood-prone regions. From June to September 2022, the Pakistani floods were among the worst in the nation's annals. The floods killed nearly 1700 people, displaced millions, and affected 33 million. Additionally, the floods caused billions of dollars in infrastructure and property devastation.

The floods were brought on by monsoon rainfall that was made worse by climate change. Several provinces, including Sindh, Baluchistan, and Khyber Pakhtunkhwa, experienced inundation as a result of rivers overflowing their banks. The floods also caused landslides and mudslides, which harmed infrastructure and property further. The government of Pakistan has been striving to provide aid to the flood victims. The government has provided food, shelter, and medical care to those afflicted by the disaster. The government has also been rebuilding flood-damaged infrastructure and property.

As per the map given in Figure 4 showing satellite observations, millions of people could be at risk. Pakistan's floods have highlighted the need for enhanced flood risk management. The Pakistani government has taken a few measures to enhance flood risk management, but more must be done. Pakistan may see greater floods in the future due to climate change. The government and the people of Pakistan must be prepared for these flooding events. The ND steps that the government of Pakistan has taken include:

- **Disaster relief**: The government has given food, shelter, and medical care to the millions of people impacted by the floods. It has also sent soldiers to help with rescue and aid efforts. In the first few weeks after the floods, the government gave food rations to over 2 million people and housing to over 1 million people. The military has helped with rescue and aid efforts, like giving medical care, clearing roads, and providing food and water to people who need it [28,29].
- **Infrastructure repair**: The government has started fixing the roads, bridges, and other things that the floods broke. It is also trying to fix drainage systems so that flooding does not happen again. The government thinks that the cost of fixing the damage caused by the storms will be around USD 1 billion. To date, the government has set aside USD 200 million to fix infrastructure [30].
- **Flood forecasts**: The government has improved its flood forecasting system so it can better predict when and where floods are likely to happen. This will help the government remove people and take other steps to lessen the effects of future floods. The government has set up new sites for predicting floods and made it easier to collect and analyze data [31].
- **Disaster readiness**: The government is working to increase public knowledge of the dangers of flooding and to educate citizens on how to prevent and deal with flooding. It is also making a national plan for dealing with disasters. The government has started a program to make people aware of the dangers of flooding. It has also taught more than 100,000 people how to get ready for storms and what to do when they happen.

The government is making a national disaster management plan that will spell out what each government agency is supposed to do when a crisis strikes [32].

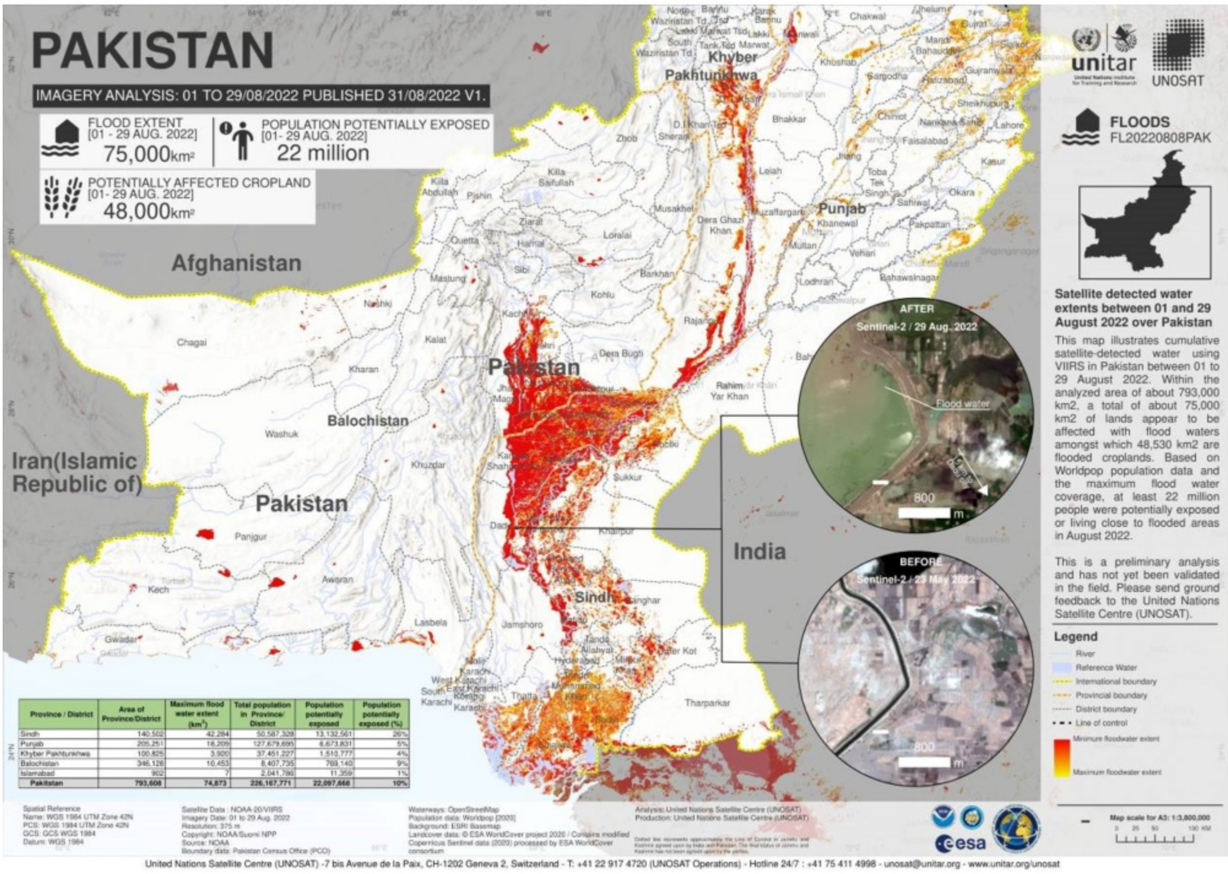

Figure 4. The figure depicts VIIRS satellite observations of precipitation across Pakistan from 1 January 2022, to 29 August 2022. The 75,000 km^2 of land, including 48,530 km^2 of croplands, appears to be damaged by flood waters in the assessed area of 793,000 km^2. Based on the world population and the most flood water that could fill an area, at least 22 million people could be at risk or live near flooded areas in August 2022. UNOSAT is credited [33].

Foreign humanitarian organizations have commended the Pakistani government on its handling of the 2022 floods. But there is still a lot to do to help the millions of people whose circumstances have been changed by the disaster get back on track.

