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ORFFM: An Ontology-Based Semantic Model of River Flow and Flood Mitigation

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ABSTRACT The provision of the heterogeneous information acquisition and managing of emerging technologies with IoT, cloud-based storage, and improved communication services have filled the data scarcity gap on one hand but raised the challenge to extract, process, and comprehend relevant data of complex integrated multiple domains involving a large number of participants with diverse spatial terminologies and methodologies. To resolve this challenge various big data and natural language processing techniques were applied. Another widely used approach to resolve the challenges of heterogeneity, interoperability, and complexity of integrated domain is ontology-based semantic modeling. We proposed Ontology for River Flow and Flood Mitigation (ORFFM) for semantic knowledge formalization with semantic understandability of irrigation, disaster management, related administrative and agricultural domain concepts by humans and machines. The semantic modeling of distributed river flow network and associated flood disaster mitigation for effective coordination, collaborative response activities leads to reduce the impact of a disaster and improve information representation among stakeholders. Furthermore, semantic formalization and inference are supported by explicitly annotated information. We populated ORFFM with Pakistan's Indus river system, flood disaster management, and Sindh administrative authorities to develop a knowledgebase for knowledge sharing and representation. The formal semantically enriched knowledgebase would contribute towards streamflow optimization and flood mitigation through effective coordination and common conceptualization during disaster management phases. The semantic model of irrigation networks would also be useful for academic purposes to acquire domain knowledge for new entrants in the irrigation and disaster management field.

INDEX TERMS Semantic web, inference, knowledge base, flood mitigation, irrigation system, semantic interpretation, semantic reasoner, ontology.

I. INTRODUCTION

Disasters cause damages to the lives and economy of the community proportional to the magnitude of the disaster and inadequate proactive measures for prevention and mitigation. Flood is one of the most frequent disasters, especially for agricultural countries having complex irrigation networks with varying spatiotemporal streamflow and managed by various administrative authorities with a different mandate.

The streamflow pattern of watersheds affects the relevant community in either way. Extreme variations generate disaster that affects a country's stability by jerking the prosperity graph due to life losses, infrastructure damage, demolishing means of livelihood, and other financial losses. In the monsoon seasons, the river belt community has a high risk of flood, whereas the far-flung living community tends to suffer in the drought. The river streamflow and flood mitigation domains are interdisciplinary and require coordination among a range of stakeholders. Limiting factors of the effective coordination includes native data acquisition format for organization-specific needs, autonomy, regional operational terminologies and procedure, data scarcity, data heterogeneity, poorly defined context, in addition to lack of semantics in models and procedures.

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The explicit formalization and specification of the domain knowledge support machine-readable format compatible with context-aware systems. The ontological model of integrating domains, shared among a vast community of stakeholders, adds a consensual knowledge generation mechanism for effective collaboration rather than reflecting the individual's perspective or raising a conflict. The ontology produces uniform, agreed, machine-processable data formats, with semantic interoperability, scalability, expressiveness features. The process of consensus development on generated data, recommended decision, applicable policy, and normalized time series data collected from the distributed locations with diverse data acquisition techniques are semantically mapped to resolve the data heterogeneity issues.

A. MOTIVATIONS OF ONTOLOGY-BASED MODEL

The non-homogeneous data acquisition and monitoring techniques of the river streamflow due to distributed gauging stations with different flow magnitude and managed by distributed autonomous authorities using dissimilar data acquisition techniques. These variations cause heterogeneity of data, ineffective communication mode, and the dearth of constructive coordination towards managing smooth streamflow through irrigation networks. To sum up, these are motivating factors of semantic modeling-based knowledge management for disaster management that leads to a transition to a KM-based system revealed from the literature and increased adaptability to resolve data heterogeneity, integrated domain complexities, and coordination issues. A study conducted by Oktari *et al.* in [47] presented their research findings that the use knowledge management for disaster management based systematic review of 72 selected papers. They confirmed the benefits of using knowledge management for disaster risk reduction and resilience throughout all phases of the disaster management cycle. Besides, Lettieri *et al.* presented a comprehensive review of disaster management findings in their survey [37]. They highlighted that one of the most crucial challenges for disaster management is the absence of an adequate knowledge base to develop an effective response strategy. Recently, Sinha and Dutta conducted a systematic review [66] flood ontologies representing increasing usage of ontological approaches for flood knowledge management. The review is parametric based covering various aspects of ontology development.

A flood management system requires an integration of information from multiple complex domains of river streamflow monitoring, administration, disaster management practitioners, community participation, and spatiotemporal context of vulnerable regions. The vulnerability assessment process includes regional profiling, environment characteristics, and the portion of associated irrigation network with under consideration regions, accessible safe locations for community depending on flood extent. The historical flooding data contribute as a seed for vulnerability assessment of a particular region. The lack of effective coordination between response-providing NGOs, and disaster managing administration with the varying sectors, operating regions, mandate, and native information storage and representation practices are hurdles for an effective mitigation strategy. The importance of the knowledge base for effective coordination is highlighted in [30]. The diversities caused by poor communication mode resulted in ineffective coordination and collaboration of stakeholders for pre, during, and post-flood disaster management activities to mitigate the adverse effects of a flood.

B. OBJECTIVES

The objectives of the ontology-based Knowledge management approach for the integrated domains of irrigation, flood management, and administration are summarized below:

- An explicit definition of the concepts and relationships integrating the relevant domains for streamflow optimization and flood mitigation
- Resolving ambiguity of concepts and similar names of regions with URI(Uniform Resource Identifiers) for improved coordination
- Definition of relationships and types of interaction for integrating domains leverage the conflict resolution among stakeholders.
- Formalize semantic information exchange using underlying RDF enables interoperability for heterogeneous systems of stakeholders.
- Implementation using OWL 2 DL enriching ORFFM with explicitly defined object properties characteristics for extended semantic formalism than RDF
- Reasoning support for domain knowledge consistency and inference to derive implicit relationships and interactions
- OWL 2 with rule languages enable to use endurant part of ORFFM for streamflow heterogeneous data acquisition and aggregation
- Reducing the risks of the community living in flood-prone areas by context-based efficient Early Warning System(EWS), and knowledge base enriched disaster management activities.

C. CONTRIBUTIONS

Semantic modeling enriches information management, representation, and integration with modern knowledge-based technologies and improves coordination. Knowledge management implementations of water flow with improved visualization enable proactive planning to tackle the complex real-time situation and even more efficient proactive contingency planning. River streamflow data is collected from a variety of distributed resources across different barrages by the personnel of management organizations with their native format for data storage and use. The river and canals water flow data sources include manual gauging [9], telemetry [8], remote sensing [28] technique for glaciers and ungauged areas, wireless sensor network [38], [52] for high variation streamflow gauging stations, barrages, headworks, spillways, outlets, etc. Other data sources means include drone imaging,citizen observational data [48], crowdsourcing for hydrographs [20], stochastic modeling [65] and many others estimation techniques. The contributions of this study are proposal, design, and development of multiple domains integrated ORFFM knowledge base. Key features of the ORFFM knowledge base is summarized as follows:

- Streamline the coordination challenges of irrigation and riverine flood mitigation among stakeholders of the irrigation system, administration, and disaster management authorities for collaborative activities, interactions, operations, and policies backed by the semantic knowledge base.
- Semantics formalism for human and machine's understandability
- Modularization of large scale system spatiotemporal integrated domains for extendable, disruption-free executing workflows, and uniform accessibility
- Modular leverage the reusability, Extendability, easy integration, and coping with scalability issues
- Reusability support of defined conceptualization for other domain's integration, such as agriculture improvement, food security, crops trade, etc
- Domain knowledge for educationalist and practitioners
- Formal knowledge base for software agents based recommendations systems
- Knowledge base for effective data visualization, linked data and intelligent system based on semantic web 3.0
- Data Interoperability for stakeholders with XML/RDF based uniform and structured data storage rather than organizational native structure or schema.
- Knowledge base of major water level alteration semantics with integrated contextual information
- Domain knowledge base for irrigation system automation applications
- Semantic Modeling of spatial administration domain for coordination mechanism other disasters and smart applications such as smart cities, smart traffic network, election and e-governance

The emergence of technologies towards intelligent application development leveraging the increasing granularity of the data produced by IoT devices and computation capability. The rapid growth of smart applications and systems development is powered by semantics and context-awareness. The context-aware systems are based on the explicit annotation of location with surrounding entities of domains along with inter and intra relationships for knowledge inference. This computational and semantic integration may leverage the design and development of semantically enabled natural disaster risk mitigation systems towards sustainable development goals [5].

Natural disasters and relevant complex domains, especially flood disasters for agricultural countries become complex due to various local and contextual ambiguous terminologies. The semantic model [54] of such complex domain's knowledge with Description Logic(DL) [6] and First-Order Predicate Logic. It enables automated system development and knowledge conferencing DL followed by inference enables software agents to process the domain's semantics. Software agents are knowledge generators from explicitly described domain concepts and knowledge base to encompass the mitigation policies of any disaster domain in general and flood domain in a specific context.

Our ontology-based semantic model is a case study of the subset of the Pakistan irrigation system and disaster management domains. We evaluate our model based on competency questions in the context of the Indus River irrigation system and the flood disaster of Sindh province. Ontology metrics are also presented to assess the complexity, completeness, and expressiveness of the proposed ontological semantic model named "ORFFM".

In this paper, we presented a few research studies that highlighted the challenges of disaster management, water quality, spatiotemporal context, proposed flood ontologies in section II. In section III, the requirement of a semantic knowledge base for irrigation networks, flood management, and the relevant domain is discussed. Section IV describes the ontology development methodology for "ORFFM". Section V presents modularization aspects of interrelated domains for ontology development. Section VI describes semantic formalism, section VII covers evaluation metrics. Finally, section VIII is a conclusion, section IX discusses the future work and possible extensions.

II. RELATED WORK

In this section, we discuss the ontology-based relevant studies of river streamflow monitoring and/or flood management practices of practitioners. Various studies present an ontological model for flood forecasting [4] using sensing devices, flood risk assessment [61] considering the stakeholder preferences for integration and other relevant domain's may affect the decision support systems. We explore the key characteristics that enhance the impact of the model on the reduction of flood damages through mitigation strategies during the disaster management cycle. The variation of models based on the implementation context of the domain. The semantic model with interrelated domain conceptualization contributes towards the development of smart context-aware systems. Flood disaster requires the rapid availability of contextual information for response and recovery activities to minimize disaster damages. The ontological model with semantics and contextually relevant data extracted from heterogeneous, unstructured, incomplete data sources. The raw data processed and transformed into an interoperable format, logically structured, and contextual annotated for a particular event, location, time, and type of response based on the semantic model of that particular domain.

Yusuf *et al.* discuss in [63], the demand of information-centric ontology for the flood management and communication of relevant information. The advancements in technologies and techniques made this possible to model environment characteristics from spatial heterogeneous data sources. Structured, contextual, semantic, and accessible information enables to design and use of smart applications such as Apple Siri, Google Now, Wolfram Alpha backed by knowledge base system in real sense. The ontologies are easier to develop, maintain, and extend as per domain expansion compared to the classical database schema.

Pilar *et al.* presented in [18] a framework for mitigating the data challenges of water resource management through publishing and exploiting linked open data. They highlighted the integration requirement of the domain for multiple and heterogeneous data sources and how semantic web and ontology harmonize different data sources. They demonstrated their approach for water supply data of the Mediterranean region of Valencia, Spain. The ontology enabled data exploited for general users and enhanced management and usage. Curating the heterogeneous data and modeling knowledge is discussed in [71]. Demonstration of domain data through navigational data visualization and interoperability of data format facilitates towards design and development of a smart system.

Similar to WaterOnto [43] a water ontology for riverine water, the ontology for wildfire information portal developed by Kalabokidis *et al.* presented in [29] to resolve the limitation of keyword-based search and transferring to navigation search used in ontoFire for wildfire information portal. The authors evaluated their ontologies based on a scenario from 60 graduate students at the geography department, the University of the Aegean through navigation to require information more efficiently compared to keyword-based searching.

The interoperability and expressiveness challenges of heterogeneous and unstructured topography of flood defense data are highlighted in [16] by integrating domain data in the ontology. Furthermore, they discussed the significance of transforming legacy datasets to semantic web-enabled data.

The knowledge management system based on the ontology for flow and quality management of water was discussed in [11] for managing knowledge objects using XML/Java technologies just three classes as section, questions, and problems are defined. The prototype demonstrated the rule-based model selection by incorporating artificial intelligence technologies. A multi-agent rule base semantic system proposed in [80] for scientific knowledge workflow in adaptive mode. The flood risk assessment by considering the stakeholder preferences normally ignored using multi-criteria flood risk assessment ontology by Scheuer *et al.* in [61]. Potnis *et al.* presented in [51], a Flood Scene ontology for remote sensing images to improve the spatial-temporal context of the flood-prone areas. Image mining of the last decade enables to identify the flood inundation and recede patterns. Voutos *et al.* in [72], proposed a semantic model for environment monitoring through wireless sensor networks to capture the spatiotemporal context for efficient and real-time monitoring. Table 1 asses some of these studies with purpose, feature, and limitations.

