# A Systematic Analysis of Flood Ontologies: A Parametric Approach

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**Abstract:** The article identifies the core literature available on flood ontologies and presents a review on these ontologies from various perspectives like its purpose, type, design methodologies, ontologies (re)used, and also their focus on specific flood disaster phases. The study was conducted in two stages: i) literature identification, where the systematic literature review methodology was employed; and, ii) ontological review, where the parametric approach was applied. The study resulted in a set of fourteen papers discussing the flood ontology (FO). The ontological review revealed that most of the flood ontologies were task ontologies, formal, modular, and used web ontology language (OWL) for their representation. The most (re)used ontologies were SWEET, SSN, Time, and Space. METHONTOLOGY was the preferred design methodology, and for evaluation, application-based or data-based approaches were preferred. The majority of the ontologies were built around the response phase of the disaster. The unavailability of the full ontologies somewhat restricted the current study as the structural ontology metrics are missing. But the scientific community, the developers, of flood disaster management systems can refer to this work for their research to see what is available in the literature on flood ontology and the other major domains essential in building the FO.

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## 1.0 Introduction

A natural disaster like a flood is a serious and recurring event. It results in loss of life, destruction of infrastructure, economic losses, disruption of normal life, food, water scarcity, loss of physical communication, traffic congestions, spreading of physical diseases, etc. Newly available technologies need to be adopted and applied to flood disaster management operations to cope with the flood. A pertinent question is, even though knowledge about flooding and the vulnerability of a place exists, for instance, consequences of major emergencies still are not minimized. According to Xu and Zlatanova (2007), when a flood hits a place, immediate resource allocation is required to minimize the damage and get the situation under control. And it depends on how the different departments, organizations— government or non-government—, teams, and individuals co-operate among themselves, which could lead to the use of different types of tools and technologies involved in collecting and recording the data, resulting in the problem of interoperability of communication between them. The problem of interoperability of communication between different organizations and data integration from different systems and tools has been highlighted by Othman and Beydoun (2010). From the discussion, it can be understood that although there exists knowledge regarding flooding, the swift organization, processing, dissemination, and communication of that knowledge is essential for prompt, proper flood disaster management (FDM). The lack of structured and organized knowledge results in delayed decision making, which underscores the need for knowledge organization in the domain. In this context, a very recent work by Yang and Wu (2019) may be mentioned. They developed a taxonomy of earthquake response and recovery for organizing and sharing earthquake-related online information resources. However, the work is limited in scope as the taxonomy is useful in classifying and organizing the objects, but it cannot support automatic information processing and reasoning in decision making by the software tools. This can be achieved with the help of the most progressive form of knowledge organization, i.e., ontology ("a formal and explicit specification of a shared conceptualization" (Gruber (1992)). The closeness of the relationship between ontology and knowledge organization has been explored by Marcondes (2013) and Herre (2013), whereas the increasing significance of ontologies in knowledge organization has also been argued in Turner (2017) and Ribeiro and Silva (2018). Ontology allows structuring and logical representation of knowledge, expressing the explicit relationships between concepts and relationships between entities and their properties, which enables knowledge to be machine-processable for better information retrieval. Ontology-driven systems have gained popularity as they enable semantic interoperability, flexibility, and reasoning support (Schulz and Martínez-Costa 2013). The general notion is ontology acts as the backbone of structured knowledge models. It can help in mapping and merging information from different domains for developing a model with semantic integrity. There have been works where ontologies have been utilized for semantic knowledge management, such as the work by Richard et al. (1998) on implementation of ontologies for knowledge management for the people in an organization so that knowledge access becomes smarter. López de Vergara et al. (2002) proposed an approach where an ontology-based management information meta-model was used to map between different network management models (e.g., the internet network management model, also known as SNMP, and the OSI network management model, also known as CMIP). Bodenreider (2008) examined a few of the existent biomedical ontologies to elucidate the roles played by them in knowledge management, data integration, exchange and semantic interoperability, and decision support and reasoning. In a similar fashion, ontologies play important roles in designing smart and intelligent FDM systems as illustrated in Section 2.0.

The objective of this work is to identify the core literature in the area of flood ontologies (FOs) that have been built for supporting the flood disaster management system (FDMS) or have conceptualized the domain of flood. We also aimed to investigate the current state of the available FOs and describe them at a granular level from various perspectives (e.g., purpose, design methodology, knowledge representation formalism, disaster phase, etc.). The primary implications of this work are: to act as a one-stop point for available FOs and to know whether they can be (re)used or if the ontologies need to be built from scratch to suffice the objective. The scientific community and the developers of FDMS can refer this work for their research to not only see what is available in the literature regarding FOs but also to find the other related domains essential in building FOs. The work allowed us to explore the various aspects of flood disaster that have been managed with the help of ontologies like forecasting flood or monitoring the flood phases while also exploring the lacunas like unavailability of resource ontologies for supporting the disaster situation. The major contributions of this work are:

- Provides a general methodology for identifying the core literature and the review of ontologies, which can be applied with the same objectives in other domains like food, medicine, etc.
- Identifies the core literature in ontology supported FDMS.
- Provides a list of parameters that can be used to describe the ontologies concisely.
- Description and summarization of the available FOs at one place.
- Identifies the basic ontologies that have been extended to suit the domain of flood.
- Identifies the research gap in flood domain where more ontologies are required.

The rest of the paper has been organized as follows: Section 2 "Flood ontology and ontology-based systems" briefly discusses the FO and its uses in an FDM system. Section 3 "State of the art" discusses the similar works conducted in disaster and other domains. Section 4 "Methodology of systematic literature review (SLR)" provides the methodology followed in conducting the current study. Section 5 "Results and discussion" explains the results and findings of the study. Section 6 "Conclusion and future works" concludes the paper with observations providing the future research directions.

## 2.0 Flood ontology and ontology-based systems

FO can be referred to as a knowledge artefact used to represent the concepts, relations, and attributes related to floods obtained by studying various sources such as experts, manuals, articles, etc. As stated above, these ontologies can be used for processing flood-related information and designing the smart and intelligent information systems. The study through the literature revealed that there have been few works that have developed a FO comprising of various classes, subclasses, and properties to fulfill the specific purposes (detailed in Section 5.0). Here, we provide the glimpses of a FO and discuss the usages of FO in a FDM system.

Figure 1, produced from Almagrabi et al. 2014, depicts a Mona-ont flood emergency ontology, which includes the concepts to identify contextual information within a flood situation, such as "disaster_management_ unit" (the component responsible for looking after and tracking emergency situations), "emergency_situation" (an event that is comprised of danger information), "region" (the whole affected area that can be a city, state, or country), "point_of_interest" (the geographical features that can be man-made or natural and are part of the region that may influence the rescue operation), and "actors" (the people within the region, inside or outside the affected area(s), including the survivor, rescuer, and the user). The ontology also includes the relations, such as danger_relation (which connects "emergency_situation" and "region" to elucidate the "danger_situation" such as "closing in," "finished," "stopped," etc.), "position_relation" (presents geographic information to provide relative position information within the ontology, such as "near," "far," etc.). The ontology has been employed by a system that generates alert messaging services to actors within a disaster area to carry out the rescue operations.

FOs are being used in various systems like flood artificial intelligence (Sermet and Demir 2018), emergency decision support systems (Shan and Yan, 2017), web-based support systems (Katuk et al. 2009), component of conceptual models (Mohd Arsi et al. 2016), and hydrological monitoring systems (Wang et a.l 2017) for capturing, structuring, and organizing the flood knowledge. The systems or framework or conceptual models are then being used for making decisions during flood response, supporting communications between various agents, describing flood emergency situations, flood forecasting, analyzing various phases of the flood, etc. For example, Figure 2 furnishes an architecture of a flood artificial intelligence system for facilitating the generation of knowledge and that supports the communication of flood data and information. In this system, the flood ontology is being used by a knowledge engine to connect user input to relevant knowledge discovery outputs on flooding.

## 3.0 State of the art

Ontologies are the supporting structure for any semantic web (SW) infrastructure. In the field of disaster, ontologies have been built in order to model the knowledge better and to provide a solid organizational structure to the domain. Ontology building is a complex and time-consuming process; thus, their existence in any domain allows researchers to decide whether to use or discard them. There have been attempts where researchers tried to summarize the available ontologies in a domain to give a fair idea about them as provided here.