4. Analysis of Existing Flood Disaster Management Techniques

4.1. Rainfall-Run-off Modeling Approaches

Rainfall–run-off models are hydrological models used to simulate the transformation of rainfall into the run-off in a catchment. These models are important for predicting the amount and timing of run-off in a catchment, which is crucial for managing water resources and flood forecasting [34]. Rainfall-run-off models can be classified into three categories: empirical, conceptual, and physical process-based models [35]. Information on rainfall-run-off models is provided in Table 2.

Table 2. Information on rainfall run-off models.

Model Type	Description	References
Conceptual Models	Based on simplified representation of hydrological process	[36,37]
Physical Process-Based Models	Based on a detailed understanding of the physics of hydrological processes	[38,39]
Empirical Models	Based on statistical relationships between rainfall inputs and observed run-off outputs	[40]

4.2. Hydraulic Modeling Techniques

Numerical flood models are computer simulations that employ mathematical and computational techniques to simulate the behavior of water during a flood event [41]. Typically, models use numerical algorithms to solve equations that characterize the flow of water in a river or stream, considering variables, such as rainfall, run-off, channel geometry, and riverbed roughness. There are several software programs available for numerical flood modeling, including:

i. HEC-RAS—This software, made by the US Army Corps of Engineers, is used to simulate the hydraulics of river systems in both one and two dimensions [42].
ii. MIKE FLOOD, made by DHI, is used for the two-dimensional and three-dimensional hydraulic modeling of floodplain and river systems [43].
iii. TUFLOW, also made by DHI, is used for the two-dimensional and three-dimensional hydraulic modeling of floodplain and river systems [44].
iv. Flood Estimation Handbook (FEH) models—Developed by the United Kingdom Environment Agency, these models are used for rainfall-run-off modeling and flood frequency analysis [45].
v. Environmental Protection Agency's (EPA) Environmental Fluid Dynamics Code (EFDC)—This software, developed by the United States Environmental Protection Agency, is used for three-dimensional hydraulic and water quality modeling of surface water systems [46].

Table 3 provides the application of flood management systems in flood.

Table 3. Numerical models in flood management systems

Model	Application in floods
HEC-RAS	i. Riverine floodplain modeling and study are possible. ii. Used to assess the effects of various floodplain management methods. iii. It is used to assess the effects of planned developments on floodplain conditions.
MIKE FLOOD	i. Can be used for riverine and coastal floodplain modeling and analysis. ii. Can be used to evaluate the impacts of different floodplain management strategies. iii. Can be used to evaluate the impacts of proposed developments on floodplain conditions.
TUFLOW	i. Can be used for riverine and coastal floodplain modeling and analysis. ii. Can be used to evaluate the impacts of different floodplain management strategies. iii. Can be used to evaluate the impacts of proposed developments on floodplain conditions.
Flood Estimation Handbook (FEH) models	i. Can be used for flood hazard assessments and floodplain mapping in the UK. ii. Can be used to support floodplain management and planning decisions in the UK.
Environmental Protection Agency's (EPA) Environmental Fluid Dynamics Code (EFDC)	i. Can be used for riverine and coastal floodplain modeling and analysis. ii. Can be used to evaluate the impacts of different floodplain management strategies. iii. Can be used to evaluate the impacts of proposed developments on floodplain conditions.

4.3. Multiple-Criteria Decision Analysis-Based Flood Management Approaches

Multiple-criteria decision analysis (MCDA) is a technique used to help decision-makers make well-informed decisions when faced with complex and conflicting decisions, such as those involved in flood management [47]. The MCDM process considers both quantitative and qualitative considerations [48]. In terms of flood management, MCDA is used to evaluate and compare different flood-control possibilities, including structural measures, non-structural measures, and land use planning, based on a variety of criteria, such as to minimize the risk of damage due to floods or to reduce the impact caused by a flood event [49]. Here is the classification of some MCDA methods and their description is given in Table 4.

These are some techniques that are used for flood disaster management with several methods. Flood modeling is a complex process that involves predicting and analyzing how floods will impact a specific area through numerical models, data, and simulations. The primary goal of flood modeling is to understand the physical mechanisms behind floods and forecast their behavior and effects, including water levels, flow patterns, inundation extent, and damage assessment. These valuable data generated by flood models aid in creating mitigation and adaptation strategies and assessing flood risks. However, flood modeling comes with its share of challenges that can affect the accuracy and reliability of the models. Let us explore some of these difficulties:

Table 4. Description of MCDS techniques.

Technique	**Description**	**References**
Value/utility function methods	These techniques involve developing a function that rates each option's value or utility following how well it fulfills each criterion. Multi-attribute value theory (MAVT) [50] and multi-attribute utility theory (MAUT) [51]] are two examples of value/utility function methods. It serves to assess and compare various flood mitigation options based on a variety of criteria including cost, effectiveness, environmental impact, and social acceptance.	[50,51]
Pairwise comparison methods	In these approaches, the options are ranked by making pairwise comparisons of the way each option compares to others in terms of how well it fulfills each criterion [52]. The analytic hierarchy process (AHP) [53] and the analytic network process (ANP) [54] are two examples of pairwise comparison techniques. These techniques are used to prioritize emergency response actions, such as evacuation, rescue, and relief efforts, during a flood event [55]. They compare the efficacy of various response actions based on factors such as speed of response, responder safety, and the affected population.	[52–55]
Outranking techniques	These techniques evaluate each alternative to every other option in terms of how well they fulfill each criterion to identify which possibilities "outrank" others [56]. Outranking techniques include, for example, the elimination and choice expressing reality (ELECTRE) approach and the preference ranking organization method for enrichment evaluation (PROMETHEE) [57]. Based on a range of criteria, such as accuracy, computational complexity, and data accessibility, these strategies are used to choose the optimal flood forecasting model	[56–59]
Distance-based methods	These methods involve calculating the distance between each option and an ideal solution, and then ranking the options based on these distances. The technique for order of preference by similarity to the ideal solution (TOPSIS) [60] and the weighted aggregated sum product assessment (WASPAS) methods [61] are two examples of distance-based methods. The methods are used to assess the risk of flooding in various areas and determine the best flood management strategies [62].	[60–62]
Fuzzy decision-making methods	These approaches involve incorporating uncertainty or imprecision into decision-making [63]. To deal with uncertainty in criteria weights, preference values, and rankings, fuzzy logic, and fuzzy set theory can be used [64]. The MADM method chosen will be determined by the nature of the decision problem, the number and types of criteria, and the decision-maker's preferences [65].	[63–65]