The information extracted from ontologies of the correlating domain provides even better results by integrating reusable ontologies. For instance the SWEET suit, forest, vegetation, weather, geographic domain to cover fire domain [29], flood disasters [24], environmental Impact Assessment (EIA) ontology for flood management domain [14]. DOLICE, SWEET, and others for Decision Support Systems based on semantic sensors [25]. The semantic modeling [54] resolve the communication gaps for the system's users and diverse datasets through representing the meaning(semantics) of the dataset and collaborative activities with common conceptualization.

The semantic modeling approach for river streamflow and flood mitigation involves the integration of interrelated domains of environment, hydraulic, hydrology, irrigation system, agriculture, and collaborative responsibilities of stakeholders with an explicit definition of entities along with interaction. For the semantic model, information about the domain is explicitly defined for context extraction. The context is obtained from the domain's formal specification of concepts, properties, and relationships. The collaboration among stakeholders for flood mitigation during the preparedness, response, recovery, and rehabilitation phases of the flood disaster management cycle demands a uniform description of phases and activities during each phase along with the assigned or responsible stakeholders. Ontologies enable rules-based inference, interoperability, and visualization structure. It enables semantic integration of knowledge with geological, hydrological, and other relevant domains for crises management [81]. The ontology support semantic integration-related domain to provide the common operating picture to reduce the risks in emergencies. Ontology engineering resolved the problems associated with the heterogeneity of multi-source heterogeneous data sets for the common conceptualization of entities, properties, relations, explicit definitions, and restrictions for concerned stakeholders [75].

Kollarits *et al.* in [31] presented MONITOR risk management ontology that captures the relevant concepts related to Hazard, risk, disaster, and represents the knowledge about the relations of risk reduction strategies for risk reduction goals to serve as a reference ontology for the of natural hazards monitoring and management.

A. EXISTING FLOOD ONTOLOGIES

Various ontology-based studies were proposed, developed for different aspects and types of flood disasters. In this section, we very briefly refer to these approaches and aspects that represent the evolution of ontology for such complex integrated problems and continuity of research in the field of semantic web technologies. Agresta *et al.* presented Flood-Ontology [4] an ontology-based framework for flood forecasting using a continuous stream of data about watersheds and sewer flow conditions. This project was sponsored by National Operation for Research and Competitiveness for smart cities. The modular approach was used for ontology development. A multiagent-based emergency management ontology for monitoring dams and flood response using Protégé 2000 by Norwawi *et al.* in [3]. The sharing of information through linked data to address power energy issues

TABLE 1. Relevant domain's ontologies representing different aspect of flow and flood assessment using ontology based approach.

Ontology domain	Reference	Purpose	Feature/s	Limitations
Flow and quality management of water	[11]	To Identify water flow direction and quality	Rule-based for model selection	Only three classes, Limited Scope
Flood Risk Assessment Ontology	[61]	To prioritize the stakeholders' preferences towards flood assessment	used METHONOLOY and UPON for ontology development, local knowledge integration, capturing stakeholder preferences	Limited to only four use cases, Covers only risk assessment, no support for risk mitigation or management
Flood Scene Ontology	[51]	Content-Based Image Information Mining frameworks Proposed for improving the semantic understanding of remote sensing imagery by leveraging ontological representations	Inferring the topological, and directional relationships from the remote sensing imagery of flood scene and temporal context	Covers only flooding of urban areas based on images mining techniques
A semantic model for Spatio-Temporal environment	[72]	Environment monitoring through WSN and semantic modeling for DSS	The novel conceptualization of an IoT and Semantics integrated environmental monitoring system	Preliminary ontology model

triggered by flooding presented by Roller *et al.* in [58] for permanent flood risk in the Netherlands. Relevant domain concepts covering stakeholders' interest are described such as ''Water Resistance Threshold'', ''Water Supply Area'', ''Pumping Stations'', ''Electrical Supply Area'', ''Cable'', ''Water Level'', etc.

The effectiveness of flood management is based on the quality of risk assessment activities. An effective risk assessment strategy depends on the magnitude of expert-level knowledge, local and contextual knowledge integration. The study [61] form a flood risk assessment knowledge base from multi-criteria risk assessments. The reusability feature of ontology-based models leverages the knowledge-based integration towards more effective solutions. Scheuer *et al.* presented in [61] reused MONITOR [31], SWEET [15] and other relevant ontologies for integrated flood risk assessment. An upper-level watershed flood risk assessment ontology extending SWEET for the environmental concepts is presented in [78] by Yi and Sun. They highlighted the complexity raising due to urbanization and climate change contribute to watershed flooding. The spatiotemporal context is the key to understand the semantics of data generated from sensors. Reuse of space and time ontology for extension hydrology classes presented by Wang *et al.* in [73]. They have also reused SOSA (Sensor Observation Sample and Actuator), Geo, DOLCE, and SSN ontology for sensors' spatiotemporal context. It is implemented using SWRL for rules and GeoSPARQL [49] for spatial querying.

The ontology-based coastal flood emergency model presented by Garcia *et al.* in [21]. Various modules are based on infrastructure data and heterogeneous data from web-accessible distributed sensor data of the coastal domain. They integrated existing upper-level DOLICE ultra-lite and SWEET ontologies. Infrastructure level ontologies are SSN, SSN Extension, Schema, and services. Coastal defences and role ontologies play a vital role at domain level modeling. The post-flood time required to recede floodwater from the inundated area using remote sensing imagery is an important activity of the recovery phase from the disaster management cycle. The spatiotemporal context-based ontological model for dynamic flood inundation monitoring presented by Kurte *et al.* in [34]. The flood inundation change was assessed by SWRL rules for topological, temporal, and spatiotemporal variations.

In [67] a context-aware system for configuration adaptability of wireless sensor network for environmental conditions. The wireless sensor network implementation for French Orgerval watershed monitoring. Sun *et al.* proposed JADE ontology integration portion of Semantic Sensor Network Ontology for main concepts such as Sensor, FeatureOfInterest Property, etc. Jess Rule engine for inference and java for developments.

III. ONTOLOGY BASED SEMANTIC MODEL FOR DISASTER MITIGATION THROUGH RIVER FLOW OPTIMIZATION

Disaster management is a multidisciplinary domain and requires an urgent response for rescue, rehabilitation of the affected community. These response activities involve a large group of peoples from a variety of technical backgrounds, social sectors, and volunteers. To reduce the complexities, avoiding misinterpretations of the terminologies used during various phases of disaster management, ontological models are proposed for the common conceptualization of the targeted flood hazard management domain. Semantic modeling for river streamflow optimization and flood mitigation is an interdisciplinary research area covering river flow management with a hefty set of rules, policies, constraints based on spatiotemporal context computing, disaster management, and computer science as shown in the Venn diagram in Fig. 1. Context sensing and computation for risk communicated to concerned authorities and vulnerable community for proactive risk reduction strategy known as *Early Warning System*.

Semantic modeling of the irrigation domain considers the distribution of water sources, storage, diversion, and channeling. Similarly, the flood mitigation strategy requires the contextual knowledge base for river streamflow patterns, variation with possible causes, vulnerability assessment of spatial region union council, tehsil, district, etc coined as *Flood Vulnerability Assessment*. The assessed vulnerability of these administratively and hierarchically distributed spatial regions with various administrative levels, the population at risk, capacity for risk avoidance, and mitigation practices conceptualized for knowledge sharing are essential components of the semantic model for flood mitigation. Other components include the data sources, acquisition techniques, and disaster management phases through semantic web technologies and programming language for knowledge inference and automated reasoning.

An adequate *Early Warning System(EWS)* is key for disaster risk mitigation. Integration of state-of-the-art technologies and computational capability has proportionally improved the effectiveness of EWS. Phengsuwan *et al.* in [50] presented the ontology-based early warning system and decision support system for landslide hazard from time-series data of urban authorities and social media data.

A. WHY SEMANTIC WEB TECHNOLOGIES FOR FLOOD MITIGATION

Studies discussed in the previous section much demonstrated that coordination is the main challenge among disaster management authorities, humanitarian organizations, and the community due to the decentralized environment with different information management structures. The respondent organization's ineffective coordination results in replication of response activities in one region and gap in other affected regions. There is an emerging demand for a common data sharing and representation framework. Peter Tatham *et al.* in [69] present the need for a logistic common operating picture for humanitarian organization emergency response.

The semantic modeling solves the domain-related implicit coordination problems and shares understand-ability across the different stakeholders by sharing information not only in an interchangeable standard format across various platforms but also in machine-processable format using semantic web languages. Provision of this interoperable information is key for an effective contingency planning to mitigate flood disaster impacts on each phase(Preparedness, Response, Recovery, and Rehabilitation) of the disaster management cycle.

Rivers flow information changed spatially and temporally at the different streamflow monitoring stations and barrages that need to be closely monitored for water distribution. The pre-planning and proactive actions are required for flood hazard to mitigate their impact. In the preparedness phase using a capacity building, contingency planning, flood-prone areas identifications, and identification of barren lands or sparsely populated areas for discharge excess water in case of unavoidable circumstances. The flood mitigation strategy in case of unavoidable flood requires contextual knowledge about zones for flood impact reduction by diverting the flood to an artificial path with a reduced risk of flood artificially. An approved plan from the administration needed to compensate sparsely agricultural lands and evocation community along with rehabilitation for sparely populated areas.

The ontology enables a search of the known and exploratory discovery of unknown terminologies of the semantic domain model. A shared web interface would enable us to explore and retrieve the required domain information for a specific context.

We formalize the irrigation system, disaster management, and administration in the context of flow optimization and flood risk mitigation with a modular approach. The following subsection, discuss a few core concepts for demonstration. The detailed description and code will be a publicly shareable repository. We selected OWL 2 DL for the ontology development of the aforementioned modules using the Protégé 5.5 [45], as an ontology development environment.

B. SEMANTIC MODELING OF RIVER FLOW

Ontological representation of semi-structured data along with contextual knowledge, particularly, where stockholders' coordination from distributed location and different mandate contributes exponentially. Sharing of information in a variety of formats is a challenging task that is manageable by developing an ontology with interoperability for information sharing that enables real-time context computation. Ontology-based Interoperability and contextual information for streamflow monitoring, support the provenance [41] of the system. The decisions based on this information can be retraced, evaluated for authenticity and efficacy of the information. The fundamental constructs of ontology include Classes, Relations, Axioms, and Instances depict the domain knowledge in a more comprehensive and natural semantic style with core concepts and their correlations.

The semantic model [40] enables the design of an automated system real-time monitoring river streamflow compliance with pre-defined rules. The classes represent concepts, which are taken in a broad sense for all stakeholders in contextual computing environments. Collaborative interaction among concepts of similar and different domains is illustrated by *Relations*. Ontologies stored in RDF triples represent an association between the domain of the relation and range through some object property defining the binary relationships in two individuals/objects.

Axioms logically elaborate information about a class of irrigation authorities using subproperties CoordinationAndCommunicationProperties to manage irrigation network with different tasks defined in ORFFM. The class of AdministraitveDistributionOfSpatialRegion is an axiom for class level description defining the places, to relate with an event, impacts, and the possible losses of disaster on the

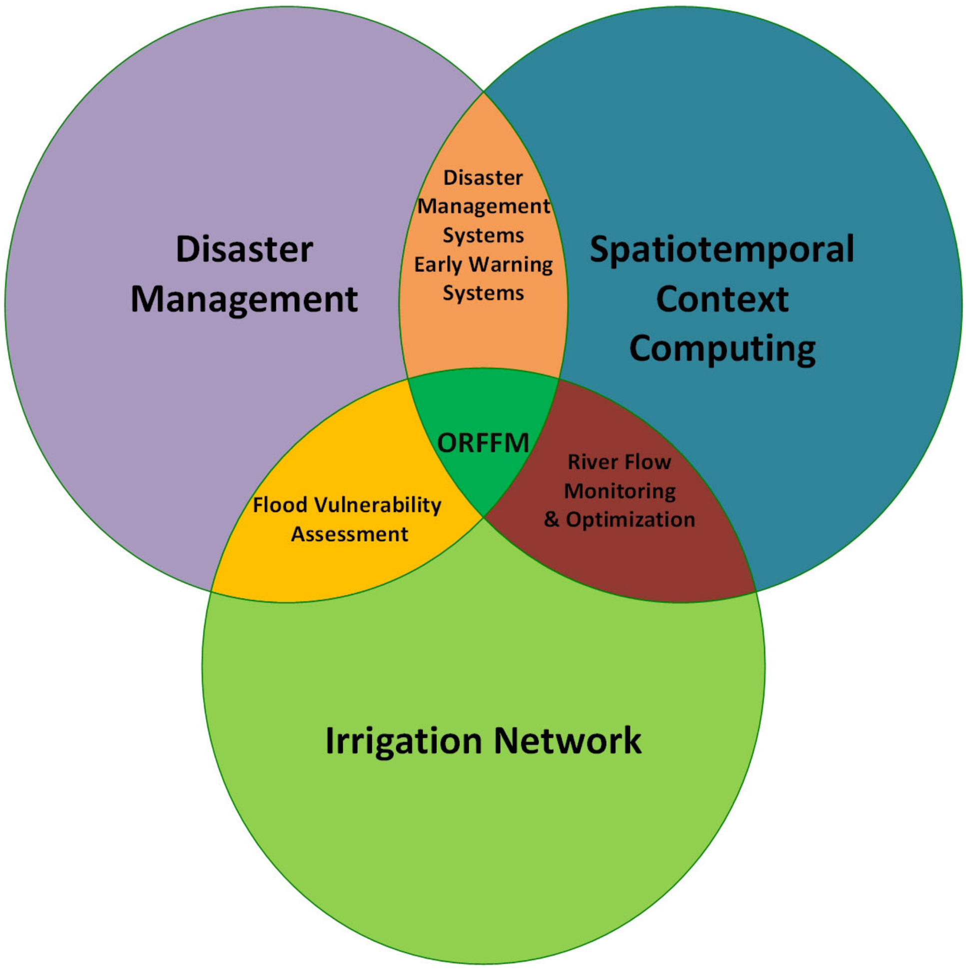


FIGURE 1. Venn Diagram for streamflow and flood mitigation represents ORFFM as spatiotemporal computing for integrated domains of Irrigation Network and Disaster Management.