Liu et al. (2013) presented a systematic review of the vocabularies (e.g., ontologies, taxonomies) available in the domain of crisis management. They identified various subject areas, such as processes, organisations, infrastructure, people, and resources. The identified vocabularies

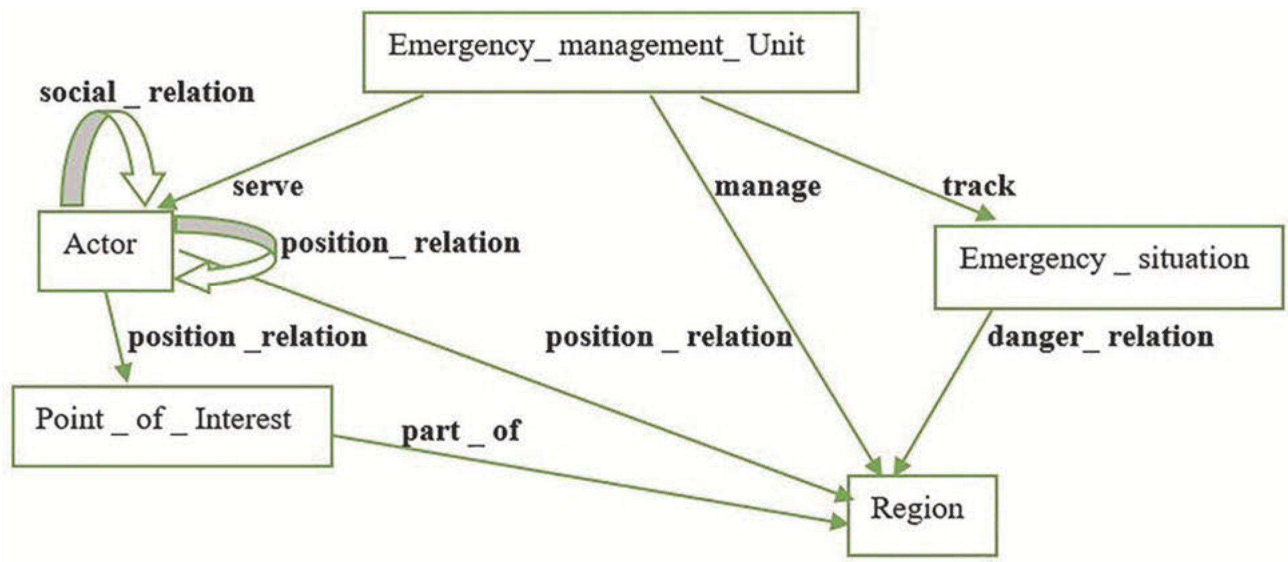


*Figure 1*. Mona-ont Flood Emergency Ontology (Almagrabi et al. 2014).

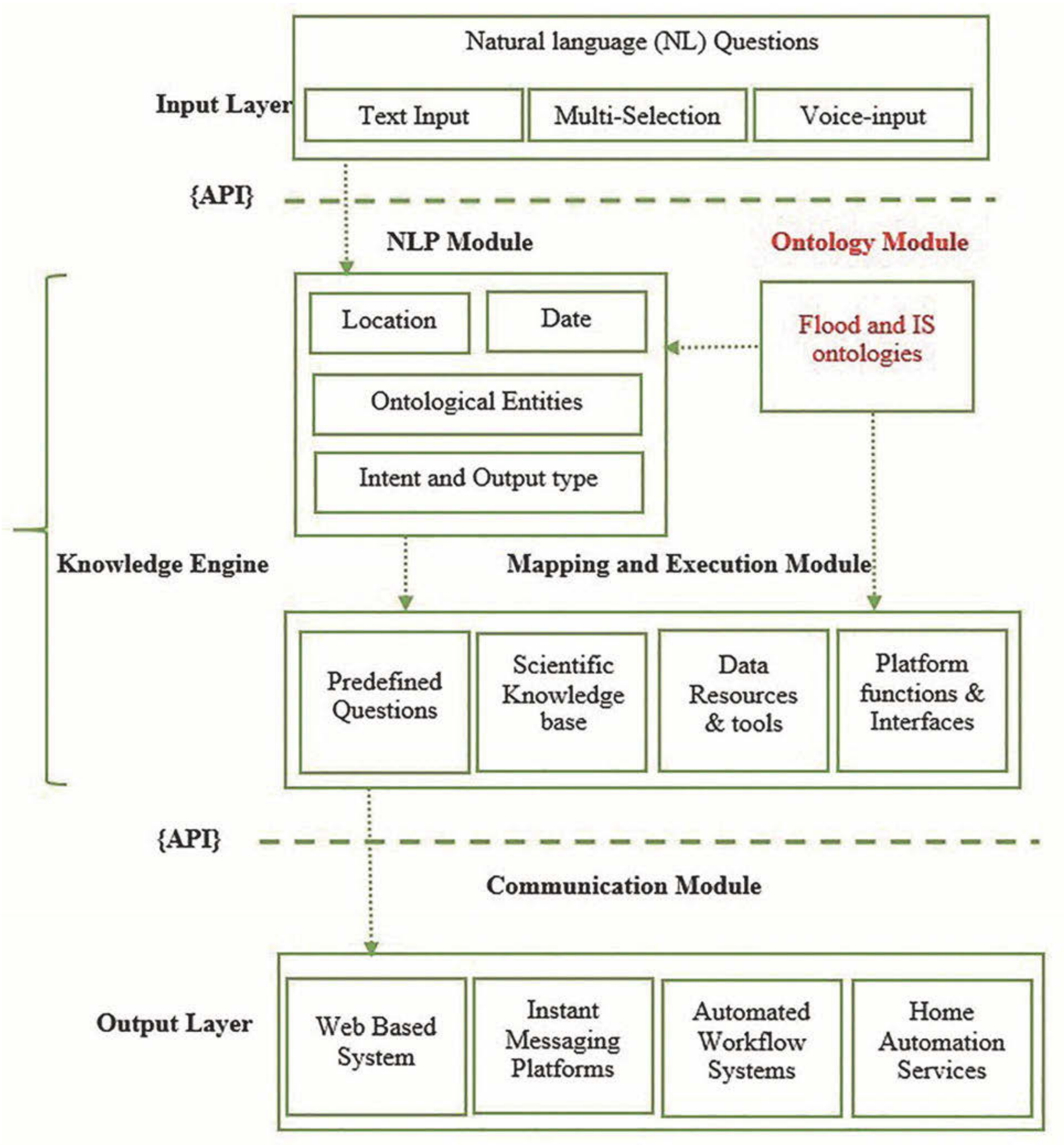


*Figure 2.* Architecture of a flood AI system (Sermet and Demir 2018).

were analyzed in terms of their coverage, design, and usability. These reviewed vocabularies are very generic in nature and not specifically designed for any particular disaster like fire, flood, tsunami, etc. Though some of the concepts from these vocabularies may be used but different disasters have different requirements and may not be beneficial if someone is working on a pinpointed topic. The work neither said nor compared the ontologies on the basis of parameters like the methodology used, ontologies reused or evaluation techniques used to validate the ontologies, which are very important as they act as a platform for the researcher to understand the ontologies in-depth. Similarly, in other domains, the researchers have summarized the existing ontologies to know what is available, like Dong et al. (2008), who were working in multi-agent systems and made a general survey on the negotiation ontology research, presenting them into two major categories—negotiation protocol ontologies and negotiation disambiguation ontologies, which were then compared from the perspective of domain, functions, implementation techniques, evaluation method, and result. Kim et al. (2008) compared various tagging ontologies from various perspectives like concepts, attributes, and format of availability. Prantner et al. (2007) described various openly available formal tourism ontologies and their current efforts. These works basically first selected a broader, mature domain, categorized the ontologies and then compared the ontologies with the basic parameters again lacking the parameters like the methodology used, design pattern, ontology reused and evaluation performed. Mascardi et al. (2007) described seven upper-level ontologies, from various perspectives such as homepage, developers, dimensions, language(s), modularity, applications, alignment with WordNet, and licensing. They described some of the ontologies that have been created by merging upper ontologies. Now, since these are top-level ontologies, they can be studied or compared as they are easier to find as compared to very narrow and immature ontologies that are difficult to access. Similarly, Giunchiglia et al. (2014) described two broader categories of ontologies: classification ontologies (used to describe, classify, and search for documents) and descriptive ontologies (used for describing and reasoning about real-world entities).