i. One major hurdle in flood simulation is the availability and quality of data. Flood models require various types of data, such as topographic information, land use data, hydrological information, and historical flood data. The accuracy and reliability of the models heavily depend on the quality and completeness of the data used. Sometimes, the data may be outdated, conflicting, or even non-existent. For instance, topographic information might not reflect the current local environment accurately. In regions with limited monitoring networks, hydrological data like precipitation and stream flow may be unreliable. To overcome this, efforts should be made to update and improve the data used for flood modeling. This can be achieved by establishing new monitoring networks, enhancing data collection, and processing methods, and incorporating satellite data and remote sensing technologies.
ii. Flood models vary in complexity, ranging from simple empirical models based on a few factors to intricate hydraulic models that replicate underlying physical processes. The complexity of models can impact their precision, reliability, and computational efficiency. Complex models can better simulate the detailed physical processes of floods, but they require more information, processing power, and expertise to construct and operate. On the other hand, simple models are easier to develop and maintain, but they may not capture the intricacies of flood processes adequately. A balance must be struck between the complexity of the models and the availability of data and computing resources to achieve the best results. Often, a combination of basic and complex models is used.
iii. Model uncertainty is another factor that can impact the accuracy and reliability of flood models. Uncertainty can arise from unpredictable data, the complexity of flood processes, and limitations within the models themselves. Sensitivity analysis helps understand how model parameters influence flood simulation outcomes, while Bayesian inference and Monte Carlo simulation update model parameters and evaluate model uncertainty using prior information and observational data.

5. Materials and Methods

5.1. Proposed Solution

The approach used in this study comprises incorporating information from various event logs, languages, and models utilizing integrated environment models. In addition, the observation requirements of the various phases of the event are examined, culminating in a meta-model of an abstract full life-cycle of a natural disaster event based on meta-objects. It aims at satisfying all emergency information needs. Giving information for only one or two stages of an emergency is not enough. Utilizing thorough life cycle information support can help manage or rapidly address a situation. In this context, the term 'complete life cycle' refers to all stages of event initiation and development. The article highlights the novel and distinctive features of the proposed flood risk management system in the following ways:

- The full life cycle natural disaster event model (FLCNDEM), a novel and sophisticated model for simulating the behavior of floodwaters, is used by the system. The FLCNDEM considers a broader range of factors that can contribute to flooding than conventional models, including climate change, urbanization, and land use change. As a result, the system is better equipped to estimate the likelihood of floods. To automate the process of creating and assessing flood mitigation measures, the system also makes use of metamodel support.
- The system can explore a large range of potential solutions rapidly and effectively with the help of a metamodel, and it can also find the most practical and affordable options. As a result, the system is better able to create and implement flood mitigation strategies.

The FLCNDEM can be used to determine locations that are at risk of flooding and to evaluate the possible effects of flooding. This information can be used to design and implement more efficient flood mitigation measures. Automating the process of creating and assessing flood mitigation strategies with metamodel help can increase efficiency and effectiveness. The following are some possible benefits of the suggested approach:

- The utilization of FLCNDEM and metamodel support enables a more precise and reliable flood hazard assessment, enhancing our ability to predict flood patterns, potential damages, and evacuation requirements.
- By considering the entire life cycle of a disaster, our approach emphasizes preparedness and proactive measures, minimizing the impact of flood events and reducing vulnerability.
- The integrated approach allows for adaptive and flexible flood management strategies. As flood patterns evolve or new data becomes available, the system can be updated and adjusted accordingly to improve resilience.
- The optimization of resources and better decision-making for our system.

5.2. Objectives of the Proposed Approach

We consider the following objectives for this work:

- To propose a novel flood disaster management system (FDMS) using the FLCNDEM as the abstract model based on the function super object.
- To integrate data from existing flood protocols, languages, and patterns into the proposed FDMS to enhance preparedness and response during various phases of a flood event.
- To construct a task library and knowledge base to initialize the FLCNDEM, leading to an FLCDEM flooding response.
- To improve emergency response by offering a comprehensive framework for flood management, which includes pre-disaster planning, real-time monitoring, and post-disaster evaluation.
- To modify the proposed system to accommodate various flood scenarios and enhance global flood management.

5.3. Significance of Proposed Approach

A modern strategy can assist flood management systems for a variety of reasons. Real-time monitoring, made possible by technologies, such as sensors, drones, and satellite imaging, enables the early detection of potential flood hazards and the speedy reaction to an impending disaster. Data-driven decision-making is also possible when data from real-time monitoring is used. This information can be used to forecast the possibility of floods and create evacuation preparations. Modern technology facilitates immediate communication by enabling the rapid transmission of flood information and the coordination of relief activities. Cooperation among the numerous authorities and groups involved in flood management can also be improved with contemporary technology, enabling a more coordinated response. Finally, flood management systems can respond faster and more efficiently by harnessing contemporary technology and data, decreasing the impact of floods on the impacted population, and potentially saving lives. Given below diagram can help to understand how problem-solving is performed by using a model-driven approach.

Here is the discussion of the feasibility and applicability of the system. That is how it can be adopted and how it can improve the efficiency of existing flood systems. Some points are described as:

i. The proposed system is feasible because it is based on existing technologies and methodologies. The disaster event meta-model is a well-established concept, and metamodel support is a well-established technique for automating the process of developing and evaluating flood mitigation measures.
ii. The proposed system applies to a wide range of flood scenarios. The disaster event meta-model can be used to represent a variety of flood events, including flash floods, riverine floods, and coastal floods. The authors also state that the system can be adapted to specific flood scenarios by parameterization of the meta-model.

iii. The proposed system can be used to improve the efficiency of global flood management by:
- Identifying areas that are at risk of flooding.
- Assessing the potential impacts of flooding.
- Developing and evaluating flood mitigation measures.
- Communicating with stakeholders.

5.4. System Architecture and Components of FDM System

The FDM-based natural disaster event manager contains models, manages, queries, and visualizes natural disasters. The system has physical, intermediate, business, and presentation levels. The physical layer contains all real NTEs, whereas the middleware layer converts them to virtual events. FDM-based modeling, administration, queries, and event visualizations enhance decision-making and NDEs (natural disaster events) management in the business layer. The presentation layer provides a graphical user interface through which customers may communicate and interact with the prototype system, allowing them to accomplish the operations possible in the business layer. Figure 5 shows the architecture supporting the Natural (Flood) Disaster Event Manager.