communities of these spatial regions. The hierarchical classes define IsA Relation, for instance, rainfall ISA meteorological factor. The restrictions can be demonstrated using cardinality restrictions for instance individuals can be restricted to related to another restriction using min, max, and exactly cardinality restriction. The sets of individuals are formed by partitioning the individual using logical conditions for division, and Boolean combinations of descriptions. Formal axioms validate the consistency of the ontology and knowledge base. Formal axioms are used for new knowledge inference. An axiom in the WaterGrid [44] infers a list of the causes of a particular variation in streamflow. Individuals are created to transform an ontology into a knowledge base. For instance, The River flow situation of a particular day is defined with the set of data properties to extract rainfall forecast information from the meteorological department portal to measure its impact on the river path. In [11], the architecture and implementation of a prototype ontology-based KM system are developed for flow and water quality assessment with three-stage. The Java/XML-based scheme is proposed for automatically extracting knowledge. The fundamental issue in the design of an interoperable GIS-based solution for urban applications is the development and use of ontologies to support semantic interoperability.

In general, most of them propose the models' based management of water with geographical and climate concerns. Very few citations reflect the gap for semantic modeling approaches for River streamflow management. Our work shall address this domain with improved data acquisition semantic, semantic modeling of irrigation stakeholders, operation services, policies, and improving data reliability by applying distributed data pre-processing, storage, replication, and communication techniques.

Feature selection techniques for information gain to develop predictive models from external and heterogeneous data sources benefited from explicitly defined features relationships and hierarchy [7], [57]. The feature in a hierarchical relation subsumes features having similar semantics. These subsumed features for feature vector from ontology-based river streamflow and flood mitigation is semantic feature vector. The predictive model with semantic interoperability and publishing on Linked Open Data performs better forecasting, fulfills data needs for other smart applications, and interactive visualization for feature selection [57] to generate the feature vector.

Petar Ristoski *et al.* in [56], presents the feature selection from hierarchical information in combination with standard metrics, such as information gain or correlation to identification and selection of features based on relevancy, and valuable hierarchical abstraction preserving predictive power. This approach also reduces the optimal trade-off for feature selection between the predictive power and the generality. The problem of over-fitting may be fixed too. RiverFlow characteristic flow velocity and inclination, depth and width, temperature, evaporation rate, precipitation, and rainfall tendency have a relationship that may assist in feature selection. Similarly, the digital elevation of the community from the river basin, the distance of community from river breach vulnerable point, the time required to access to a safe location, tracks to a safe tract, transportation, time interval of early warning information available to the community, and time in which floodwater inundate that area, possible inundation extent, etc, have strong relationships that may assist feature vector selection for an optimal flood mitigation model. Balancing granularity of the data for computational power requirements the feature pruned to standard feature with higher predictive power.

We proposed the ontology of the Context-Aware Grid-Based real-time river flow and breach identification assisted Riverine Water Management System [44] and semantically classified water-related terminologies as WaterOnto [43] a top-level ontology. We extended this work for domain and task level ontology for river flow and flood mitigation semantic model to represent domain knowledge and task level concepts through semantic modeling.

"Ontologies based solution were triggered by increasing numbers of natural disasters and man-made disasters, such as Landslides [50] earthquakes, tsunamis [17], floods [76], air crashes [77]. Post disasters recreation, rehabilitation, and restoration cost are ten times higher than pre-disaster mitigation strategies. This finding posed challenges for authorities and demonstrated the importance of a semantic knowledge base to plan rapid response from disaster management authorities and other authorities to use shared knowledge that shall assist in proactive mitigation strategies in emergencies. The effectiveness of the response strategies depends on the availability of the contextual information integrated with GIS, local context, infrastructure, recovery equipment provision, relief goods, spatial administration, and other related information. The information is extracted from the integration of static data and operational data. Most of this information is geographically related and therefore when discussing the integration of information for disaster management response, we often refer to the integration of geo-tempo information.

Keyword-based searching of spatiotemporal information is not sufficient in rapidly increasing data size. The interoperability challenge can be solved via the use of an ontology to reveal implicit and hidden knowledge. Our research includes investigating semantic effectiveness and proposed ontologies-based solutions for the distributed but integrated river flow and flood management system. This includes developing three types of ontologies. Generic or upper-level ontology of related concepts spatial regions, administrative or government entities, hydraulic, meteorologic, and environmental concepts. Then domain ontologies of the irrigation system in the context of flood disaster management. An ontology with a focus on riverine flood risk mitigation by considering riverine suburb contextual information and other river flow and related entities to fill the contextual knowledge base gap of an irrigation country.

For the proof of concept, we develop and evaluate the said ontologies with Abox and Tbox consistency for the subset of the Spatio-temporal scattered irrigation network of Pakistan. This contextual information system is based on a modular approach for emergency response and contingency planning but extendable for water resource optimization, efficient management, and agricultural productivity improvement.

Moreover, a semantic repository enables a search of unknown concepts and exploratory discovery of unknown terminologies of a domain. A shared web interface would enable us to explore and retrieve required domain information for a specific context to achieve the objective of sustainable growth.

IV. METHODOLOGY

Various ontology development methodologies adopted for ontologies based projects and presented in literature such as Cyc KB [36], Uschold and King's method [70], Gr€uninger and Fox [26], UPON [13], and METHONTOLOGY [39] To the best of our knowledge, there is no standard methodology for ontology development. A comparison of methodologies and tools for the ontology development and consensus points discussion is available in [12]. However, we have used the merger of UPON [13], and METHONTOLOGY [39] methodologies for ORFFM development. The workflow along with phases of ORFFM ontology development is shown in Fig. 2.

The first phase of ontology development is a specification of streamflow and riverine flood mitigation's concepts, attributes, and relationships from the phenomenon associated with the riverine flood. This includes river streamflow data acquisition techniques, the usage of that data for calculation of streamflow levels, discharge to withdrawing canals, and flood vulnerability assessment of communities on the river belt, associated agricultural lands, infrastructure in flood-prone areas. Based on the types of flood damages, mitigation strategies in all four phases alongside necessary rules and constraints explicitly. The details of concepts and sources are described in section IV-B. The defining the Competency Questions for refinement of scope presented in section IV-D. Then conceptualization and implementation of integrated modules are presented in section V. The evaluation of the model is based on the competency questions and results derived using SPARQL depicting CQs are presented in section VII-A.

A. SCOPE OF ORFFM

The ORFFM model captures the domain definition to resolve the coordination issues among the stakeholders for river streamflow measurement optimization, efficient water distribution scheme development. The contribution to the flood mitigation domain includes explicit conceptualization of domain and task concepts for flood management phases. The coordination from shared knowledge base reduces wastage of effort and resources of duplication of services and reduces damages of unaddressed flood-affected areas. The key characteristic of the ontology model and mapping to ORFFM are presented in Table 2. For the sake of scalability and reusability, we preferred the modular approach for the domains of the irrigation system, disaster management, administration, and agriculture. To cope with the challenge of expressiveness vs. computational performance, the implementation partitioned based on the regional hierarchy was recommended. The integration of these modules was sculpted into ORFFM. The extension of any regionally independent subset of the knowledge base may be configured to the required expressiveness level.

B. DOMAIN KNOWLEDGE ACQUISITION

The ontology concepts are defined based on the major entities with their characteristics and interactions. We have reused few relevant concepts of ontologies [4], [79] discussed in the literature review but defined in our domain and task context. The other source of domain knowledge is manuals and reports of stakeholders. Furthermore, the confinement to their workflow context extracted from interaction with stakeholders such as National Disaster Management Authority,[1] State or Provincial Disaster Management Authority,[2] Relief Department, Irrigation Department's personnel, and Oxford dictionary[3] for generic concepts. meteorological department,[4] Water And Power Distribution Authority(WAPDA),[5] and online knowledge systems e.g. Wikipedia.[6] Besides the secondary data source, the primary research to extract the right usage of concepts, we conducted meetings with DMAs, Irrigation Officers, and expert of relevant domains for refinement of concepts, relation, and constraints extractions from meeting refined the user requirements and enabled for mapping user' requirement's to competency question The ORRFM model evaluated based on the response of competency question from stakeholders. The top-down development process adopted with the consultancy of a domain expert to create classes and subclasses hierarchy with the most general classes and specialize afterward and so on. For instance, in the riverine flood ontology, the types of disaster class have subclasses(Biological, Climatological, Hydrological, Metrological, ...) then Hydrological has further subclass (Flood, Avalanches, ...) and Flood has a subclass(Flash Flood, Riverine Flood, ...) on so as shown Fig. 6. The details of the class hierarchy discussed in the following sections with their use for each relevant module.

[1] http://cms.ndma.gov.pk/

[2] http://www.pdma.gos.pk/new/

[3] oxfordlearnersdictionaries.com

[4] https://www.pmd.gov.pk/en/

[5] http://www.wapda.gov.pk/

[6] https://www.wikipedia.org/

C. ONTOLOGY DEVELOPMENT TOOLS

Various IDEs, plugins, and frameworks that ease the design, development, and implementation of the ontology-based models are recommended by the World Wide Web Consortium (W3C).[7] Nur Liyana Law *et al.* [35] discussed popular ontology development IDEs includes Protégé [19], [45] freely available open-source tool for desktop and web-based ontology editing, OntoEdit [68] for collaborative ontology editing, Differential Ontology Editor (DOE) [19], and many others with various features. We opted for the Protégé desktop for the ORFFM development with HermiT 1.4.3 semantic reasoner for consistency checking. The OWLVis and OntoGraph for graphical visualization. The SWRLtab [46] support for adding and editing of SWRL(Semantic Web Rule Language) rules in ORFFM OWL 2 DL for implementation and execution with Drools [53] rule engine. The SWRLB contains built-in functions to infer axioms executable on Drools rule engine. To query the ORFFM knowledge base the SPARQL query tab of Protégé 5.5 enables to query and view the result of the knowledge base for competency questions based on evaluation of the domain ontology.