## 4.0 Methodology of systematic literature review

A systematic literature review (SLR) in any domain results in enhancing the quality of research. The method is composed of an inquisitive methodology to pinpoint, choose, assess, and harmonize the major scientific research outputs, allowing a holistic review of the existing publications. Our methodology of systematic review has been inspired by Camacho and Alves-Souza (2018). Though the skeletal of the methodology has been kept the same, we have tweaked it to suit our study. The proposed methodology is divided into two stages: stage one-literature identification and stage two-ontological review. Stage one deals with finding the core literature, and stage two deals with reviewing the existing FOs from various perspectives. These two stages consisted of eight steps in total as depicted in Figure 3. They have been further described as follows:

Step 1: Query formulation
The process of SLR started with the formulation of queries keeping in mind the objective of this paper. Various search terms such as "flood," "ontology," "flood ontology," "knowledge management," "disaster management," "flood management," "disaster ontology," and "semantic model" were used in different combinations on the selected databases to retrieve the publications in the area of FO.

Step 2: Selection of databases
After the formulation of query, the databases were selected to search the literature. The selection of databases was dependent on the availability of the databases through the institute and also some of them were used because they are freely accessible on the web. The selected databases are Library and Information Science Abstracts (LISA) (https://search.proquest.com/lisa/products-services/lisa-set-c.html), Library, Information Science and Technology Abstracts (LISTA) (https://www.ebsco.com/products/research-databases/library-information-science-and-technology-abstracts), Scopus (https://www.scopus.com/home.uri), ScienceDirect (https://www.sciencedirect.com/), IEEE (https://ieeexplore.ieee.org), and GoogleScholar (https://scholar.google.co.in/).

Step 3: Formulation of inclusion and exclusion criteria
To suffice the objective of the study, inclusion and exclusion criteria were devised as provided below. These criterions were used to select the papers for complete reading and analysis.
Inclusion criteria (IC)

- Papers published in journals and conferences.
- Papers dealt with representation of flood using the semantic techniques.
- Papers dealt with systems including an ontology in the backend that supports the flood disaster.
- Papers dealt with ontologies and/or focused on a particular stage of the flood.
- Papers dealt with FO and have provided the ontologies (expressed in web ontology language (OWL), resource description framework schema (RDFS), or in any other languages) and/or have at least presented the ontology classes and properties in the paper.

Exclusion criteria (EC)

- Papers not published in English.
- Papers that spoke about FO but have not given any information on ontology, ontology classes, or properties, for example, in Zuhaili Mohd et. al 2016.

Step 4: Search
In this step, the queries that were formulated with different combinations search terms, such as "flood management" AND "ontology," "flood ontology" AND "knowledge management," "ontology" AND "disaster management," and "flood" AND "semantic model" were utilized to search through the databases selected in step two. When the database searches were performed using the query, a lot of redundant results appeared, which were discarded using the Excel workbook.

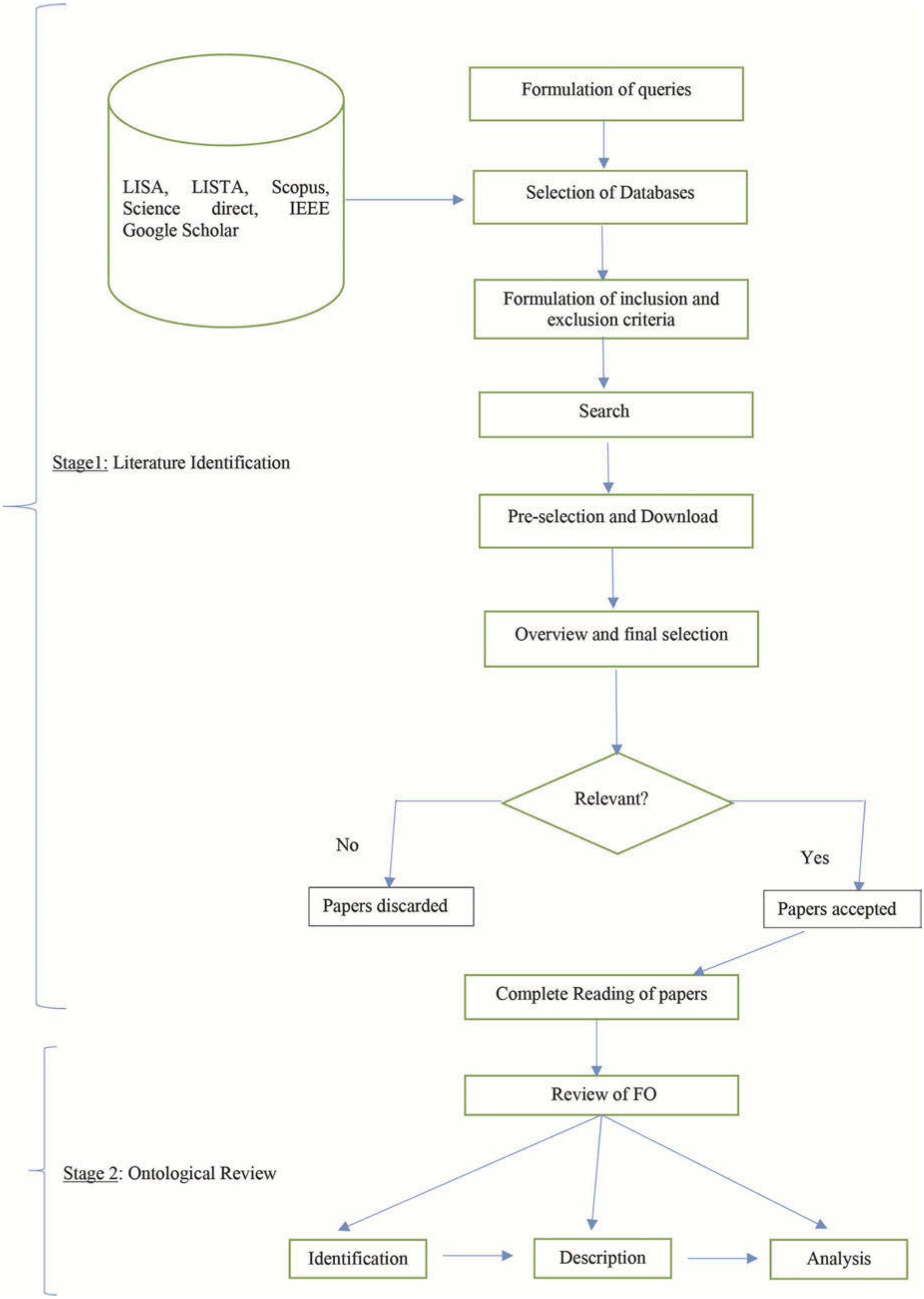


*Figure 3*. Workflow for systematic literature review.

Thus, a dataset of papers was prepared with unique results for each database. The databases were of different types, but all of them allowed the search strings with the provisions of Boolean operators like "AND"/ "OR" to be specifically used in it. For example, in ScienceDirect, "flood ontology" AND "knowledge management" was used as a query in the search box labelled "Find articles with these terms," which searched through the full text of all available articles. Various other filters could also be applied, for instance, content type (journal, conference), publication year, etc. Similar provisions were available and utilized for the databases, like Google scholar and LISA.

Step 5: Pre-selection and downloading
While searching through the databases to retrieve the papers, the abstract and title of the papers were read carefully to identify the core set of relevant papers and accordingly, their full text was obtained. But sometimes, this process was found to be insufficient to identify the relevant papers, thus we downloaded the full-text papers and read through them. The papers that talked about ontology and flood together were considered as relevant, whereas the others were deemed as irrelevant.

Step 6: Overview and final selection
One of the important inclusion criteria to perform a review of the ontologies, was the availability of ontologies in the paper or in any format just to get a glimpse of them. Hence, a thorough study of the full-text of the obtained papers revealed that only a few of them had spoken about FO specifically, or had explained the ontology-based flood management system. Even among these papers, a set of papers neither presented the FO nor made it available following any of the ontological file formats (e.g., .owl, .rdfs) anywhere on the web and, thus, were discarded from the study.