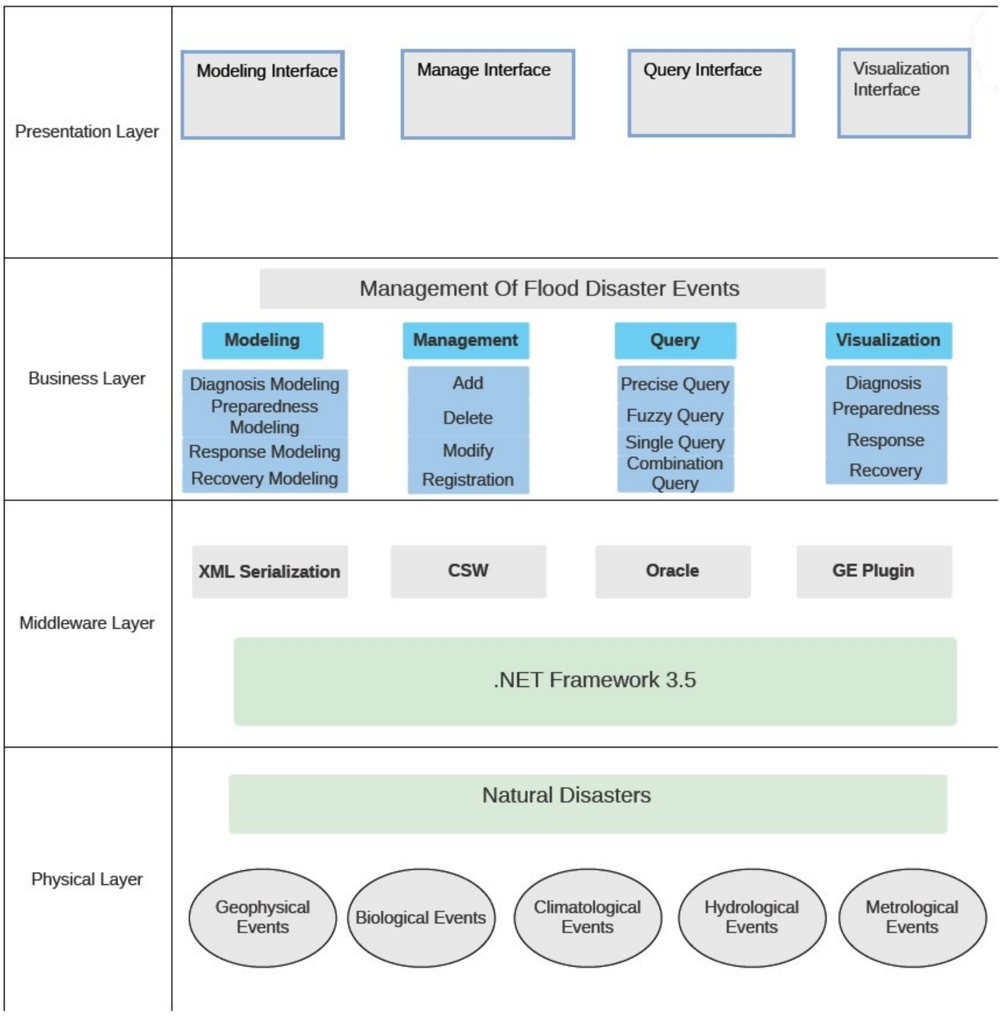

Figure 5. Architecture of the natural disaster event management system.

5.5. Model of Flood and Disaster Management

The meta-object facility (MOF) is a powerful tool for software development and modeling, featuring a four-level hierarchy that incorporates a vast array of fundamental concepts. The ability to abstract event information makes this horizontal architecture the perfect design architecture for FDM systems. The FDM design is built on a four-level MOF structure, as seen in Figure 6. NDEs of all types (geophysical, meteorological, hydrological, climatological, and biological) are accounted for at the ground-zero (M0) level of data collection.

There are M1-level models that employ nine-tuple data, descriptive elements, models for NDE representation, and event markup language (EML). Meta models, which abstractly describe the nine aspects of information description, EML, and catastrophe event representation models, are what make up the M2 level. Models for information description, modeling object meta-models, and formalization meta-models are all present at this level. The M3 level, which is a high-level abstraction of meta models, defines the fundamental ideas and connections of FDM. Class, package, and binding notions are the fundamental building blocks of modeling, and the M3 modeling layer can support a wide variety of meta-models. This four-level MOF hierarchy makes it possible to manage and model FDM systems effectively, giving disaster response and mitigation operations a potent tool.

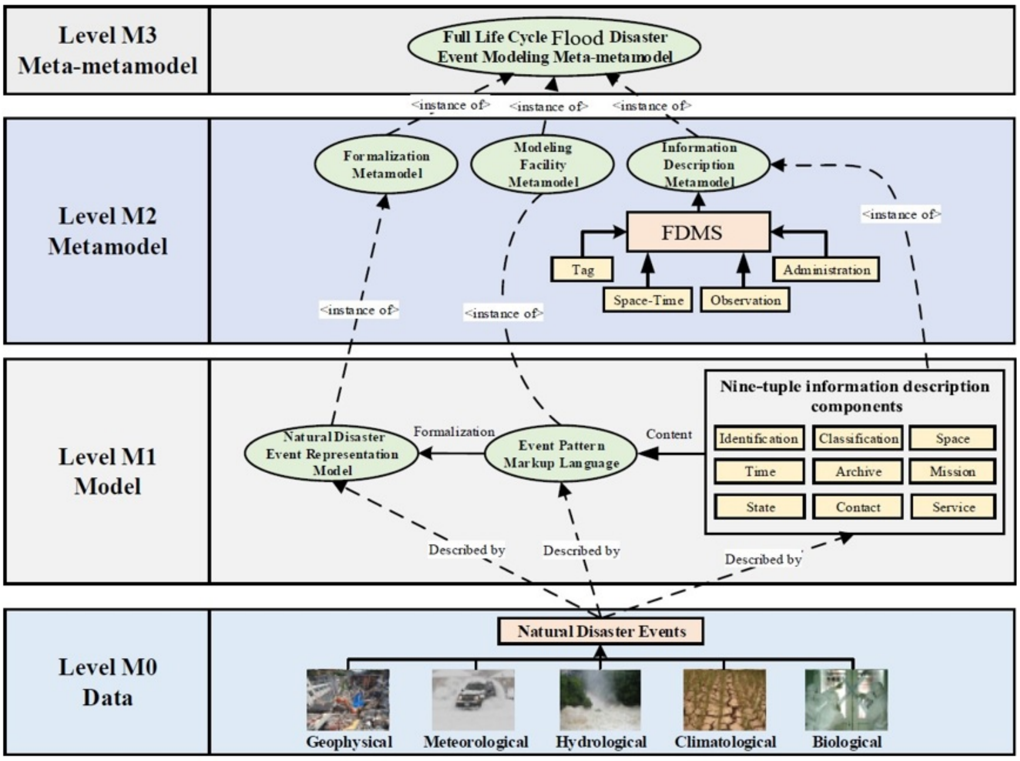

Figure 6. Meta-object facility MOF architecture with four levels for the flood and disaster management system.