D. COMPETENCY QUESTIONS

The user requirements are translated as Competency Questions(CQs) in natural language. CQs outline and confine the scope of knowledge base [74]. A satisfactory response to competency questions is the way to assess the objective's accomplishments of an ontology-based project. Our competency questions capture the scope of flu flood ontology. The sound responses of competency questions reflect the quality of the ontology. CQs mapped to SPARQL query language to retrieved required knowledge from the knowledge base and extended it to comply with ontology usage for context-aware computing systems. The CQ is defined in natural language to support novice user's interaction with the ontological knowledge base. NLP-based API and software tools enable the translation of the natural language to SPARQL query compatible with the RDF and OWL. QAKIS [10] used for querying linked data DBpedia through multilingual natural language statements. Besides that domain, the specific application provides means of access the contextual data depending on the domain. The queries were formulated to retrieve the information about water distribution from river flow and managed by the irrigation department, disaster management department for fluvial flood's forecasting. Administration streamlines coordination in irrigation and disaster management for field

[7] https://www.w3.org/

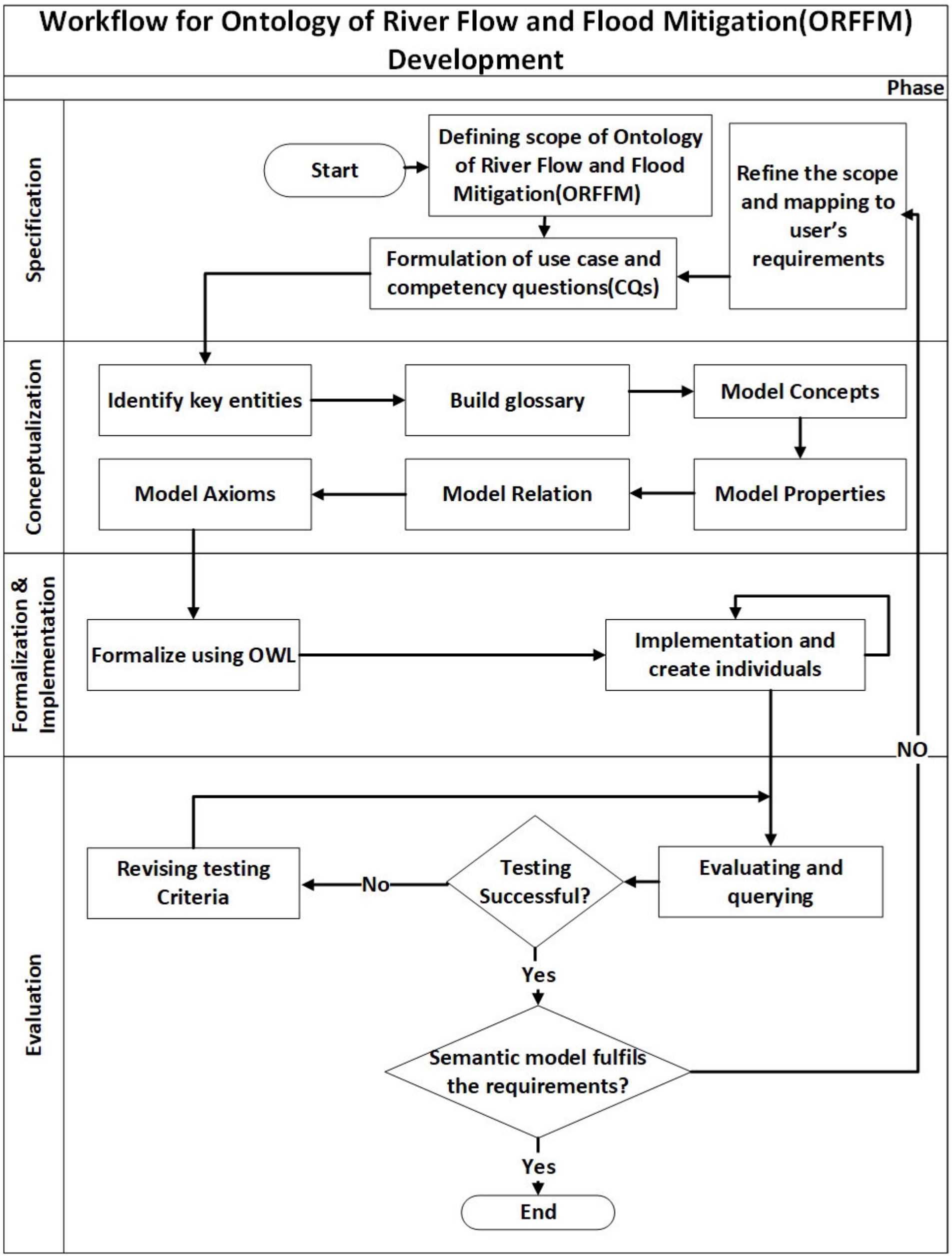


FIGURE 2. The Workflow of Ontology development describe the activities of each stage according to ontology development guidelines of UPON and METHONTOLOGY methodologies.

TABLE 2. Ontology characteristic mapping to ORFFM.

Requirement	Description
Visualization	Graphical components for public visibility of fluvial knowledge base
Simulation	Enable multiple stakeholders to maintain and enhance the ontology
Interoperability	Ontology underlying RDF exchange information among heterogeneous systems

activities. The ORFFM ontology may be queried for spatial, administrative, and management relations with classification and connectivity analysis. The stakeholder's requirements are mapped to competency questions as the functional requirements of ORFFM. A few types CQs are represented in Table 3 related to the irrigation and disaster management domain along with possible responses.

E. ONTOLOGY STORAGE

The ontology storage model discussed in [2] with native and database perspectives. The ontology storage model is assessed based on the query language support, API support, remote interface, inference support, versioning, access control, reliability, materialization, update, indexing, granularity, platform, pricing policy, and benchmarking. The

TABLE 3. Types of competency questions relevant to knowledge base of irrigation and disaster management domain along with possible responses.

Type of Competency Questions	Expected Action
What will be the extent of the riverine flood with the current streamflow situation?	Map Output (i.e. System shows high stream flowing portion of the network along with associated flood vulnerable areas on the map)
Which region may be affected in the next 24 hours?	Textual output as region names(i.e. System returns the vulnerable UCs based on flow)
Which DMA authorities required to respond?	Name of the authority (Textual Output)
What may be possible damages?	List of damages (Textual output)
On which point artificial breach may reduce the impact of the flood?	Name of a portion of land with minimal impacts (Textual output)
What is a safe location after a flood to move the community?	Digital elevation model with accessibility network

straightforward method of native storage perspective allows disk files.The triples as hierarchical stores have the limitation of scalability and share-ability. We opted for the JENA TDB [2] with Apache Jena Fuseki [1] server REST API for our ORFFM ontology storage and retrieval respectively.

V. CONCEPTUALIZATION OF MODULARIZED ORFFM

The modular approach resolves the complex domain problems to an aspect-oriented [60] problem for simplicity and manageability. Development of modules for disaster management, rehabilitation department, volunteer organization, rural communities, irrigation, and agriculture, are defined in ontological conceptualization for improving interaction and coordination. For instance, agricultural improvement semantic portal to improve the efficiency of water utilization through water availability based crop recommendation to farmers towards improving the agricultural productivity. A farmer that is interested in river streamflow current and forecasted information, rotational program, irrigation network water, and rainfall forecasting data to plan to water their cultivated crops, etc.

The core concepts are portioned for a modular approach towards the design of irrigation systems, disaster management, and administration. The corresponding classes are conceptualized in the ontology for better understanding and contingency planning. ORFFM ontology is developed using the most popular ontology development IDE Protégé 5.5, hosted by Stanford University [45].

The following are major top-level classes integrating multiple modules:

- Process
- Person
- Organization
- Infrastructure
- Event
- DisasterManagmentCycle
- Administration
- Agriculture
- Livestock
- IrrigationSystem

The top-level classes of each module are explained in each respective subsection. Moreover, the description of logical relation is explained in section VI.

A. CONCEPTUALIZATION OF IRRIGATION SYSTEM DOMAIN

In this section, we are describing the domain and subdomain that are directly or indirectly related to the irrigation system. The irrigation departments with management hierarchy, service, operation, type of involvement towards water resource management, mandate, and other relevant concepts. Then the ontological representation of concepts, relations, individuals, rules, and axioms are defined. Domain experts are involved in domain concept extraction for the proposed model.

1) COMPONENTS OF RIVER FLOW MANAGEMENT

A well-structured and efficiently managed irrigation network with adequate availability of freshwater resources is the backbone of agricultural countries. Besides efficient distribution, the storage of water in dams and reservoirs for the power generation and winter season is equally important. Planning for storage of water along with its distribution in the monsoon season may reduce the over-spill of water that causes damage to the irrigation land, infrastructure, and communities in the suburb of the irrigation network. The irrigation system authorities have a major role in optimizing freshwater distribution and management, especially during monsoon seasons. Here, we first focus on the main concepts extraction from the irrigation domain to develop the domain ontology and their activities as task ontology. We populate the ontology with Pakistan's irrigation system to transform it into a knowledge base. The following are main irrigation system and water resource management phenomena:

- Streamflow sources, storage and distribution mechanism
- Spatially distributed infrastructure for reservation and distribution
- Flow control mechanism and distribution policies
- Management authority with structure and their responsibilities

- Streamflow data acquisition techniques and data aggregation

Keeping in view the complexity of the heterogeneous data sources and variety of the domain concepts. We shall classify the concepts in groups, modeling the context of a generic, modular, reusable, integrate-able with other relevant domains for the development of context-aware systems. Then predefined policies and decisions along with recommended mitigation strategies are adopted. In the absence of an available mitigation strategy pattern, current information is forwarded to responsible authorities. WaterOnto proposed in [43], Generic ontology defines general terms such as Water, Glacier, Lake, River, etc with the standard common definition. This WaterOnto ontology's generic concepts extended in the irrigation system module of ORFFM. For instance ORFFM: WaterSource is generated from WaterOnto: Glacier, ORFFM: StreamFlow has subclass River, etc. Furthermore, the Module of irrigation System populated with a real-world instance of the Pakistan Irrigation System.

2) STREAMFLOW MANAGEMENT OF IRRIGATION SYSTEM

The classes hierarchically defining the aggregated concepts of a knowledge base. Top level concept/s are abstract and may contain the hierarchy of concept/s with more concreteness. `Streamflow` is one of top level classes of `irrigationSystem` module. The `DiversionStations`, `RiverStreamflowPath`, `WaterDistrbutionScheme`, ...,and `WaterWays`. An important concept `WaterWays` with subclasses `River`, `Canal`, `Distry`,...,`moga` etc. These `WaterWays` are grouped in `CanalSystem`, `CanalCircle`, and `CanalDivision` for efficiently management by distribution authority. The `WaterWays` groups are mapped to concerned flow managing official for gauging, maintenance, theft detection and elimination, desilting basin, high flow mitigation and diverting streamflow. The `IrrigationNetwork` subclasses representing subset of physical irrigation network and mapped to respective manager from managers hierarchy from `Person` class as `WaterResourceManager`, `CheifEngineer`, `SubEngineer`,...,`Zilladar`, etc.

The river streamflow originated from the water resource of the glacier, through snow melting or rainfall in these areas. Then passes on the path and stored in `WaterStorage` (dams, reservoirs). For the distribution of water `WaterDistributionScheme`(rotational programs) following administrative policies and water division through `DiversionStations` such as barrages, headworks, spillway, and distributaries. The other relevant classes along with the relationship are sown in Fig. 3. Water quality is also assessed for contamination of dangerous chemicals as this freshwater is also used for water supply to household and animal's drinking. The research departments are also relevant for research on storage, efficient utilization, electric power generation, and quality assessment. The `RiverStreamFlowPath` has five subclasses of major river passage and mapping of tehsils within a 3-kilometer radius. The vulnerable tehsil spatiotemporal context computing and storing as a spatial index. The vulnerable tehsil profile with the spatial index used for early warning system and communicated to relevant administrative authority through GeoRSS [55].

Expansion of the WaterDistribution involves the different levels of the irrigation network entities, managing authorities levels such as provincial, regional, zonal divisional authorities for rotational program and distribution logic. The snapshot of relevant entities of river streamflow represented in term of classes shown in Fig. 4.

The topological elements are used for the contextual profiling and vulnerability assessment of any spatial location on the passage of the major river. The digital elevation of the location enables the forecasting of the flood inundation outspread and flood inundation period. The information about the barren area assists in the decision of an artificial breach to save the community and agricultural lands towards minimization of the losses. The roads, railways, and safe locations enable us to respond to the flood disaster and evacuate the village, Deh to the nearest and easily accessible safe locations, and rescue community. The object properties connecting topological classes presented in Fig. 5.

In case of the flood disaster, the parameters to assess the impacts and damages of a flood are estimated from areas affected, asset affected, livestock(cattle, goats, chicken, ...) affected, crops affected, equipment affected, house affected, peoples affected(people died, injured and relocated), Masjids affected, roads affected, hotels affected, bridges affected, powerhouses affected, etc. The encoded damage classes are presented in Fig. 6. The Provincial Disaster management authorities collect daily and weekly information from each district to assess the damages and communicate to federal authority NDMA for the collaborative response, recovery, and rehabilitation activities. The national and international NGOs, charity organizations, social individuals join hands for the provision of shelter, food, health facilities, and reconstruction of damaged houses. The common conceptualization of all these stakeholders along with the real-time collaboration for reducing the duplication of response activities and gaps of the unattended affected community contribute to the optimization of efforts and resources. The contextual knowledge base for the spatial-temporal information also optimizes the response time of reactive rescue activities. For instance, the house damaged in Ghotki District during the Flood 2010, the weekly damages of Kucha and settled areas for the month of August to December 2010 are expressed in Fig. 7 based on the data of PDMA Sindh. Embedding this weekly information using semantic representation and sharing among stakeholders enables to provide relief activities on time to affected communities for shelter, food, health, and other essential services.