Step 7: Complete reading of the papers
The selected papers were read through in order to perform the study. Complete readings elucidated the various facts about the FO already built in the domain, like their purpose, type, the methodology used to develop them, formality level, etc.

Step 8: Review of FO
The major aim of this work was to locate the availability of FOs in the literature, which disaster phase have they focused on, their creation, scope, objective, uses, and so forth (detailed in Section 4). For this purpose, a review of the existing ontologies subject to availability was done. Previous steps helped to identify the core set of literature on FO, whereas this step was performed to explore the ontologies from different aspects. This is the second stage of the study, i.e., "ontology review." It constituted three parts, namely, identification, description, and analysis, as described below.

- Identification of ontologies: The first step of reviewing the FO deals with identifying the ontologies with some basic information, such as whether an ontology was developed under a project, who sponsored, design pattern, number of classes, etc. It has been performed by reading through the core literature plus searching through the ontology libraries, for example, OBO (http://www.obofoundry.org/), DAML (http://www.daml.org/ontologies/), ONKI (http://onki.fi/), and Protégé (http://protegewiki.stanford.edu/wiki/Protege_Ontology_Library). An ontology library is a kind of organizational network easily accessible remotely and offers relevant or admissible ontologies in a well-organized manner and with a competent approach, which is based on different well-established ontology representation languages, such as RDFS, OWL, etc. (Noy et al. 2008; Naskar and Dutta 2016).
- Description of ontologies: It basically deals with the elucidation of the FO at a granular level. It aimed at bringing out the various facts like the design methodology, knowledge formalism, tools used to design, etc., for the holistic view of FO.
- Analysis of ontologies: It was about analyzing the existing FO after their description from various perspectives to draw the inferences on them.

## 5.0 Result and discussion

Here, we detail our study and analysis of FO following the above discussed two stages approach of SLR.

### 5.1 Stage 1: literature identification

The first stage of SLR was "literature identification" where through rigorous search, the core literature in the area of FO was identified. The selected topic of study was pinpointed, i.e. "flood ontology," thus to perform a literature review on such a topic was tedious. The concept of ontology development in itself is not very old, thus it was expected when performing a literature review on such topics the number of relevant papers would be less than a prolific topic. But here only lies the opportunity of identifying the untouched areas of research. All the search terms were used with different combinations on the seven databases one by one, to perform the study as depicted in the previous section. Total unique results yielded per database at the initial level has been depicted in Table 1. One of the main reasons for having so many results was the phrase "ontology." Though there exists a large amount of literature on ontologies, the number of relevant results ultimately obtained was quite small since the topic was very specific.

LISA, LISTA, Scopus, Science Direct, and IEEE were chosen because of their availability through our institute; these gave substantial results. The results obtained out of these databases were examined, and if the same papers or irrelevant papers were obtained, they were discarded. Google Scholar was also consulted since it is freely available. The study investigated the presence of research material on a narrow topic, hence though initial screening resulted in thirty-six papers to be downloaded for the study, the final dataset consisted of only fourteen papers to be read completely. The results of the selection have been given below in Table 2.

Of the fourteen papers that were selected for complete reading, nine were from journals and five were from conferences. The majority of the papers were published after the year 2010 except one that was published in 2002 and another that was published in 2009. These facts clearly indicate that the idea of FO development is fairly new and in the budding stages, allowing more working opportunities. The results of SLR answered one part of the objective, i.e. though thirty-six publications discussed FO, only fourteen of them fairly discussed the FO while presenting them in some format (.owl, .rdf, .xmi). Hence, these fourteen publications (as depicted in the first column of Table 3) can be considered as core literature in the field of FO. The next sub-section deals with the review of these FOs, intended to reveal detailed information about them.

| Sr.No. | Research Databases | Number of papers retrieved |
|---|---|---|
| 1 | LISA | 53 |
| 2 | LISTA | 8 |
| 3 | Scopus | 1461 |
| 4 | Science Direct | 646 |
| 5 | IEEE | 85 |
| 6 | Google Scholar | 391 |

*Table 1*. Number of unique results yielded using the queries.

| Research Databases | Papers retrieved after queries | Papers pre-selected and downloaded | Papers Overview and Final Selection |
|---|---|---|---|
| LISA | 53 | 1 | 0 |
| LISTA | 8 | 0 | 0 |
| Scopus | 1461 | 16 | 6* |
| Science Direct | 646 | 3 | 1* |
| IEEE | 88 | 5 | 4* |
| Google Scholar | 391 | 11 | 3* |
| **Total** | 2647 | 36 | 14 |

*Table 2*. Number of papers obtained during different stages of SLR.

**Note:** The * for Scopus, Science Direct, IEEE, and Google Scholar indicates that papers from these databases were obtained for final selection because the rest did not provide ontology in any form.


*Figure 4*. Workflow for Ontological review.

### 5.2 Ontological review

This section discusses the remaining objectives of the study, i.e., fine-grained study of the FO. To perform the study, a core set of parameters were defined for both identifying and describing the ontologies. For selecting the parameters, the existing literature by Dutta et al. (2017) and Dutta et al. (2015) were studied. The referred works provided the metadata for ontology description and publication. Besides selecting the parameters from the stated work, a few more additional parameters were identified (e.g., ontology design pattern, the operation used, evaluation approaches) while studying the literature about ontologies. These are essential enough from the point of view of ontology identification and description. The domain of flooding is complex, and the ontologies are not serving one purpose only; these parameters could bring out more illustrative ideas about the available ontologies. The ontological review process is further detailed in the following section.

#### 5.2.1 Identification of ontologies:

This step is intended to bring out the versatility of FOs, increasing interest in the area of developing FOs and the concepts and relationships that the different FOs possess. The ontologies have been identified with the basic information such as sponsored agencies, project name, ontology design pattern, operations used, example classes, properties, etc., as defined below. The summary of the study has been provided in Table 3.

- Sponsored Agencies: The development of an ontology is a tedious process and is generally sponsored by various agencies for their development. This information allows us to understand the kind of people and organizations showing interest in the development of FOs and providing support. It encourages the researchers in the field to work and contribute more.
- Project Name: Project name narrows down the information about the ontologies that were funded by any agency giving a greater picture of the ontology. The project name allows us to pinpoint the purpose of the ontology and identifies them as individual work or part of a work that has a bigger objective to achieve.
- Ontology design pattern: A creative process related more to the structural framework of ontologies. Although there is no single appropriate way to design an ontology, design remains dependent on understanding, use and plans for the ontology's future development. Still, two loosely connected terms are used to explain the ontology design, namely modular ontology design and non-modular ontology design. Modular ontologies are the ones that use the concept of inheritance (https://www.obitko.com/tutorials/ontologies-semantic-web/ontologies.html) whereas non-modular ones do not.
- Operation used: Refers to the process that has been performed to build the desired ontology. These operations are of different types such as integration, extension, and pruning (https://www.obitko.com/tutorials/ontologies-semantic-web/ontologies.html). Ontologies can be developed from scratch or by reusing existing ontologies, thus these operations come into the light. Most of the ontologies are developed by using the existing related ontologies as it saves time, labor, and conforms to the best practices of ontology development.
- Example classes and properties: Refers to the building blocks around which the ontology revolves. A class is a collection of things sharing common attributes, whereas properties are the ones that represent the kind of relationships that exist between two things. The properties can be of two types: object property (which connects two entities belonging to two different or same classes) and data property (which connects an entity to a literal). These classes and properties directly convey the scope, purpose, and function of the ontologies.
- Approximate classes and subclasses: Gives a glimpse of the ontology's structural metrics that contains particular information, like the number of classes, subclasses, data properties, object properties, axioms, etc. Since full ontologies were not available and only a snapshot of the ontologies was provided in the published papers, we counted the number of classes and subclasses from them as presented in Table 3. Only one of the works (García-Castro et al. 2012) provided us with the OWL file, so ontology structural metrics is available for it.