5.5.1. Information Organizations of FDM System

FDM divides danger intelligence into four functions: etiquette, space-time, surveillance, and management. All representative meta-model types require tag information, which should be included in the FDM system. So that we can be prepared and take the proper measures, information concerning spatiotemporal calamities should be made available. Observation, which consists of archived data, can reflect the onset and progression of events and is crucial for planning and quick catastrophe reaction. Thus, observations ought to be noted down. When receiving confirmation or new information, management is utilized to locate the information's sender. The four FDM data points fall into the following categories:

i. Label: Information regarding the product's identification as well as its classification can be found on the label. The event ID, name, and other identities are described using credentials. The types of events in various classes are described by a classification. The criteria can assist you in locating and recognizing events. When you select an event type, the cases that are related to that event are discovered.
ii. Spatial-Temporal: geographic and temporal data are included in spatiotemporal information, which is meant to describe, respectively, the geographic and temporal elements of NTEs.
iii. Observation: The data gathered through observations are organized into three categories: archives, missions, and reports. The three different sorts of information change depending on the event's nature and stage.
iv. Administration: Administration information includes contact information and information about the service. Event sender contact details and event service information are recorded. Information is used to record event service details.

Figure 7 shows the arrangement of information in flood disasters even meta-models regarding dangers.

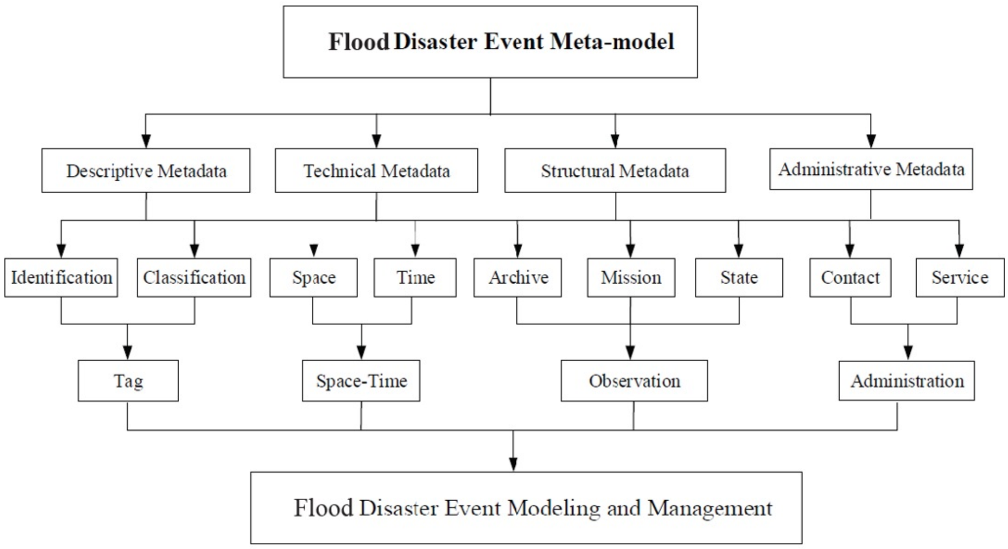

Figure 7. Arrangement of information regarding dangers.

5.5.2. Observation Needs from Different Event Stages

The requirements for monitoring change as a crisis progresses since each stage has a distinct goal. Regular monitoring is an essential responsibility throughout the diagnosing phase. Consequently, real-time detection of the most imminent disaster triggers. Monitoring precipitation during floods is extremely important. Understanding the distribution of roadways, residential areas, courtyards, and other elements is also crucial for comparative study. Predicting the magnitude of catastrophe components and the timing and location of the event are the primary responsibilities during the preparatory phase. By overlaying the land use situation with the scale of the disaster area during the response stage, the diagnostic phase can be utilized for evaluating the existing roadway situation and likely places of trapped people.

An evaluation of the damage is necessary before moving on to the recovery phase, and it should primarily focus on fatalities, financial losses, and other effects like environmental damage and farm floods. The specific information needed for each stage of an emergency is shown in Figure 8 while responsibilities associated with flood disaster management are given in Table 5.

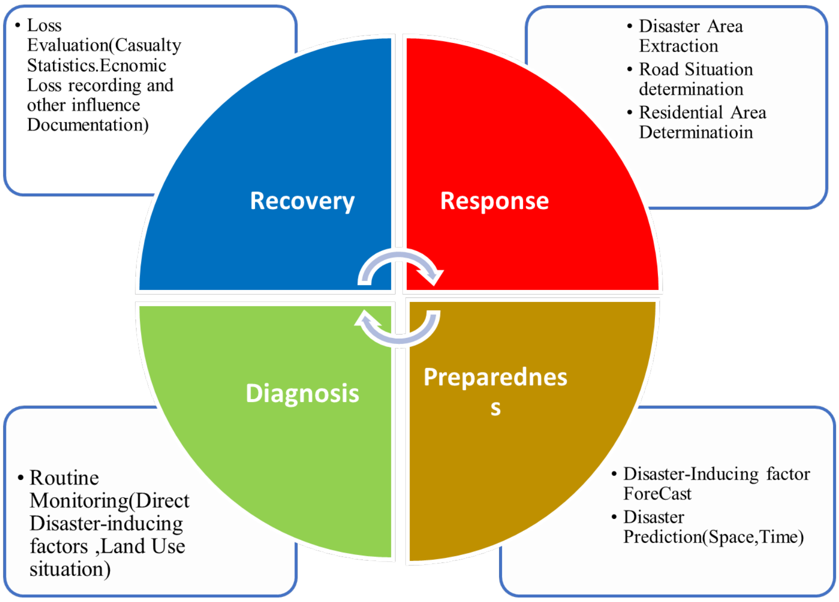

Figure 8. Requirements for observation at various emergency stages.

Table 5. Responsibilities and associated activities with flood disaster management.

Before disaster events	Disaster-free situations	• Disaster management planning, • Risk reduction, • Prevention, • Integration into development planning, • Risk analysis requirements, • Spatial structure plan implementation and enforcement, • Education and training, • Technical standard requirements.
Disaster risk		• Early warning, • Alertness, • disaster mitigation.
Crisis response	No subsets	• Quick location, damage, and resource assessment, • Declare disaster emergency, • Evacuation of a disaster-stricken neighborhood, • Needs, • Protect vulnerable group, • Immediate recovery of vital facilities and infrastructure.
After disaster event	Recovery	• Improve disaster region environment, • Rebuild public facilities and infrastructure, help communities repair homes, socio-psychological recovery, healthcare, • Reconciliation, conflict settlement, socioeconomic, cultural, and security and order restoration.
Rehabilitation		• Rebuilding infrastructure and social facilities, reviving socio-cultural community life, • Design with better, disaster-resistant equipment, • Join social groups, businesses, and communities, • Improve social, economic, and cultural circumstances, public service functions, and other basic services.