Moreover, we have many other water diversion mechanisms [42], which are applied on rivers such as Barrages

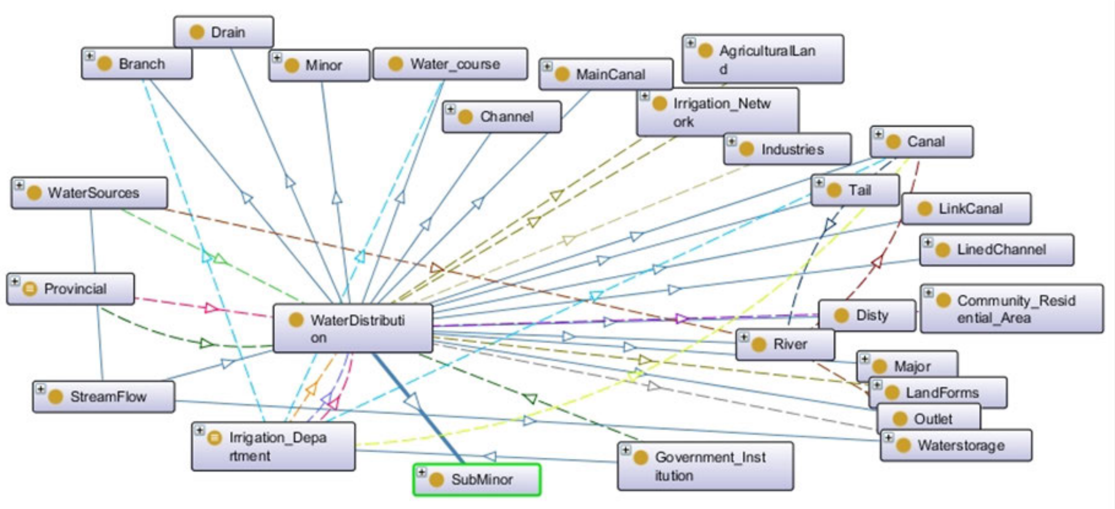


FIGURE 3. **WaterDistribution subclasses represent concepts representing streamflow mechanism.**

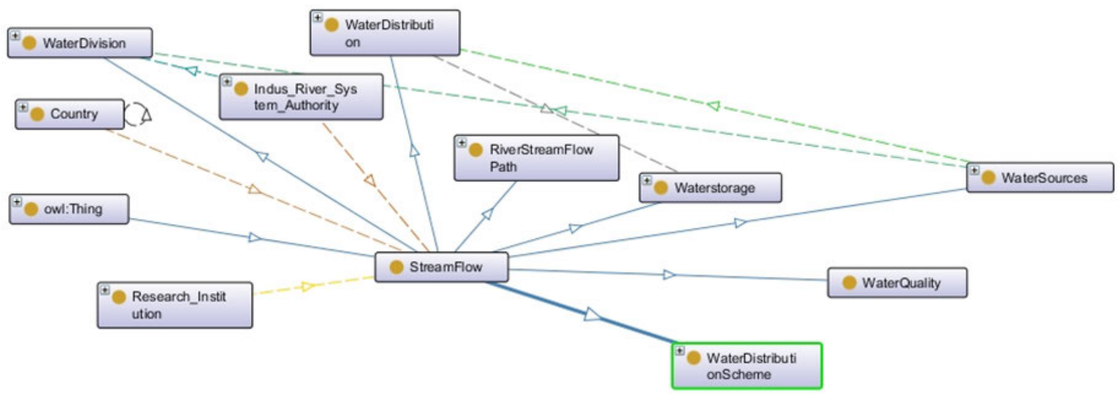


FIGURE 4. **Some River streamflow related classes.**

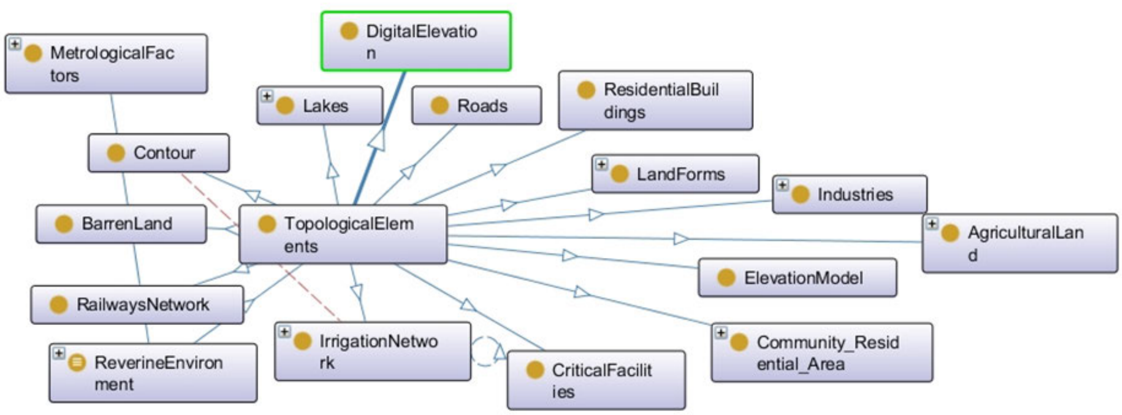


FIGURE 5. **Topological element for spatial information.**

"an artificial barrier across a river or estuary to prevent flooding, aid irrigation or navigation, or to generate electricity by tidal power". `Barrages` help us to divert and control the follow of the river of water. In most cases, barrages divert the flow of rivers towards dams and dams store the water and branch-outs to different canals "an artificial `WaterWays`

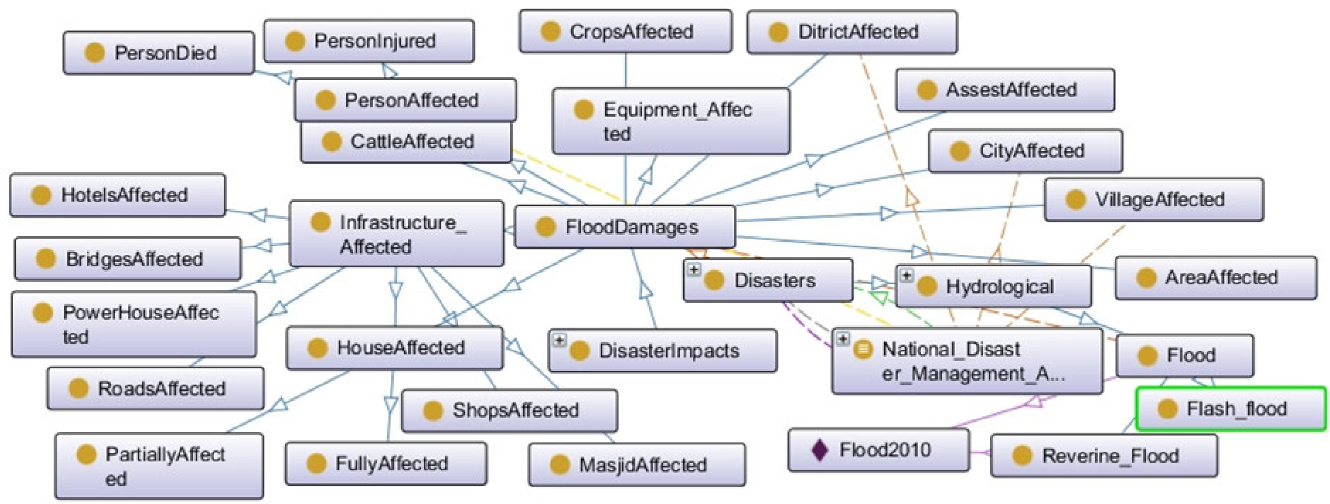


FIGURE 6. Types of Flood Damages.

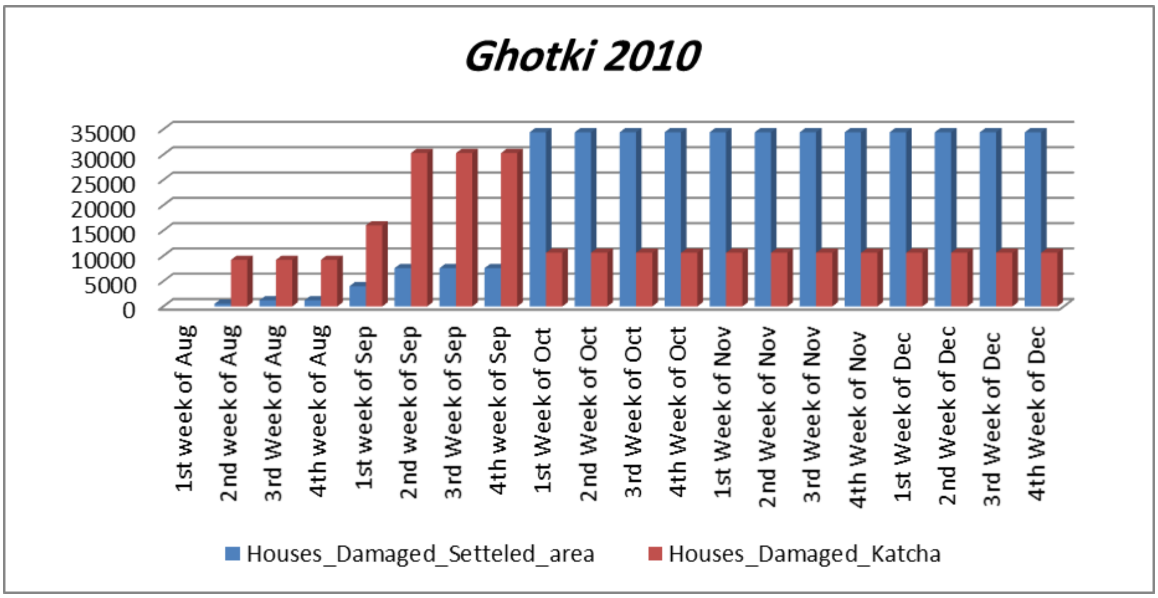


FIGURE 7. Flood Damages- House damaged ratio of Ghotki District affected by flood 2010[Data Source PDMA Sindh (weekly damages updates)].

constructed to allow the passage of boats or ships inland or to convey water for irrigation''. Further, we have a diversion mechanism on canals called `Headwork` [42] ''apparatus for controlling the flow of water in a river or canal''. These headworks manage the flow of water in different watercourses (a brook, stream, or artificially constructed water channel). These watercourses are used in irrigation lands and supplied to different tanks that supply water for the irrigation of fields, fishponds, and domestic water supply purposes.

3) IRRIGATION MANAGEMENT STRUCTURE

The irrigation management spatially and administratively distributed in departments, zones, Canal division, Canal circle, and canals system for distribution, maintenance, water theft detection and eradication of hidden withdrawal means, desilting basins of `WaterWays` for an assigned subset of the irrigation network, and other related services defined in ORFFM semantic model.

B. CONCEPTUALIZATION OF DISASTER MANAGEMENT DOMAIN

Disaster management activities are performed by disaster management authorities with different mandates and region coverage. National Disaster Management at the Federal authority, Provincial disaster management authority for each province, and district disaster management authority for each district to plan disaster risk mitigation and management. The contingency plan for unavoidable situations of monsoon season was developed and shared with the collaborative organization with necessary precautionary measures and top management for budgeting and technical support to cope with hazardous situations. The main outcomes of contingency planning involve the identification of the vulnerable community, locations, capacity, and required technical support for risk mitigation. Knowledge management is key for mitigation and risk reduction, but the expertise becomes tacit knowledge at the individual or organization level lacking an ineffective sharing mechanism and knowledge management practices [47]. The highest research studies for knowledge management from types of disasters are flood disaster studies i.e 20 out 72 presented in a systematic literature review by Rina Suryani Oktari *et al.* in [47]. The data, information, and knowledge at the individual level became the limiting factor of effective coordination and collaboration among stakeholders for effective mitigation and risk management strategies. Individual or organization level information suffers the syntax and structural heterogeneity. The problem of heterogeneity and ambiguity tackled by the interoperability of information and adding semantics to information through ontology development of the disaster management domain and incorporating the local contextual knowledge in a semantically interoperable knowledge base system. The success of the disaster management system depends on the accessibility of the right information to the right people at right time with preciseness and semantically annotated entities of the integrated domains [77].

1) STRUCTURE OF THE DISASTER MANAGEMENT AUTHORITY

Disaster Management authority performs the coordination of their services with provincial authorities as well as with division, district, and tehsil level administration for vulnerability assessment in preparedness phase, rescues, relief goods distribution in the response phase, reallocation, reconstruction, restoration in rehabilitation and recovery phase. Besides that in the situation of severe impacts of disaster the provincial, division, district, tehsil administration coordinate and collaborate for risk mitigation during each phase. The knowledge base with shared conceptualization for this information contributes to the effective management of disaster and implementation of mitigation strategies. The class hierarchy of administration and disaster management authorities with semantic relationship encoded in OWL language and presented using Protégé 5.5 visualization plugin OntoGraph as shown in the Fig. 8. The rectangle with a yellow circle represents the class and directed arcs in different colors represent their interactions and relationships. The preparedness phase for flood risk assessment includes identification of vulnerable communities in riverine suburbs, accessibility to a safe location, roads, infrastructure for shelter, machinery required by DMA for a response, and relief goods distribution to affectees. The local and contextual knowledge base is integrated with real-time curated data for vulnerability assessment by the ontology-based system.

2) DISASTER MANAGEMENT PHASES

The disaster management activities are partitioned into four phases(Preparedness, Response, Recovery, and rehabilitation) reflected in Fig. 8. The preparedness phase is briefly described in V-B. Few damages assessment information encoding object properties are described in Table 4. Other properties with details may be accessible from ORFFM shared through GitHub repository URL link in section VII-A.

3) FLOOD ESTIMATION PARAMETERS

The river environmental characteristic enables to assess the possibility of flood and magnitude are based on the physiographic attributes and meteorological information. Physiographic attributes include catchment area, the elevation of breach point, and slope of basins or channels along with the distance from residential regions and agricultural lands.