As from Table 3, it can be seen that most of the identified FOs are modular in nature and have been developed using the extension operation and only a few of the ontologies, non-modular in nature, have used other operations like integration or pruning. There are quite a few of sponsoring agencies, though it is an amalgamation of government agencies and academic institutes (e.g., Andalusian Regional Government, German Ministry for Education and Research, University of Iowa.), most of the ontologies have been funded by government agencies. Few of the existing ontologies are developed as part of a project, for instance, SmartCities/AQUASYSTEM, SemSorGrid4Env, Flood AI Knowledge Engine, etc. We have also given a few example classes and the properties of the FO. The number of classes and subclasses of the ontologies has also been mentioned, but since the full ontologies were not available, as stated above, the ontology structural metrics are not provided here.

| Name of ontology | Creators | Sponsored agencies | Project Name | Ontology Design pattern | Operations used | Example Classes and properties | Approximate Classes and subclasses |
|---|---|---|---|---|---|---|---|
| FloodOntology | Agresta et al. 2014 | National Operational Program for Research and Competitiveness(PON R&C 2007-2013 ) | SmartCities/AQUASYSTEM Project | Modular | Integration | Drainage_Component, Motion_Related_Quantity, Sensing_Device, is_measured, is_quantity_of | 55* |
| Flood Ontology$_a$ | Norwawi et al. 2002 | NA | NA | Non modular | Integration | Flood Analysis, EmergencyCommittee, ContactPerson, | 8* |
| Crisis Management Ontology | Roller et al. 2015 | NA | NA | Non modular | NA | WaterLevel, ElectricityComponent, ElectricalAsset, ElectricalSupply, WaterSupplyArea, WaterResistanceThreshold,isResponsibleFor, isLocatedIn | 11* |
| Flood Risk Assessment Ontology | Scheuer et al. 2013 | German Ministry for Education and Research (BMBF), Contract 02WH1038 | Era-Net CRUE project RISK MAP | Modular | Extension | Flood,EventIntensity, RecurrenceInterval, SusceptibilityFunction, ElementAtRisk, DamageRatio, Stakeholder, Authority, intensityOf, hasSusceptibility | 24 |
| Flood Risk Ontology | Yi and Sun 2013 | NSFC | NA | Modular | Extension | WaterSystem, Watershed flood , Watershed drought Waterquality, Climate, Precipitation | 10* |
| Flood Ontology$_b$ | Wang et al. 2017 | NSFC , National Key Research and Development Program of China, China Scholarship Council (CSC) Foundation, National Institute of General Medical Sciences | NA | Modular | Extension | WaterLevel, WeatherStation, HydrologcalStation,RainGuage,WaterLevelGauge,Waterbody,HyrdrologicalMonitorPoint, isHostedBy, isObservedBy | 10* |
| Freshwater Flood Ontology | Garrido et al. 2012 | Andalusian Regional Government | Projects (CICE) P07-TIC-02913 and P08-RNM-03584, | Modular | Pruning | Rainfall, WaterDischarge, Flood,Management, hasCharacterizingindicator, dischargeProducedby | 91 |
| Flood Domain Ontology | García-Castro et al. 2012 | NA | SemSor-Grid4Env European project (FP7-223913) and by the Spanish project myBigData (TIN2010-17060) | Modular | Integration, extension | OceanRegion, OceanRegionProper-ties, FloodPlain, FloodZone, FloodDefencePol, Duties, Organizations, Roles, locatedInRegion,appliesTo | 47 |
| Dynamic Flood Ontology | Kurte et al. 2017 | NA | NA | Modular | Extension, integration | GeoSpatialRegionTimeSlice,timeSlice,GeoSpatialRegion,Timeinterval, ImageSegment,hasFloodFiliation | 8* |

*Table 3*. Identification of ontologies. (Continued on next page)

| Name of ontology | Creators | Sponsored agencies | Project Name | Ontology Design pattern | Operations used | Example Classes and properties | Approximate Classes and subclasses |
|---|---|---|---|---|---|---|---|
| Flood Ontology$_c$ | Ding et al. 2014 | NHTRD, NSFC | NA | Modular | Extension | FloodEvent, DynamicObservation, Sensor, FloodProperties, UrbanFlood, isSpecifiedFor, Observes | 21* |
| Flood Scene Ontology | Potnis et al. 2018 | NA | NA | Modular | Extension | FloodWater, Road Vehicle, hasVehicle | 4* |
| Flood Ontology$_d$ | Katuk et al. 2009 | NA | NA | Non-Modular | NA | FloodDisasterManage ment Committee, FloodOperation CommandCenter, On Scene Control Post, Victim, Supply, Health, EvacuationCenter, | 13* |
| Flood Ontology$_e$ | Sun et al. 2016 | French Auvergne-Rhône-Alpes, European Regional Development Fund (ERDF). | NA | Modular | Extension | FeatureOfInterest, Sensor, Property, Observation, flood, waterflow, rainfallamount, PrecipitationNode, WaterCourseNode, sensorID, newFrequency | 9* |
| Flood Ontology$_f$ | Sermet and Demir 2019 | Iowa Flood Center and University of Iowa. | Flood AI Knowledge Engine software | Modular | Extension, integration | NaturalHazard, Instrument, EnvironmentalPhenom ena, RiverineFlood, flowDirection, flowRate, hasWaterSource, measuredBy | 42* |

*Table 3*. Identification of ontologies. (Continued from previouspage)

**Note:** (i) The number of classes/subclasses marked with an asterisk (*) indicates that the respective ontologies were only partially available to us and hence we do not know the exact number of classes/subclasses in them. (ii) Example classes (beginning with a capital letter) and properties (beginning with a lower-case letter) are provided here in the style they were originally found.

Abbreviations used: NA-Not Applicable, NSFC-National Natural Science Foundation of China, NHTRD-National High Technology Research and Development.

### 5.2.2 Description of ontologies:

The forteen obtained ontologies are briefly described here. The description of the ontologies is provided in Table 4 for an easy understanding. A total of twelve parameters have been identified as discussed below to study the ontologies at a granular level.

– Purpose of ontology: It elucidates the use of the ontology or function it will perform if included in a system for flood management. It acts as a compass to the scope of an ontology. The purpose of each ontology was different, because the ultimate goal of these works differ from one another, for example, FloodOntology developed by Agresta et al. (2014) has concepts to gather information about water parameters in watersheds and sewers for forecasting flood, whereas, the top-level flood ontology$_d$ by Katuk et al. (2009) was developed to classify the flood management activities into categories in accordance to the responsibilities of the agencies and so on.
– Type of ontology: It enables us to understand the kind of ontologies developed in the domain of flooding, giving an idea about the general-purpose, scope of the ontologies, and also about the available, missing ontological resources. The ontologies are generally of various types: upper ontology (aka generic, top-level—aims at capturing general knowledge about the world, providing basic notions and concepts for things, e.g., time, space), domain ontology (captures the knowledge valid for a particular type of domain, e.g., chemical, electronics), task ontology (provides terms specific for particular tasks), method ontology (provides terms specific to particular problem-solving methods, e.g., assembling

parts of a computer), application ontology (contains all the necessary knowledge for modelling a particular domain. Usually, it's a combination of domain and method ontologies), metadata ontology (describes the content of on-line information sources like Dublin Core), representational ontology (it does not refer to any particular domain but provides representational entities without stating what should be represented), terminological ontology (a lexicon specifying the terms that are used to represent knowledge in the domain of discourse, e.g., Unified Medical Language System), information ontology (specifies the record structure of the databases, e.g., level one of the PEN & PAD model, a framework for modeling medical records of patients), and knowledge modeling ontology (specifies conceptualizations of a knowledge area, e.g., level two description of the PEN & PAD model) (Kaewboonma et al. 2014).