5.6. Content of Flood and Disaster Management

The FDM system is made up of several information elements and a nine-part information description structure. The components are given in the following while their benefits are described in Table 6.

Table 6. Component with their benefits concerning flood disaster management.

Component	Benefits
Pre-disaster Planning	• Effective risk assessment to identify vulnerable areas and high-risk zones. • Early warning systems for timely alerts to communities and emergency responders. • Strategic resource allocation, positioning essential supplies and personnel. • Community engagement and awareness, fostering resilience.
Real-time Monitoring	• Timely data acquisition, providing up-to-date information on flood conditions. • Early detection of flood events, allowing for rapid response and evacuation. • Continuous monitoring of flood developments to adjust mitigation strategies. • Improved situational awareness for better decision-making during emergencies.
Post-Evaluation	• Assessment of response effectiveness and identification of areas for improvement. • Understanding the impact of floods on communities and infrastructure. • Learning from past events to enhance future flood management strategies. • Data-driven insights to support policy making and resource allocation.

i. Identification: Consists of the event's name, ID, and a succinct description. The ID remains constant throughout the event's development stages, whereas the name and description change according to the event's stage and category.

ii. Classification: The categorization, certainty, urgency, pattern, and severity of the occurrence are all included in this section. While urgency, certainty, and severity are inherited from the common alerting protocol (CAP), the category is the same as MOF. CAP is a standard data format used to exchange emergency alerts and public warnings between various alerting systems. It is designed to ensure interoperability among different emergency communication systems and devices. Values for patterns can be straightforward, intricate, timed, or repeated.

iii. Space: These geographical occurrences, like natural disasters, require spatial information. This information may be expressed as exact place names or coordinates of the location.

iv. Time: All meta-models require time information, which is supplied in FDM using the geography markup language (GML). Archive information comprises text and e-mail messages, as well as the names and locations of text information and e-mail message websites.

v. Mission: Real-time monitoring is critical for event planning and response, and missions are established for distinct phases.

vi. Status: Status is a summary of all phase-based observations that show the event's status, which varies depending on the phase of the event.

vii. Contact: This area comprises the name, organization, zip code, address, phone, fax, and email of the event's sender and can be used to validate details and seek additional information.

viii. Service: This part gives readers information about the publisher, the kind of publication, and the location. Name, nature, and address of the service are the three categories.

This FDM system content gives a holistic picture of flood management by integrating critical information such as identification, categorization, space, time, logs, mission, status, contact, and service information. This knowledge can be applied to various flood scenarios and enhance global flood management.

5.7. Stages of Flood Events Phases

Floods come in many different forms, each with a unique set of traits, objectives, and circumstances that correspond to different periods of time. To demonstrate this, consider a flooded lake in Hubei, China, a country known for its many lakes. In the case of a flood, the information stored comprises ground and stream information relevant to each type of flood. For lake flooding, subsurface information comprises population, economic, topographical, and land feature facts obtained in government documents or online. Typically, information on maritime flood care includes vital details on medications, fire, and rescue crews, and the potential help of extra services like electricians and plumbers. Regular monitoring and the detection of anomalies are the primary tasks throughout the diagnosis phase. Rainfall and water levels are direct causes of flooding and are thus regularly monitored. Understanding land use status is essential for developing an overlay study after a natural disaster. Precipitation statistics, water level assessments, and land use evaluations are all tasks of the diagnosis phase.

The status item showing whether the observation value exceeds the threshold summarizes the diagnosis procedure. In the planning phase, the primary objective is to predict the spatiotemporal occurrence of flooding; consequently, precipitation and water level forecasts are required. Precipitation forecasts and water level projections are included in standby phase missions, while status information includes possible flood extent, prospective flood time, and flood alerts.

During the intervention (Response) phase, the primary goal is to save the people. Flood zone delineation and feature extraction including the identification of damaged highways and the isolation of residential zones, are thus critical responsibilities. The status data comprise a flooded region, a damaged road, and a damaged structure.

The fundamental goal of the rebuilding (recovery) phase is to evaluate the victims. During the diagnosis stage, all land features must be categorized with respect to how the area is used. The number of causes, revenue losses, and additional impacts of the disaster must also be decided. The flood protection activity library is created by all teams and countries that help build the FDM system. Table 7 summarizes the missions and states at various stages of a flood.

Table 7. Purposes and conditions throughout various flooding stages.

Phase	Mission	State
Diagnosis	Precipitation statistics Water level determination Land use	Status
Preparedness	Precipitation statistics Water level determination Precipitation forecast Water level prediction	Possible spatial range Possible temporal range Flood alert
Response	Precipitation statistics Water level determination Flooded area determination Feature extraction	Flooded area Damaged road Destroyed construction
Recovery	Precipitation statistics Water level determination Loss assessment	Casualty Economic loss Other influence

6. Results and Validation

6.1. M2 Level Meta Model of Flood Disaster Management System

The proposed meta-model of an FDM system is a conceptual model that describes the structure and behavior of an FDM system. It defines the various components of an FDM system, their relationships, and the interactions between them. The meta-model is used to help understand, design, and optimize the FDM system.

The meta-model of an FDM system typically includes the following components:

i. Factors inherent to flood hazards, such as precipitation, river flow, and geography, all play a role in increasing the likelihood of flooding.
ii. The component of 'response and recovery', includes the non-physical or intangible activities that are offered as part of the FDM system, such as emergency response, evacuation plans, and recovery efforts.
iii. The component of 'infrastructure', including the physical and digital resources needed to deliver the FDM system, such as emergency shelters, transportation systems, communication networks, and information systems.
iv. The component of 'users', includes individuals or organizations that interact with the FDM system, including government agencies, emergency responders, and citizens.
v. The component of 'Value proposition', refers to the unique value that the FDM system offers to its stakeholders, such as increased safety, reduced damage, and improved recovery.
vi. The component of 'lifecycle' includes the stages of the FDM system, from design and development to implementation, maintenance, and end-of-life.

An FDM system meta-model can be used to assess the strengths and limitations of existing flood management models and to create new models that better suit the needs of stakeholders. It can also be used to optimize the performance of the FDM system by identifying opportunities for improvement and innovation. The meta-model depicting the FDM system is made using software tools such as Obeo-Designer, and it represents the essential concepts and relationships of the FDM system.

Figure 9 shows the M1 level meta model without attributes and operations. While considering operations and attributes in a figure in the context of model-driven architecture, it would typically represent the platform-independent model (PIM) at the M1 level, where the system's design is refined and tailored for a specific technology platform. Figure 10 illustrates the M2 level meta model diagram of the proposed FDM system where operations and attributes are considered in a figure in the context of model-driven architecture, and represent the platform-specific model (PSM) at the M2 level. Here the system's design is refined and tailored for a specific technology platform.