C. CONCEPTUALIZATION OF ADMINISTRATION DOMAIN

The spatial regions are administered by distributed hierarchically administrators with responsibility overall administration of assigned jurisdiction. They are also part of the flood commission and flood-related responsibilities include coordination, removal of difficulties, performance evaluation, etc. The spatial regions are grouped and mapped to the administrative hierarchy. The continent was partitioned into countries. The country has capital territory and provinces. The administration powers transferred to provinces, divisions, districts, tehsils, towns, and union councils for efficient management, budget distribution, law enforcement, monitoring, relief activities, assessment, etc. We mapped administration concepts in ontology towards coordination and collaborating for water resources management, theft reduction, disaster management, response, and relief goods distribution transparently and effectively. Our administration domain covers conceptualization of spatial regions hierarchy and relation with irrigation network, administrator hierarchy for their contribution to disaster management and relief activities. The top level classes of `Administration` module are `AdminsitrationsOfSpatialRegions`, `Infrastructures`, and `SpatialRegions` with subclasses for details hierarchy of Administrative officials, infrastructure(Education, health facilities, Trasnportation, . . .), and regions.

The ORFFM accomplish aforementioned activities and complex relationship by explicitly defining concepts, objects, data properties, and individuals. A subset of the properties along with characteristics, domain, and range presented in Table 5. A graphical complex relationship of classes, instances, and relationships among individuals of spatial regions, managing administrators, spanning irrigation networks generated using OntoGraph of Protégé v5.5 as shown in Fig. 9.

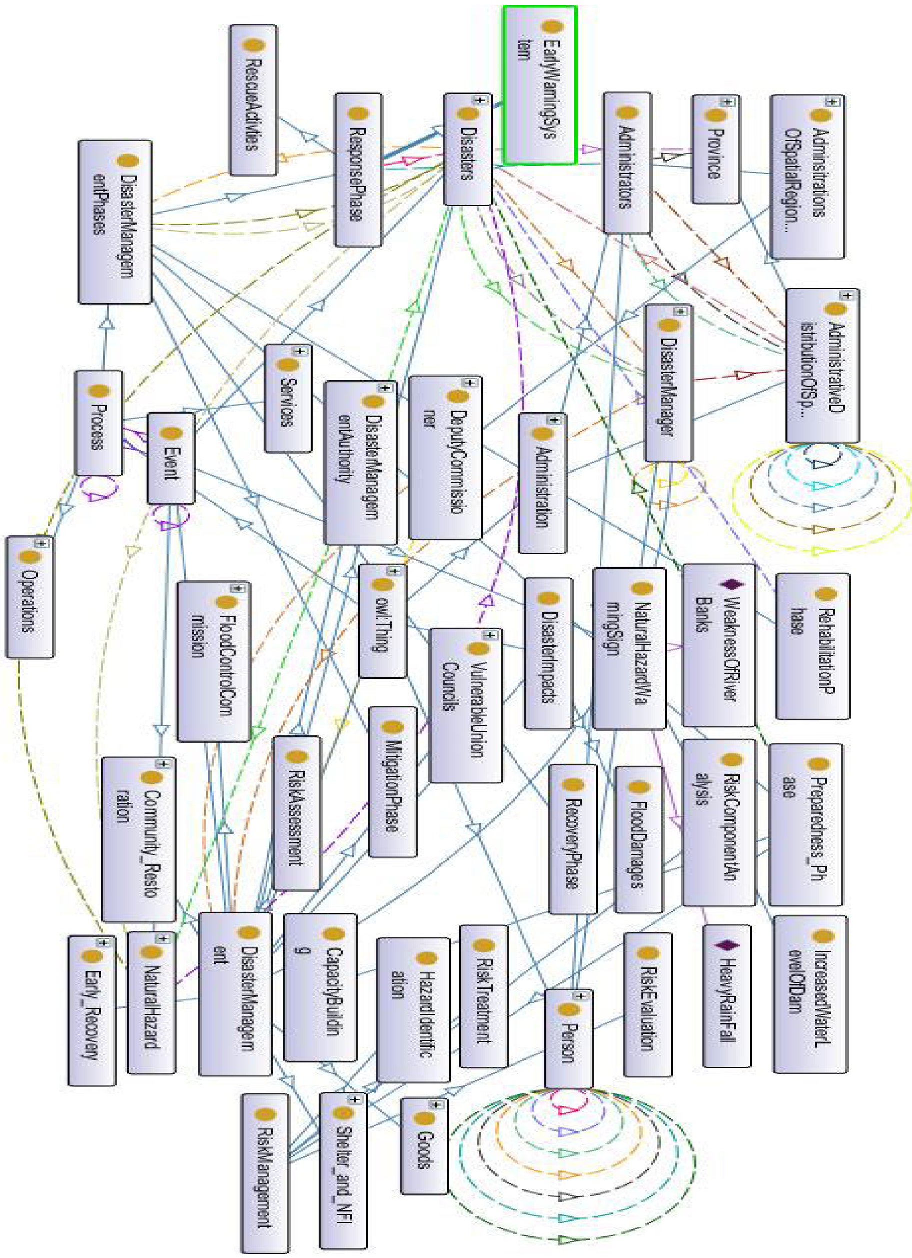


FIGURE 8. Disaster management authorities phases, activities and interaction. Directed dotted arcs represent relations and types of interactions with individuals of relevant classes.

TABLE 4. Object properties for damages assessment information.

Property Name	**Characteristics**	Range / Domain	Domain / Range	Inverse Property
CountryIsAffectedBy	Asymmetric	Country	Disaster	HasCountryAffected
ProvinceIsAffectedBy	Functional	Province	Disaster	HasProvinceAffected
DistrictIsAffectedBy	Asymmetric	District	Disaster	HasDistrictedAffected
TehsilIsAffectedBy	Asymmetric	Tehsil	Disaster	HasTehsilAffected
VillageIsAffectedBy	Asymmetric	Town	Disaster	HasVillageAffected
HouseIsAffectedBy	Asymmetric	House	Disaster	HasHouseAffected
IsManagedBy	Functional	Disaster	DisasterManager	IsManagerOf

VI. SEMANTIC FORMALISM OF ORFFM

We would model river flow and flood domain using Description Logic(DL) $\mathcal{ALC}$ and predicate logic for the tableaux algorithm to ensure the satisfiability of the Knowledge base. Our semantic model represented in **SROIQ** DL most expressive from a family of knowledge representation languages

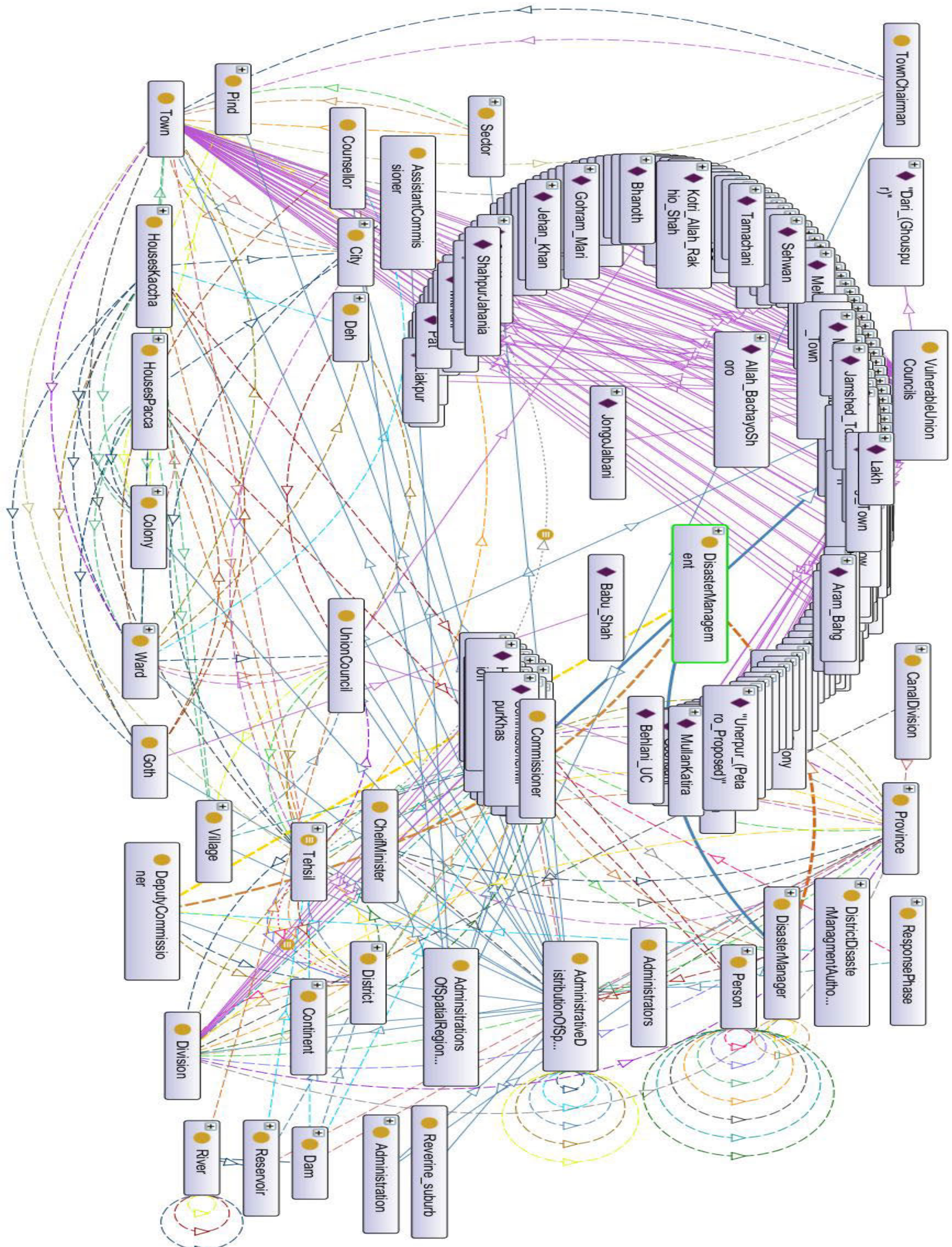


FIGURE 9. Graphical representation of classes, instances, and relationship of spatial regions, spatial region managing administrators, spanning irrigation network, vulnerable union councils.

and covering description logic $\mathcal{ALC}$ [59]. The DL is a decidable fragment of First Order Predicate Logic equipped with precise semantic formalization for OWL DL languages [33]. We provide a formal semantic of our OWL 2 DL ontologies using **SROIQ** syntax and notations. Our ontology provides a semantic knowledge base theoretically partitioned into Tbox, Rbox, and Abox with formal semantic descriptions for irrigation system, disaster management, and administration classes of Riverflow and flood mitigation model [59]. The assertion part is further divided into terminology assertion Tbox and Role assertion Rbox. Three disjoint sets of primal elements are as follows: The set C represented a set of concepts explicitly defined in ORFFM semantics. The Role set **R** is the relationship between concepts and enables role assertion for instances represented by setting I. For a demonstration of semantic formalism, we discussed here the irrigation sub-module of the Ontology-based semantic model for River Flow and Flood Mitigation(ORFFM). Similar semantic followed for disaster management, administration, and other related domain of our model. Each set is further explained in the following subsection of Tbox, Rbox, and Abox.

A. TBOX

The concept expression is defined using **SROIQ** Tbox notation. Every class belongs to the primal set of the class concept represented by **C** in (1). The classes hierarchy with symbols$\sqsubseteq$ (subsumption axioms) and classes more than one are grouped in the set notation for each main class. The top concept is represented by the symbol $\top$ and $\bot$ represents more specific class concepts. The irrigation system, DisasterManagement, and Administration are a subclass of $\top$. The union of two classes represented by $\sqcap$ and the intersection of two classes represented by the symbol$\sqcup$. The other symbols are negation $\neg$, existential quantifier $\exists$, universal quantifier $\forall$, and set notation. The `IrrigationSysetem`, `DisasterManagment` and `Administration` are topmost general classes in semantic representation of ORFFM. These are subclasses of `Thing` class represented by $\top$ as shown in (2). The watercourse and tent of a specific class of ORFFM have no further subclass and the conjunction of these two classes has nothing common represents $\bot$ shown in (3).

$$C_{IS} = \{StreamFlow, RiverFlowAndFloodMitigation, RiverEnvironment, Process, Person, Organizations, IrrigationNetwork, Infrastructures, \ldots\} \quad (1)$$

$$IrrigationSystem \sqcup DisasterManagement \sqcup Administration \sqsubseteq \top \quad (2)$$

$$watercourse \sqcap Tents \sqsubseteq \bot \quad (3)$$

The vulnerability assessment is the activity performed by the disaster manager in coordination with administration at tehsil level, district level and provincial level belongs to the preparedness phase of disaster management as represented in (4).

$$VulenerabilityAssessment \sqsubseteq PreparenessPhase \quad (4)$$

The Vulnerable Tehsil identified during the preparedness phase is a subclass of the preparedness phase and Tehsil represented by (5).

$$VulnerableTehsil \sqsubseteq PreparenessPhase \sqcap Tehsils \quad (5)$$

Every `Tehsil` has administrator called `AssistantCommission` assists in vulnerability assessment activities with disaster management authority as disaster commissioner for the respective region according to his/her job description is represented by as cardinality restriction for `Tehsil` administration shown in (6). The seepage is an IrrigationIssue of IrrigationSystem as stated by (7).

$$Administrator \sqsupseteq\ \geq 1 HasAssistantCommissioner.Tehsil \quad (6)$$

$$Seepage \sqsubseteq IrrigationIssues \sqsubseteq IrrigationSystem \quad (7)$$

Following are T-Box axioms related to major classes of ORFFM. This represents the subsumption property between the classes using **SROIQ** Description Logic. These classes belong to irrigation system module of semantic model ORFFM as shown in Table 6.