- Focussed Phases: It relates to the disaster management phase (DMP) in which the FOs are concentrated. The disaster management model (DMM) by Nojvan et al. (2018) was referred to as it was the most recent model available in the literature to identify the phases. It covered most of the aspects of DM. The model has divided the whole DM into three major phases: hazard assessment, risk management, and disaster management actions through thematic analysis. The DM actions were further divided into four major actions, i.e., preparedness, mitigation, response, and recovery. So, for this study, we considered the six phases of DM. They are hazard assessment (a process of recognizing the potential hazards to eliminate or control them), risk management (methodical use of management protocols, methods, and practices for understanding, assessing, restricting and even communicating about risk issues), preparedness (actions framed to curtail the effect of disaster when forecasted), mitigation (actions framed to reduce the consequences of upcoming probable disasters), response (the immediate actions taken during disaster, which is short term after a disaster, to save human lives and supply aids), and recovery (to repair the damage, restore services, and reconstruction of facilities after a disaster has struck) (Manitoba-Health-Disaster-Management 2002; Hidayat and Egbu 2010; Alexander 2002). To understand which disaster phases the ontology has concentrated on, we compared the objectives of the work to the DMP. It may be the case that one ontology had concepts that concentrated on more than one phase of disaster, but we generally considered the phase that had maximum attention. According to Table 4, it is clear that the majority of the FOs have been built for the response phase of the disaster, few of them have been built for risk management, some of them have been built for contributing towards the preparedness and hazard assessment phases, and a few of the studies were spread around more than one phase like the Flood Ontology$_b$ developed by Wang et al. (2017).
- Ontology re-used: One of the most important parameters for the study was ontology re-use, referencing to the ontologies that support in the construction of a FO. This parameter served two purposes: 1) it gave an idea of whether the FO was made from scratch or used some concepts from previously available ontologies; and, 2) it revealed the kind of ontologies that were used to build the FO like top-level ontologies, domain ontologies, etc. Some of the most favored ontologies used for creating the FO were the Semantic Web of Earth and Environment Technology Ontology (https://bioportal.bioontology.org/ontologies/SWEET), the Semantic Sensor Network, (https://www.w3.org/2005/Incubator/ssn/ssnx/ssn), the Time ontology (https://www.w3.org/TR/owl-time/), and the Hydraulic ontology. Some of the other ontologies that were used to develop FO are MONITOR (Ontological basis for Risk assessment, http://www.monitor-cadses.org), Environment Impact Assessment Ontology (Garrido and Requena 2011), DOLCE (http://www.loa.istc.cnr.it/dolce/overview.html), A Geographic Query Language for RDF Data (GeoSPARQL, http://www.geosparql.org/), Spatial Image Information Mining (SIIM), Basic Formal Ontology (http://basic-formal-ontology.org/), etc. Of these ontologies, DOLCE, SWEET, and BFO are the top-level ontologies, whereas MONITOR is a domain ontology for risk management.
- Contributing domains: It means while gathering the concepts for the construction of FOs, other domain concepts were used. The other domain concepts contribute to the FO as it is generally created for ad-hoc applications. This surfaced the domains frequently used in the creation of FOs. Some of the most used domains for the construction of FOs are Sensor Network, Hydraulic, Hydrological, Time, and Space. Some ontologies developed for flood risk management also had concepts from risk domains.
- Design Methodology: It refers to the systematic steps followed for the construction of ontologies, for instance, METHONTOLOGY (Fernández-López et al. 1997), UPON (De Nicola et al. 2009), etc. An appropriate methodology used to build the ontology will ensure the quality of the ontology and the researchers shall have ready to use methodology at their disposal. Such solutions are difficult to obtain precisely but having a pool of methodologies for the construction of FOs will reduce the effort and time for researchers. Though there is no standard methodology (Sermet and Demir 2019), which should be followed in creating an ontol-

ogy, but following anyone of the existing methodologies makes the ontologies more scientific. The interesting fact is that out of the fourteen ontologies developed only five of them have mentioned the methodologies followed. Two of the works followed METHONTOLOGY, whereas others followed, Uschold and Gruinger method, Brief Ontology (Delgado et al. 2005), Ontology Development 101(Noy and McGuinness 2001), etc., as depicted in Table 4.

– Class hierarchy development: To develop the class hierarchy, there are generally three approaches used namely, top-down, bottom-up, and middle out, which have been explained in the literature with their pros and cons. All of these approaches can be used to create the class hierarchy for the ontology. The top-down approach identifies the root concept first and then slowly narrows down to more specific concepts, so it goes from the abstract level to the concrete level. The bottom-up approach investigates and studies the features of base concepts, then groups them according to their similarities to form a larger aggregate. The process is continued iteratively until the root concept is obtained. So, the bottom-up approach proceeds from the concrete ground and reaches to the abstract level (Dutta et al. 2015). A middle-out approach, by contrast, strikes a balance in terms of the level detail. Detail arises only as necessary by specializing the basic concepts, so some effort is avoided. By starting with the most important concepts first and defining higher-level concepts in terms of the the higher-level categories naturally arise and, thus, are more likely to be stable. This in turn leads to less re-work and less overall effort (Uschold and Gruninger 1996).
– Representation language: Refers to the language in which the concepts and relations are represented, for example, OWL and RDFS (McGuinness and Van Harmelen 2004). Again, there are various ontology representation languages available, but choosing appropriate ontology representation language amidst various feasible options is difficult. This parameter will allow researchers to see which language has been used mostly for the FO representation. In our study, it was found that almost all of the ontologies were developed using OWL, whereas few of them used UML to represent their ontologies as shown in Table 4.
– Level of formality: It is directly proportional to the language and language expressivity used to construct the ontology. The level of formality can be of three types namely; informal, formal, and semiformal ontology. Informal ontologies are the ones that have been built like a taxonomy such as Yahoo! Directory and DMOZ, formal ontologies are the ones using a formal ontology language (e.g., OWL) like DOLCE, semiformal ontology has a more schema like structure and is built using a language like RDFS (Uschold and Gruninger 1996). Almost all of the ontologies developed here are formal except three, two of them being informal (Roller et al. 2015; Katuk et.al 2009), and one of them was semiformal (Ding et al. 2014). Thus, making most of the ontologies machine-processable.
– Ontology editor: It refers to the software that facilitates the ontology development, allowing visualization, modification, maintenance, updating, and syntactic evaluation of the ontology (Altarish 2012), for example, Protégé (Stanford University School of Medicine), WebVOWL (Lohmann et al. 2014), etc. Generally, ontologies are developed to solve a specific problem at hand, hence choosing the right ontology editor amidst various feasible options for the ontology development is difficult. Hence, this parameter will help to save the time of the user by supplementing the information of popular ontology editors for a FO development. The study revealed very few of the works mentioned about the ontology editors used by them, but even among them Protégé was a popular choice except a few, where, one used Java Agent Development Framework (https://jade.tilab.com/) and another one used GenMyModel (https://www.genmymodel.com/).
– Evaluation: It refers to the evaluation done of the FO. It is very much essential that the FOs are evaluated and the results are explained to build the trust of the users. Evaluation acts as a platform for designing a new FO, analyzing whether the ontology is suitable enough for certain applications and domains, and also helps in updating the ontology. To evaluate the ontologies, various approaches exist like golden standard (based on comparing the ontology with an existing one), application-based (based on using the ontology in an application and evaluating the results), data-based (based on involving comparisons with a source of data, e.g., a collection of documents about the domain to be covered by the ontology), human evaluation (by humans who try to assess how well the ontology meets a set of predefined criteria, standards, and requirements), task-based (evaluating an ontology-based on the competency of the ontology in completing tasks), and criteria-based (evaluation based on proposed criteria) (Brank et al. 2005; Yu et al. 2007). Depending upon the availability of the standard ontology, expert, data, application, and evaluation criteria must be performed. As we see from Table 4, a few of the ontologies (seven) were evaluated and some (five) were not. There is a mixture of methods that have been majorly used like application methods or data-based methods, whereas some of them used two or three methods to evaluate the ontology, for example, Flood Domain Ontology (García-Castro et al. 2012) and Flood Ontology$_f$ (Sermet and Demir 2019).

- Availability in ontology library: Ontology libraries can serve as a link in enabling diverse users and applications to discover, evaluate, use, and publish ontologies (d'Aquin and Noy 2012). The availability of ontologies allows researchers to analyze the ontologies from various perspectives making it more usable. Some of the ontology libraries that were searched are Open Biological and Biomedical Ontology (http://www.obofoundry.org/), DAML ontology library (http://www.daml.org/ontologies/), ONKI (http://onki.fi/), and Protégé Ontology Library (http://protegewiki.stanford.edu/wiki/Protege_Ontology_Library). Unfortunately, no FO could be found in them.
- IEEE1074-1995 compliance: The IEEE 1074-1995 standard elucidates the process and activities that may be followed for developing software. These processes and activities can also be followed while developing an ontology leading to a sustainable and quality ontology that can be used, studied, further developed in the future, and can be researched on. These activities provide a platform for the developers of ontology to have a clear idea about the activities they need to perform while developing ontologies. The standard defines three kinds of processes (De Nicola et al. 2009):
  a) Project management processes (PMS): refers to the development of a project management framework for the entire ontology lifecycle, comprising of project initiation, monitoring and control, and quality management of the ontology.
  b) Ontology development processes (ODP): refers to the whole creation process of an ontology. The process is divided into three sub-processes:
     - Pre-development process: is concerned with an environment study and a feasibility study.
     - Development process (DP): is concerned with requirements, design, and implementation of ontologies.
     - Post-development process: is concerned with installation, operation, support, maintenance, and retirement of an ontology.
  c) Integral processes (IP): refers to knowledge acquisition, evaluation, configuration management, documentation, and training of the ontology.