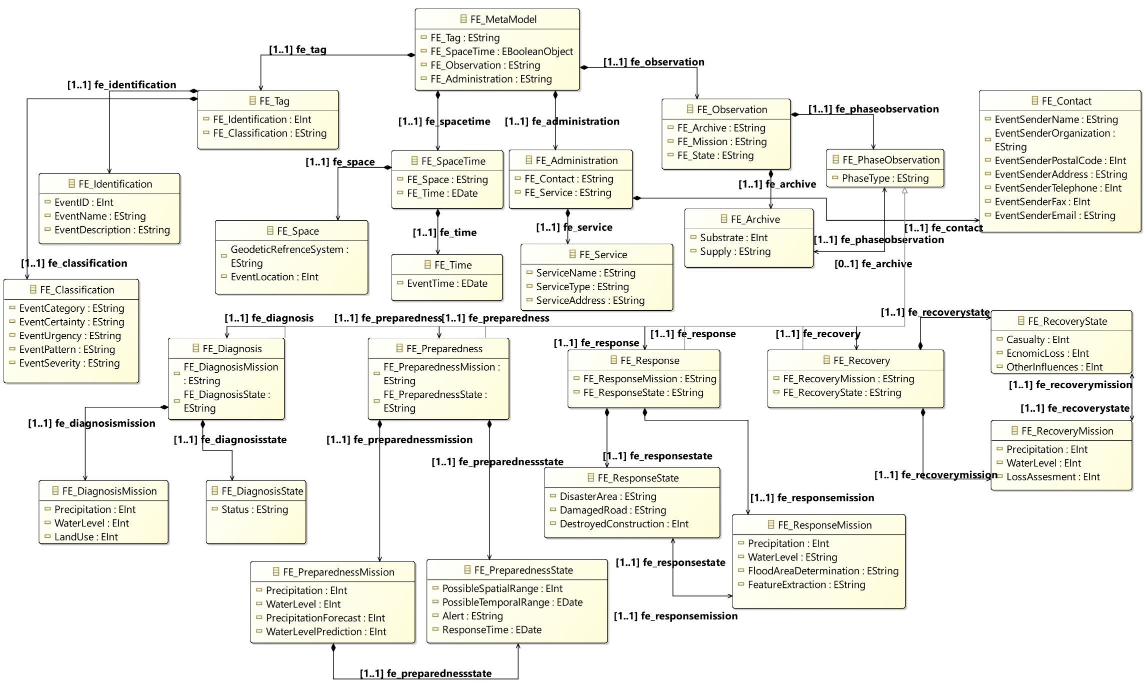

Figure 9. M1 level meta model without instances (attributes and operations).

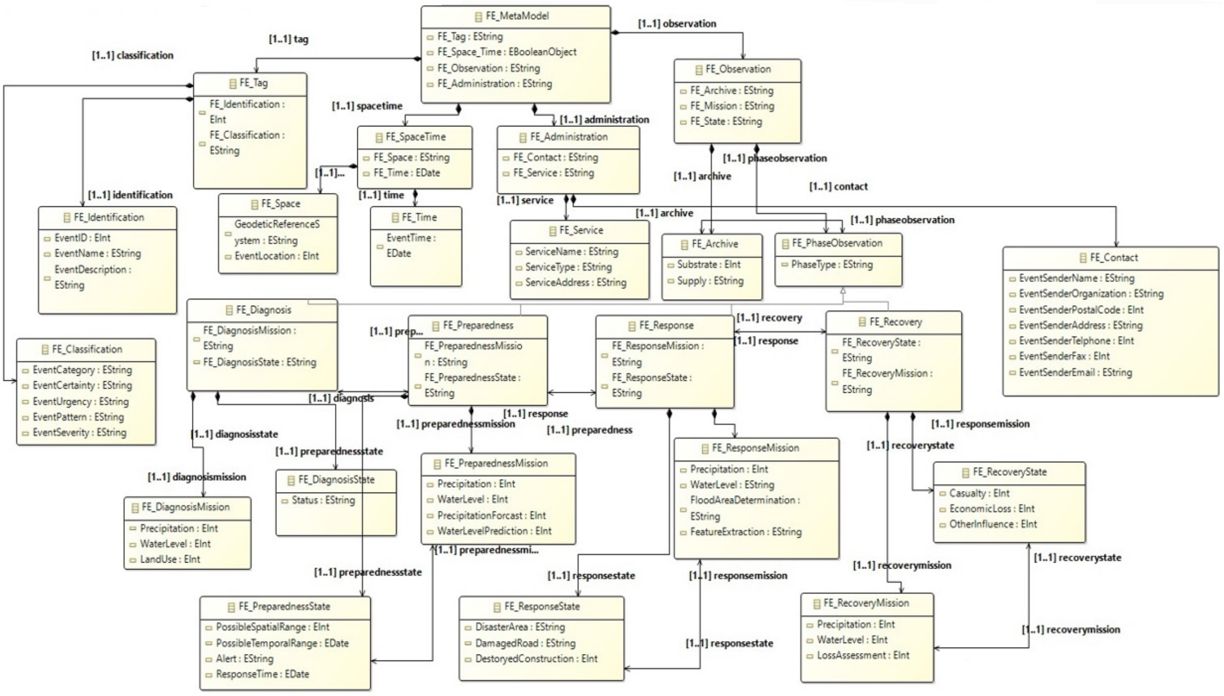

Figure 10. M2 level meta model diagram of FDM system; FE denotes a flood occurrence.

The Ecore tree view shows the tree view of the proposed flood and disaster management system. The instances can be represented in a tree view that can be generated in Ecore using OBEO Designer Community, as shown in Figure 11.

Figure 11. Tree view diagram of FDMS for the flood.

6.2. Validation

Checking the FDM system through case studies in meta-modeling can be an efficient technique to ensure that the final model accurately represents the real-world flood disaster management system being modeled. In this work, the checking of the proposed system has been completed within the context of the Sirius editor, which serves as a tool for modeling and simulating the behavior of the FDM system. The target achieved by checking the approach in Sirius enables us to ensure that the designed model conforms to the intended meta-model and accurately represents the envisioned FDM system. In this regard, the FDM system proceeds as follows:

i. Step 1: Identify the problem or system being modeled, in this case, the FDM system.
ii. Step 2: Design the meta-model that will represent the FDM system. This meta-model should incorporate all the FDMS's significant variables, inputs, and outputs.
iii. Step 3: Choose a case study that reflects a realistic scenario of flood catastrophe management that can be applied to the meta-model. This case study should be chosen based on its resemblance to real-world scenarios.
iv. Step 4: Assign the inputs, outputs, and other relevant variables to the meta-model that are specific to the chosen case study.
v. Step 5: Put the meta-model into action, set constraints, and validate it by creating instances. This entails generating instances of the classes (such as flood level, available resources, evacuation routes, etc.) defined in the meta-model and populating them with sample data. Disagreements between the meta-model and the FDM system restrictions or rules must be found and resolved.