B. RBox

The concepts are related using role or relation in semantic formalism stated as properties on OWL 2DL. The **SROIQ** Rbox captures inter-dependencies between the roles of the considered ORFFM knowledge base. The roles in the irrigation submodule of ORFFM denoted by R_{IS}. The role set contain all role in the module along with the function stated as characteristic in OWL such as in (8). The characteristic of role is represented by the (9) as `Assigntask` is inverse of `ReportToManager`.

$$R_{IS} = \{CoordinationAndCommunication, AssignTask, Collaborate, CoordinatWithStakeholders, CoordinateWithColleague, GuideToTeam, ReportToManager, DataAcquisition, HasIrrigationZone, StreamFlowProperties, StreamFlowDirection, StreamFlowManagers, StreamFlowMonitoring, WaterDistributedThrough, \ldots\} \quad (8)$$

$$Inv(AssignTask) \equiv ReportToManager \quad (9)$$

The role in a particular hierarchy or role inclusion axioms (RIA) also referred to as role chain represented by (10) and (11).

$$DataAcquisition \circ StreamFlowDataAcquired \circ UsingManaualGuaging \sqsubseteq IrrigationSystem \quad (10)$$

$$HasMeasureDischargeRateOf \circ AssignTask \circ IrrigationWorkflow \sqsubseteq IrrigationSystem \quad (11)$$

The impact of the semantic model by adding restriction on the role hierarchy through stating the hierarchy level and

TABLE 5. Object properties relating spatial region with regional Administrator.

Property Name	Characteristics	Range / Domain	Domain / Range	Inverse Property
HasPrimeMinister	Functional	Country	PrimeMinister	IsPrimeMinisterOf
HasCheifMinister	Functional	Province	CheifMinister	IsCheifMinisterOf
HasCommissioner	Functional	Division	Commissioner	IsCommissionerOf
HasDeputyCommissioner	Functional	District	DeputyCommissioner	IsDeputyCommissionerOf
HasAssistantCommissioner	Functional	Tehsil	AssistantCommissioner	IsAssistantCommissionerOf
HasTownChairman	Functional	Town	TownChairman	IsTownChairmanOf
HasCounsellor	Functional	Ward	Counsellor	IsCounsellorOf

TABLE 6. Tbox- Irrigation System concept's semantic representation.

{ StreamFlow, IrrigationIssues, IrrigationDepartment, Irrigation Managers } $\sqsubseteq$ IrrigationSystem
{ WaterDivision, RiverStreamFlowPath, WaterDistribution } $\sqsubseteq$ StreamFlow
{BasinSilting, WaterTheft, Conveyance, seepage } $\sqsubseteq$ IrrigationIssues
{ RiverChenabPassageStations , RiverIndusPassageStations, RiverJhelumPassageStations , RiverKabulkPassageStations , RiverRaviPassageStations } $\sqsubseteq$ RiverStreamFlowPath
{ Khanki, Marala, Panjnad, Qadirabad, Trimmu } $\sqsubseteq$ RiverChenabPassageStations
{ Chashma, Guddu, Kalabagh, Kotri, Sukkur, Tarbela, Taunsa } $\sqsubseteq$ RiverIndusPassageStations
{ Mangla, Rasul } $\sqsubseteq$ RiverJhelumPassageStations
Nowshere $\sqsubseteq$ RiverKabulkPassageStations { Balloki, Jassar, Shahdara, Sidhnai } $\sqsubseteq$ RiverRaviPassageStations
{ GandaSinghWala, Islam , Sulemanki } $\sqsubseteq$ RiverSutlejPassageStations
{ Branch, Canal, Channel, Disty, Drain, LinedChannel, LinkCanal , Major, Minor, Outlet, River, WaterCourse } $\sqsubseteq$ WaterDistribution
Rotationalprogram $\sqsubseteq$ WaterDistributionScheme
{ StreamFlow, IrrigationIssues, IrrigationDepartment, Irrigation Managers } $\sqsubseteq$ IrrigationSystem
{ WaterDivision, RiverStreamFlowPath, WaterDistribution } $\sqsubseteq$ StreamFlow
{ BasinSilting, WaterTheft, Conveyance, seepage } $\sqsubseteq$ IrrigationIssues
{ RiverChenabPassageStations , RiverIndusPassageStations, RiverJhelumPassageStations , RiverKabulkPassageStations , RiverRaviPassageStations } $\sqsubseteq$ RiverStreamFlowPath
{ Khanki, Marala, Panjnad, Qadirabad, Trimmu } $\sqsubseteq$ RiverChenabPassageStations
{ Chashma, Guddu, Kalabagh, Kotri, Sukkur, Tarbela, Taunsa } $\sqsubseteq$ RiverIndusPassageStations
{ Mangla, Rasul } $\sqsubseteq$ RiverJhelumPassageStations
Nowshere $\sqsubseteq$ RiverKabulkPassageStations
{ Balloki, Jassar, Shahdara, Sidhnai } $\sqsubseteq$ RiverRaviPassageStations
{ GandaSinghWala, Islam , Sulemanki } $\sqsubseteq$ RiverSutlejPassageStations
{ Branch, Canal, Channel, Disty, Drain, LinedChannel, LinkCanal , Major, Minor, Outlet, River, WaterCourse } $\sqsubseteq$ WaterDistribution

reducing computational complexity. Every role r occurring in a RIA, DL expression represented by (12).

$$r_1 \circ r_2 \circ \ldots \circ r_n \sqsubseteq r \tag{12}$$

The Role r repeated or recursive is called non-simple otherwise simple role. The upper limit of n may be restricted for computation performance. Another restriction on the role order can be asserted to comply with the semantics of domain to convert into regular by imposing strict partial order $\prec$ on the nonsimple rule hierarchy. Other role characteristics for semantic model also validated for regularity of **SROIQ** Rbox roles such as Ref(DischargeTo) for reflexivity, Sym(Coordinate) for Symmetric, Asy((ReprotTo) for asymmetry, or Dis(Disilting; DischrgeGuaging) for role disjointness, and Fuc(ReportToManager) for functional characteristic. The role hierarchy of the semantic relations expressed as "The FloodVulnuerabilityAssesmentOf is sub-property of PreparednessPhaseActivities property which in-turn sub-property of DisasterManagementCycle " and "`Desilting` is part of `RiverMaintenance`" is represented by (13). Similarly, the Desilting process of WaterWays Maintenance with in-turn subprocess of Irrigation System represented by RIA and (14).

$$\begin{aligned} &FloodVulnuerabilityAssesmentOf \\ &\quad \sqsubseteq PreparednessPhaseActivities \\ &\quad \sqsubseteq DisasterManagementCycle \end{aligned} \tag{13}$$

$$\begin{aligned} &Desilting \\ &\quad \sqsubseteq RiverMaintenance \\ &\quad \sqsubseteq IrrigationSystem \end{aligned} \tag{14}$$

C. ABox

The Abox of the ORFFM knowledge-based contains the individuals level information as opposed to *Generalized Conceptual Inclusion*(CGI) axioms in Tbox, which classify the type of individual into subgroups. Subset of ORFFM individuals as CGI of `WaterWays` a submodule of irrigation system(IS) are presented in (15).

$$\begin{aligned} I_{IS} = \{&ChanabRiver, ChapursanRiver, \\ &AJK_I rrigation_D epartment, \\ &Irrigation_K PK, \\ &RiceCanal, KotriBranch, \\ &\ldots\} \end{aligned} \tag{15}$$

An individual assertion can have any of the following forms.

- River(IndusRiver) called concept assertion,
- HasCanalCircle(BahawalpurIrrigationZone; RahimyarkhanCanalCircle) called role assertion
- ¬HasCanalCircle(BahawalpurIrrigationZone ; NaraCanalAWB) called negated role assertion
- CommissionerSukkur $\approx$ FloodCommisionerSukkur, called equality statement
- BahawalpurCanalCircle $\not\approx$ BahawalnagarCanalCircle called inequality statement

D. SEMANTIC INTERPRETATIONS

The knowledge base contains semantic realities' representation by developing interpretation models. The interpretation models are reflected by $\mathcal{I}$. DLs are capable to handle incomplete information following open-world assumption [6], [59]. DL semantic processes are the axioms of an ontology to drive all possible situations explicitly defined about real-world entities of a domain. DL handles the incomplete information of ontological axioms and keeps specified information about a domain open for extension of that knowledge base. The DL being monotonic and open-world assumption has the beauty of extendability for the addition of axioms leading to additional consequences.

The interpretation model can assess the consistency or satisfiability of an ontology by assessing the axioms against consequences. To endorse the formal semantic of our ORFFM ontology by developing an interpretation model $\mathcal{I}_{FM}$ for flood mitigation to assess the defined conceptualization of the irrigation, disaster management, and administration domains.

Following the intuition of description logic discussed in the previous section. Here we define an interpretation model of the ORFFM. The interpretation for flood mitigation is based on the knowledge from integrated domains the irrigation, disaster management, and administration represented by $\mathcal{I}_{FM}$ with a nonempty set of$\triangle^{\mathcal{I}}_{FM}$ as the domain of discourse which represents all individuals or discrete concepts represented by $\mathcal{I}$. The interpretation function is represented by $.\mathcal{I}$ connect the individual concepts and role with the association of an individual with its set like Moro $\in \mathcal{N_N}$ for corresponding individual $Moro^{\mathcal{I}} \in \triangle^{\mathcal{I}}$ for disaster management domain. Similar abstract concept VulnerbaleTehsil $\in \mathcal{C_I}$for corresponding VulnerbaleTehsil$\in \triangle^{\mathcal{I}}_{FM}$. The role name IsResponseActivtity $\in \mathcal{N}_R$ for the corresponding set IsResponseActivtity $\subseteq \triangle^{\mathcal{I}} X \triangle^{\mathcal{I}}$. The confusion is removed by separating syntactic and semantic entities referred to as role extension.

$\mathcal{N}_I$ = {IndusRiverFloodForecast, ...}, $\mathcal{N}_C$ = {Barrage, River, Canal, ...}, $\mathcal{N}_R$ = {HasPredecessorBarrage, hasSuccessorBarrage, TimetoReach, HasMaxFlowCapacity, HasCurrentFlowLevel, HasPredecessorHeadworks, hasSuccessorHeadworks, ...}. Illustrating the above interpretation model $\triangle^{\mathcal{I}}$ = {SukkurCurrentOutFlow, ChashmaCurrentOutFlow, GudduCurrentOutFlow, KalabaghCurrentOutFlow, KotriCurrentOutFlow, TarbelaCurrentOutFlow, TaunsaCurrentOutFlow, ChashmaMaxCapacity, ChashmaMaxCapacity, GudduMaxCapacity, KalabaghMaxCapacity, KotriMaxCapacity, SukkurMaxCapacity, TarbelaMaxCapacity, TaunsaMaxCapacity, ...} represents variable flow and capacity of individuals used for contextual situation inference.

Representation of streamflow data for flood forecast of Indus River. Let CurrenOutflow at GadduBarrage 2 million cusecs and sukkurBarrageMaxCapacity is 1.2 million cusecs this forecast high flood after time extraction from DistanceToPredecessorKM, and FloodSpeedKMPH. We prefer the unique name assumption (UNA) for a stronger and confusion-free interpretation of the model. For graphical representation of our domain flood management, we define $\mathcal{I}_{StreamFlowPath} = (\triangle^{\mathcal{I}}_{FM}; .^{\mathcal{I}})$ as subset of the domain $\triangle^{\mathcal{I}}_{FM}$ represented by **S** for*StreamFlowPath*'s of Indus river and individuals by (16), Terminology Concept (17) and role elements by (18):

$$\begin{aligned} S_I = \{&Jinnah\_Barrage, Chashma\_Barrage, \\ &Taunsa\_BarrageGuddu\_Barrage, \\ &Sukkur\_Barrage, Kotri\_Barrage, \} \end{aligned} \tag{16}$$

$$S_C = \{Barrage, River\} \tag{17}$$

$$\begin{aligned} S_R = \{&PredecessorBarrage, \\ &SuccessorBarrage\} \end{aligned} \tag{18}$$

The symbolic mapping of the elements are shown in Fig. 10. To clear the understanding of semantic interpretation by a directed graph with labeled nodes and arcs. Thereby, the nodes correspond to the domain of individuals $\triangle^{\mathcal{I}}_{FM}$ and the node $\delta \in \triangle^{\mathcal{I}}_{FM}$represented the individual names assigned. The directed arrow represents an extension of roles abbreviated with the first letter P and S for predecessorBarrage and successorBarrage respectively. The semantic interpretation of the barrage's role extension for the streamflow path of the Indus River is shown in Fig. 11. Attaching pictures or some interesting icons may assist novice users to interpret and easily memorize the irrigation system's river flow path and understand the early warning recommendations. Adding this topographic data with real-time water flow information leads to optimize water distributions.