From Table 4, it is evident that when we apply the ISO 1074-1995 to the evaluated FO, a very few of the ontologies are compliant to the processes and even if they are compliant, they are partial, i.e., the three processes mentioned above are composed of sub-processes, for example, PMS is comprised of project initiation, monitoring and control, and quality management of ontology. All the sub-processes were not applicable for the ontologies, hence deemed as partial, for instance, ontologies by Agresta et al. (2014), Norwawi et al. (2002), and Sermet and Demir (2019) support project management and integral process partially as the project initiation and evaluation is applicable. The rest of the sub-processes are not applicable, but the sub-process DP was applicable fully as the requirements, design, and implementation of ontologies were applicable; hence, they were deemed as full support for DP. For some of the ontologies, only sub-processes were applicable like DP but that also partially, for example, Flood Risk Ontology (Yi and Sun 2013), Dynamic Flood Ontology (Kurte et al. 2017), hence deemed as partial support for DP.

#### 5.2.3 Analysis

This step of ontological review is about analyzing the existing FOs based on the descriptions provided in the previous section. This brings out the inferences to achieve the objective of the granular study of ontologies.

The purpose of ontology acts as the compass to define the scope, concepts required, and domains to be reused leading to its development. As depicted in Table 4, although all the ontologies were related to flooding but each also had a different purpose, so different concepts from various domains were used to construct them. Some of the major domains are hydrology, hydraulic, sensor, time, and space. Each of these domains has concepts either related to natural phenomena, captures information about the natural phenomena, or captures the temporal and spatial components, which are required for building the FO. But since purpose differs, they are required in different combinations. Ontologies that carry knowledge about natural phenomena are favored, because flood is a natural phenomenon and thus it is bound to have concepts that can be reused. Similarly, if the purpose is to capture flood flow information, ontologies having concepts about such devices will be favored. Thus, we see that the majority of the ontologies are task or application ontologies.

Focused phases deal with the fact that the developed ontologies majorly support which phase of the disaster out of the six phases that are considered. In the study, it was discovered that there were no ontologies that were built to support the phases like recovery and mitigation specifically. All of the ontologies were built for different purposes, but the majority of the ontologies were built around the response phases and had a common link. All these ontologies were built assuming a certain scenario, which may take place during a flood, like Flood Ontology$_b$ (Wang et al. 2017), which was developed to monitor the various stages of flooding of the Yangtze River. For the experimental purpose, observational data of two months from twenty-two sensors were obtained. Then with the help of semantic querying and knowledge acquisition, the workability and

| Name of ontology | Purpose | Type of Ontology | Focused phases | Ontologies re-used | Contributing domains | Design Methodology | Class hierarchy | Representation language | Level of formality | Ontology Editor | Evaluation | Availability in Ontology Libraries | IEEE1074-1995 Compliance |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FloodOntology | Provide a consolidated, structured knowledge base for flood prediction. | Application | HA | SWEET,SSN | Sensor, Hydraulic, Hydrological | Uschold and Gruinger | MO | OWL | Formal | Protege | NA | No | PMS,IS (Partial) DP(Full) |
| Flood Ontology[a] | Organizing knowledge about flood occurring event, deriving data from hydrology ontology and supply a report to response team for action. | Task | Response | NA | Hydrological, Emergency Management Team | Methontology | MO | OWL | Formal | Protege | NA | No | PMS,IS (Partial) DP(Full) |
| Crisis Management Ontology | Capturing knowledge of a scenario where electrical asset is down due to flood that can be used to develop a data sharing solution, provided through the linked data available between various stakeholders involved. | Task | Response | NA | Hydrology, Electrical, Stakeholders | NA | NA | NA | Informal | NA | Application and data based | No | DP,IS (Partial) |
| Flood Risk Assessment Ontology | Capture knowledge relevant to the flood risk assessment with the stake stakeholders involved for overcoming the situation. | Application and domain | RM | SWEET, MONITOR | Risk Domain, Hydrology domain, stakeholders | Modified Methontology and UPON | MO | OWL | Formal | NA | Application based | No | PMS,IS (Partial) DP(Full) |
| Flood Risk Ontology | Developing a flood risk assessment workflow. | Task | RM | SWEET, Watershed Ontology, Water resource risk ontology | Watershed science | NA | TD | OWL | Formal | NA | NA | No | DP (Partial) |
| Flood Ontology[b] | Managing the flood related knowledge so that various stages of flood can be recognized based on the existing knowledge. | Task | Preparedness, Mitigation,Response and Recovery | SSN, Time, OGC GeoSPARQL | Sensor Network, Time, Hydrology. | NA | TD | OWL | Formal | Protege | Data based | No | DP,IS (Partial) |
| Freshwater Flood ontology | Simplify and optimize use of the ontology for flood information. Also describe the semantic modeling of floods and flood-related concepts. | Domain | RM | EIA, DOLCE | Hydrology, Hydraulic, management | Brief Ontology | TD | OWL | Formal | NA | Manual | No | DP,IS (Partial) |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Flood Domain Ontology | Act as supporting ontology to semantic sensor web infrastructures representing infrastructural and coastal flood data. | Task | Preparedness | Role, Additional region, Coastal Flood defence | Sensor domain, Hydraulic | NA | NA | OWL | Formal | Protege | Static approach, data and application, manual | No | DP,IS (Partial) |
| Dynamic Flood Ontology | Model the spatio-temporal changes in flood disaster situation. | Task | Response | Time, SIIM | Image Domain, Time, Space | NA | NA | OWL | Formal | NA | NA | No | DP (Partial) |
| Flood Ontology[c] | Developed as a unifying semantic description model to map relations between geo-models and geo-observational data. | Application | All Phases | SWEET | Hydraulic, hydrology, meteorological, Geoscience | NA | NA | NA | Semi-Formal | NA | Data based | No | DP,IS (Partial) |
| Flood Scene Ontology | Mine the topological and directional knowledge in context to the flood disaster phenomenon. | Task | Response | BFO | Image Domain, Time, Space | Ontology Development 101 | NA | OWL | Formal | NA | NA | No | DP(Full) |
| Flood Ontology[d] | Modelling the flood management activities that needs to be carried out by different agencies according to their responsibilities. | Task | Response | NA | Flood Management Committee, Hydraulic, hydrology, | NA | TD | NA | Informal | NA | NA | No | DP (Partial) |
| Flood Ontology[e] | Act as a central ontology to which other ontologies can be connected, helping to develop a full context data model. | Task | All Phases | Climate and Forecast ontology and Irstea Hydro Ontology | Sensor, Hydraulic, hydrology, meteorological | NA | NA | UML | Formal | JADE | Data based | No | DP,IS (Partial) |
| Flood Ontology[f] | Developed for comprehending and resolving complex environmental queries to support the Flood AI intelligent system. | Information | Preparedness, monitoring, Response,and recovery | NA | Natural Hazard, Instrument, and Environmental Phenomena | NA | TD | UML | Formal | GenMyModel | Data driven ,application approach and partially manual | No(Present in GitHub) | PMS,IS (Partial) DP(Full) |

*Table 4*. Describing ontologies.

Ontologies extended: Semantic Web of Earth and Environment Technology Ontology(SWEET), Descriptive Ontology for Linguistic and Cognitive Terminology(DOLCE), Environmental Impact Assessment(EIA), Semantic Sensor Network(SSN), Time Ontology , Sensor web Ontology, MONITOR (Ontological basis for Risk management), A Geographic Query Language for RDF Data, (GeoSPARQL), Spatial Image Information Mining (SIIM), and Basic Formal Ontology(BFO).

Abbreviations used: RM-Risk Management, HA-Hazard Assessment, MO-Middle Out, TD-Top Down, NA-Not Applicable JADE-Java Agent Development Framework, UML-Unified Modelling Language operation of the developed ontology was shown. Although, a few of the ontologies took into consideration the various actors involved during the flood when such a situation comes, these actors require different kinds of resources and need to communicate between them. Hence, there is a need for ontologies for the flood, which could organize the different resources that could be used by the various agencies and individuals to support the response phase of an FDM system.