Once the meta-model adequately depicts the FDM system, it can be validated by testing it on a different flood disaster management scenario to confirm that it is adaptable and effective in a variety of conditions. This procedure helps to ensure that the FDM system is dependable and effective in managing flood disasters and that the meta-model appropriately depicts the real-world system it is designed to simulate. We validated the proposed system in Sirius editor; a tree view of the entire meta-model of the proposed FDM system is shown in Figure 12. The screenshots of model validation by the OBEO Designer Community are shown in Figures 13 and 14.

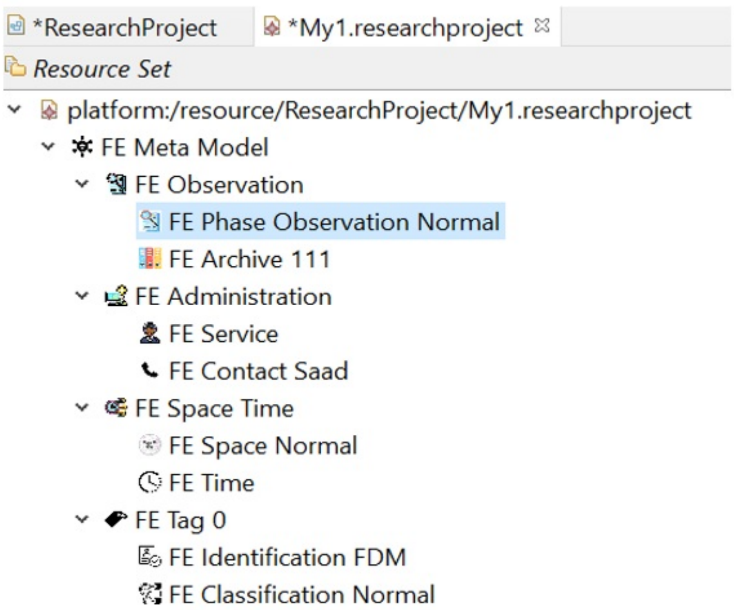

Figure 12. Tree view diagram of FDM system for the model in Sirius.

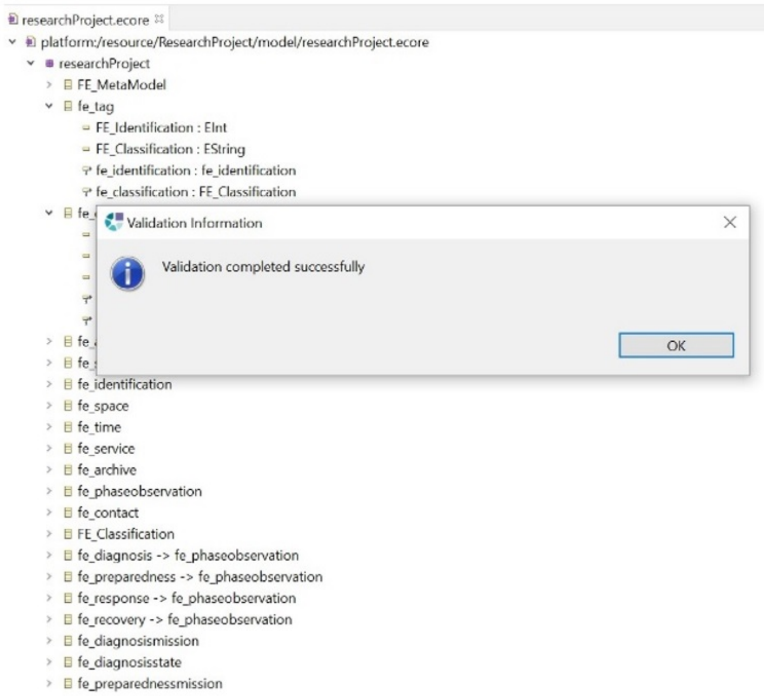

Figure 13. Validating the connections of the meta-model.

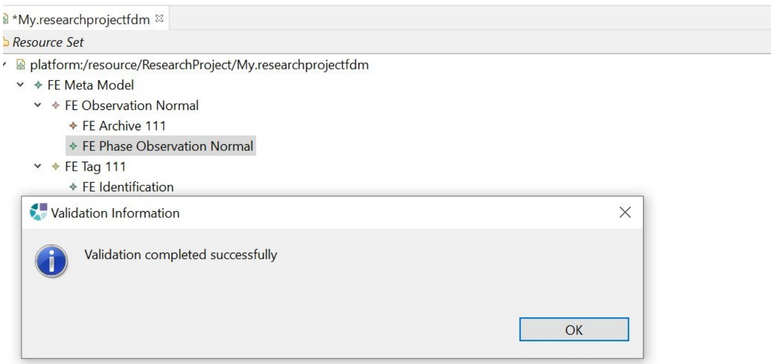

Figure 14. Validating the connections of meta-model in Sirius.

7. Conclusions

In the current research, we proposed the use of comprehensive disaster management, called the FDM information sharing and data preparation system, to enable effective detection, warning, reaction, and recovery. The system is built on a catastrophe event meta-model developed with the meta-object facility framework. An FDM system can integrate numerous sources of historical data and information to give early warning, rapid reaction, and the minimization in loss of life and economic loss. More research, however, is essential to improve the efficacy as well as effectiveness of the FDM system. There is a need to summarize all missions and remote sensing data for many types of natural disasters, as well as to do an additional study into how historical data may be efficiently integrated with the FDM system for early warning, rapid response, and the reduction of the loss of lives and economic losses. Furthermore, the system can be improved by employing formal languages, like EML, to formalize the FDM system and by establishing online and mobile applications to integrate data from a variety of sources for disaster reporting and response.

The conclusions of this paper may open several new study directions. First, the suggested meta-model in this article needs to be improved and enhanced to include additional types of disaster events and enable more effective integration of historical data and information. Second, the use of formal languages, such as EML, should be researched further to improve the effectiveness and efficiency of the FDM system. Also, establishing web and mobile applications that can combine information from many sources for disaster reporting and response is important to an FDM system's effectiveness. As a result, future research should concentrate on building and testing these applications to guarantee that they are simple to use and can handle massive volumes of data. Overall, the creation and improvement of the FDM system have considerable potential to improve disaster management and lessen the effect of natural disasters.

Funding: This research was supported by the European University of the Atlantic.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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