Building ontology from scratch requires a lot of time, effort, and cost (Dutta et al. 2015). It is always suggested to reuse the existing ontologies. This work investigated which of the existing ontologies were used predominantly for the FO development. Table 4 clearly depicts that the flood-related ontologies have been built mainly using the SWEET ontology as it is holistic, unified, and application-independent (Ding et al. 2014). It has both integrative and faceted structure, with terms from various domains, such as environmental and earth system sciences, physics, chemistry, or maths to describe human activities and natural phenomena. SWEET has been used in FO, because it defines a hierarchy of many flood risk-relevant terms, e.g., flood/inundation and different infrastructure facilities (Scheuer et al. 2013), making it a versatile ontology to support the semantic systems built for flood management systems. Similarly, the SSN ontology has been used often to create a FO, because the data required to monitor flood situations can be collected through the installed sensors, thus making this ontology a very essential component of a FO. There are few other ontologies, like the Environment Impact Assessment ontology (Garrido and Requena 2011), that have concepts already available to directly model the flooding domain and those which are not directly included can be generalized in the representations of other concepts. MONITOR (Kollarits et al. 2009) models the concept of risk and describes the relations between natural, social, and built environments. It also describes potentially hazardous events, associated risks, risk assessment, and risk management terms that are important components of flood risk ontologies. There are other ontologies like the Time ontology which is used to ensure the temporal component so that the dynamic information about flooding can be collected. Other top-level ontologies like DOLCE and BFO are also used as base ontologies for building the flood domain knowledge and other relationships.

The design methodologies for ontology describes everything about the developmental steps of ontologies with their motives, weaknesses, and strengths. There exist few principles and recommendations for developing ontologies; when these are followed it leads to more comprehensive and acceptable ontology. In this study, it was found that very few works have explicitly stated the methodologies used, so it was difficult to point out a particular methodology that is popular or appropriate, but among them, it was seen that METHONTOLOGY is the preferred one as it is a structured, generic, and application-independent approach method for building ontologies from scratch. In one of the works, authors used a mixture of two methodologies, METHONTOLOGY and UPON, where the later methodology introduces use cases and competency questions to help define the scope and purpose of the ontology. Some of the works used very recent methodologies, like the Brief Ontology; formally defined by Garrido and Requena (2012) as an extraction algorithm and a tool for creating ontologies. In essence, it produces a reduced version of the ontology with relevant knowledge with limitation of requiring an ontology. Using this, we cannot build ontologies from scratch, whereas one of the works used the Ontology Development 101, for a declarative frame-based system that was free of this limitation. So although there is no single correct design methodology for ontology development in any domain, it is the scope, purpose, and envisioned application that drives the choice.

A majority of the ontologies were developed using OWL language and Protégé as the ontology editor. The primary reasons for their preference is their popularity and varieties of functions they provide. For instance, OWL is a W3C recommended formal language for representing the information making it ready for machine processing since the purpose of developing an ontology is making it usable rather than coding the information for the sake of it. OWL also provides different species with various levels of expressivity making it a powerful tool for representing concepts and their relationships. Similarly, Protégé is a knowledge-based editor, open-source, easy to use, allowing the user to create, edit, update, and visualize the ontology very easily. However, Sermet and Demir argue that most of the ontology editors do not support the simultaneously accessed workplace and online development. Though the Protégé desktop supports illustrations and visualizations but visual editing is limited, whereas Web Protégé facilitates online and collaborative environment but does not offer any visual editing capabilities. Thus, they used GenMyModel, an online modelling platform.

Ontology evaluation is an important part of the ontology life cycle adopted in the SW and other semantics-aware applications. Trust and confidence in the ontologies for its immediate usage comes from the fact whether the ontologies have been evaluated or not. In this study of the FOs, it was observed that some of them have been evaluated using application-based or data-based approaches, whereas two of them have been done by manual method but many of them were not evaluated; hence there is no guarantee that these ontologies are trustworthy. The domain of flooding does not possess as such any standard ontology that can be used to compare. Thus, it becomes difficult to evaluate the ontologies in isolation. There are few ontologies that were developed as a part of the research and development program of major organizations; hence, for them, it was easier to get data, but for independent scholars, it was difficult to get the data. So, this may be another reason why few of the ontologies were evaluated.

We observed that most of the FOs support sub–processes of ODP, i.e., DP if not fully, but at least partially meaning some of the activities are applicable. The activities related to DP are requirements, design, and implementation of ontologies; these mainly deal with the purpose, scope, usage, and designing of ontologies, which at least need to go through these processes for its development. Hence most of them support the DP. But the processes, like installation, operation, support, and maintenance of ontology are not applicable, because it may not fall under the purview of their scope. Some ontologies support the IP partially, especially the evaluation and documentation activities as these increase the trust in the ontologies and give a fair idea about the ontology, whereas configuration management and training of the ontology are generally absent. Very few of the studied ontologies partially support the PMS as it treats ontology development as a project management framework that deals with project initiation, monitoring and control, and quality management of ontology, and some of these activities are not applicable for studied ontologies.

### 5.2.4 Discussion

It was observed that most of the FOs studied were built around small tasks performed during a flood. Among these, very few tried to conceptualize the whole flood disaster together. Ontologies are considered computational artifacts like software programs. Similar to programs, ontologies can become big and complex; thus, using the modular approach makes it easier to process, update, asses, and reuse. The choice of the evaluation approach may be based on the matured ontologies available in the domain. As this domain can be considered fairly new, application or data-based approaches are mostly used. In most of the ontologies, the top-down approach has been chosen for hierarchy development. If a flood disaster strikes, there are some general resources required, for example, boats, food, and medical aid to provide an immediate response. Information about them has not been captured in these FOs, which is essential to carry out the rescue and relief operations. A very few papers, for instance, Shan and Yan (2019) discussed that the strategic and tactical features of flood emergency response include the resources required for rescue, which are comprised of emergency equipment, relief supplies, and materials for daily living. Thus, we need more ontologies, modelling the resources and connecting it to phases like the response phase and recovery phase. Although, as claimed in the literature, most of the ontologies are in OWL, the access to them is tough as very few (only two) of them were available. The research focus should be on developing the FO systematically for various other DMP by adopting available methodologies. Also, making the ontology available should be emphasized to make it reusable.

## 6.0 Conclusion and future work

The work was built on two primary objectives: 1) identifying the core literature in the area of FOs; and, 2) exploring the existing ontologies at a granular level from various perspectives. The first objective was achieved through the process of SLR, yielding a set of core literature, i.e., fourteen papers discussing the developed FOs presenting their core concepts in the paper or as an OWL file. These works were published in various conferences and journals of different subjects, proving it as an interdisciplinary area of work. Both subject experts and ontology experts collaborated for these works, which can be easily observed from the affiliations of the authors. But since the concentration of the work was not on bibliometric studies (Pritchard 1969), this was not mentioned specifically. Next, the ontological review was performed using the parametric approach. The existing literature was studied to identify and select the parameters. These parameters were then defined and applied for the granular study. This stage of the study was done to review the ontologies and to understand the current state of the FO from various perspectives like its purpose, scope, design methodology used, tools used, the kind of ontology be it functional wise or structure-wise, etc., rather than their critical point of view. This review also laid the foundation of studying ontologies from the parametric approach where they can be used to identify and describe the ontologies in any other domain concisely, and even the whole methodology used can act as a general methodology for similar kinds of studies. The study revealed that there is no standard FO available in the field. The major constraint of this study was the unavailability of the full FO, even though the developers were contacted for making the ontology available, but very few of them replied. So, with limited resources, maximum information is provided here. Structural ontology metrics for all the ontologies could not be made, because of the aforementioned reason. Ontologies reviewed here were mostly scenario/task-specific, and only a few of the ontologies were intended to organize the knowledge in the flooding domain. Alhough it is true that flooding in villages and in urban areas will pose a different problems, the minimal resources required to tackle the situation remains almost the same; just its type may vary, for example, boats will be required for both the places, but the type of boat required for an urban area to a village area may vary. Hence, a resource ontology that organizes these kinds of resources will be helpful to tackle the situation during a flood. In the future, we would like to build an ontological model for resources.

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