E. INFERENCE REASONERS

Semantic web reasoners enable to deduce and infer the knowledge from explicitly defined concepts of the domain. DL knowledge base contains the portion of distributed information pool as open-world assumption compared to the classical database having complete information set covering domain with the closed-world assumption. The W3C webpage[8] share a list of the reasoner with detailed specifications for resolving standard reasoning problems of consistency checking, satisfiability testing, classification, query answering, module extraction, explanation generation, abduction, etc.

The modern reasoner discussed in [62] includes tableaux, hypertableaux, and other advanced algorithms to handle the

[8]https://www.w3.org/2001/sw/wiki/OWL/Implementations

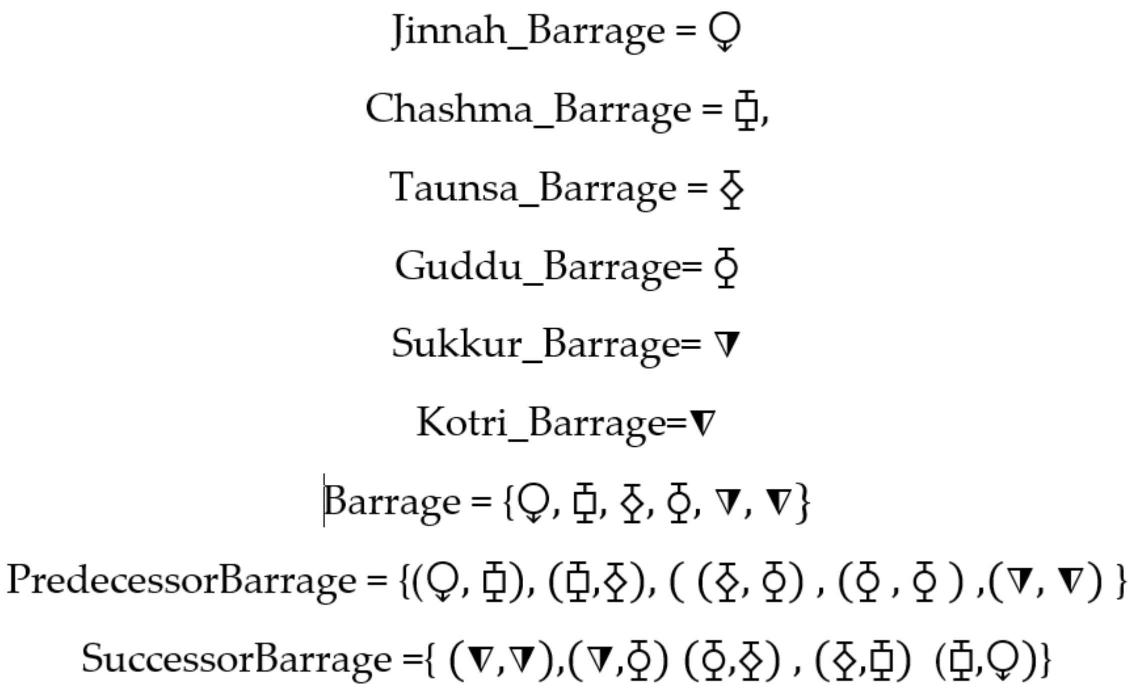


FIGURE 10. Semantic interpretation-Symbolic mapping to model individuals.

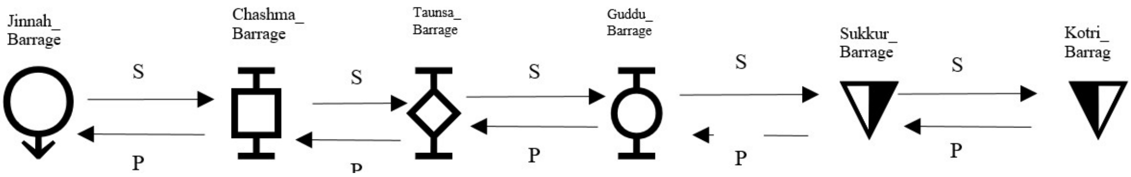


FIGURE 11. Semantic interpretation of StreamFlowPath.

business domain needs and cannot be model hierarchically such as tableaux, hypertableaux, and other advanced algorithms to handle the business domain needs and cannot be model hierarchically. We have used for advanced reasoner for our ORFFM semantic model a hypertableau calculus-based, OWL 2 direct semantic complaint HermiT reasoner [22]. Besides OWL 2 essential features, HermiT supports a wide range of outside features such as safety rules, description graphs, and SPARQL queries. HermiT produces inferred classes, properties, and individual assertion of ORFFM using description logic from the ontology model. ORFFM consists of Tbox $\mathcal{T}$, Rbox $\mathcal{R}$ and Abox $\mathcal{A}$ for consistency checking and raise the errors and warning with explain facility from reasoner. We have used HermiT version 1.4.3.456 for this ontology. The inferred classes are displayed in the left window of 12, based on HermiT reasoner classification and the right window displays the direct instance of the inferred class flood vulnerable tehsils of Sindh province according to contingency planning of 2020 issued by NDMA,[9] Pakistan.

[9]http://cms.ndma.gov.pk

In Fig. 13, 13(a) object properties, and 13(b) data properties of ORFFM along with the inferred data and object properties plus inferred domain and range. The right-upper window also displays 20 and 12 usage of DataAcquisition object property and DateAndTime data properties respectively. The figure also reflects the object and data properties hierarchy presented in Role Inclusion Assertion of DL expression by (10) and (11).

F. RULE LANGUAGE

The rule is a set of statements from a premise that leads to a consequence or conclusion. The interpretation represents the theoretical semantic formation of OWL 2 DL and rules transform it into actionable ontology. Various rules languages are supported by semantic web technology as a subset of First-Order Predicate Languages such as Datalog, and Semantic Web Rule Language (SWRL) implementing formal semantic of description logic [46]. Our ORFFM ontology contains most of the classes in tree structure and rules are imposed by defining necessary conditions and converted these classes

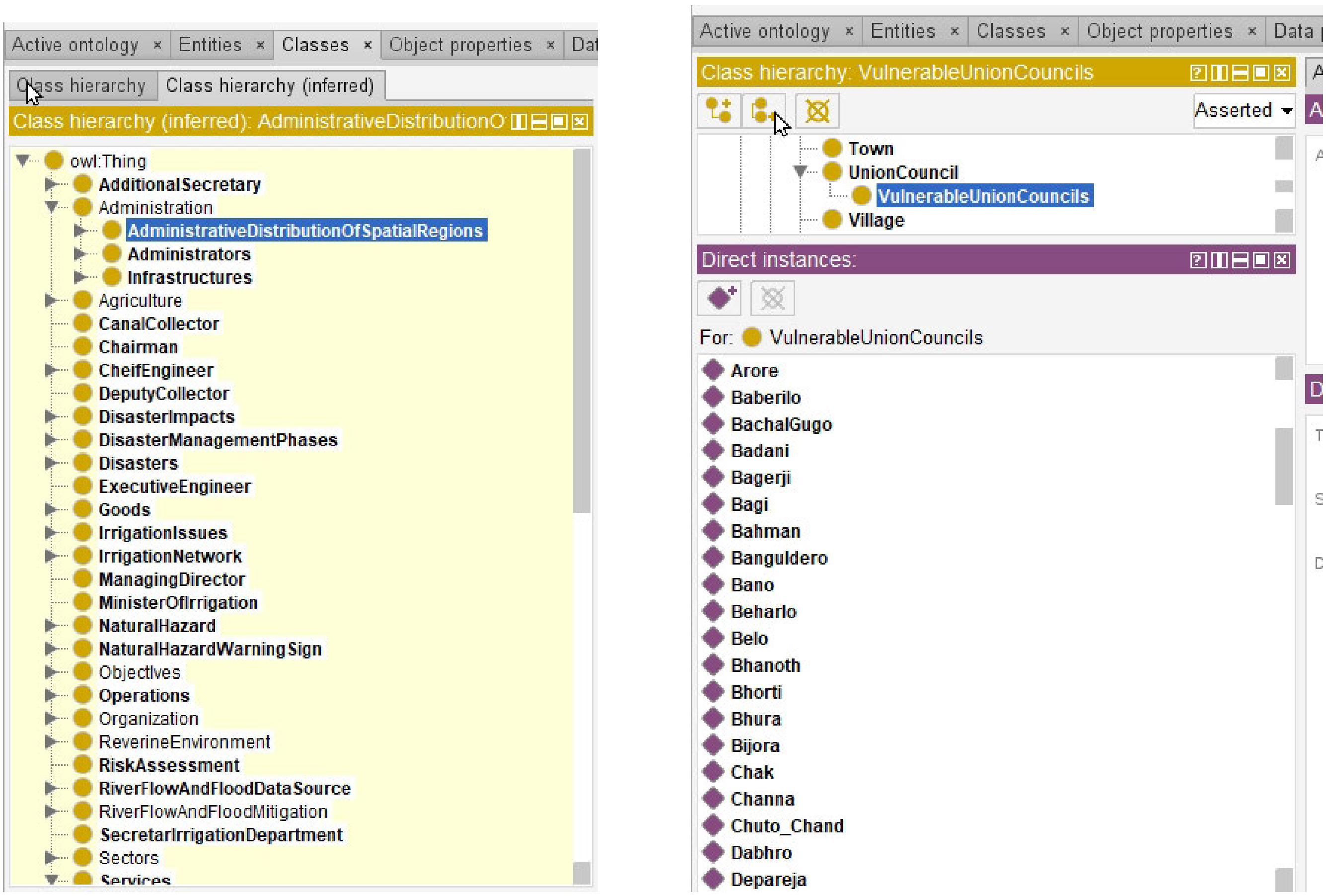
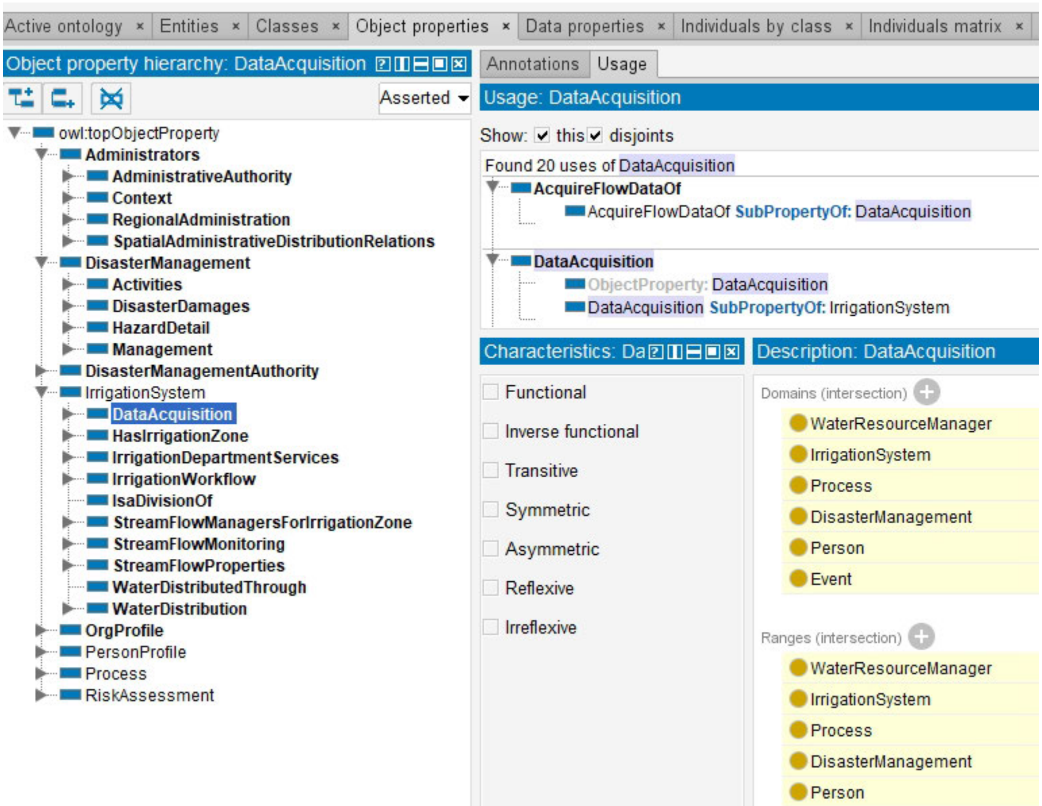


FIGURE 12. Inferred Classes and Instances Of inferred Class Vulnerable Tehsils.

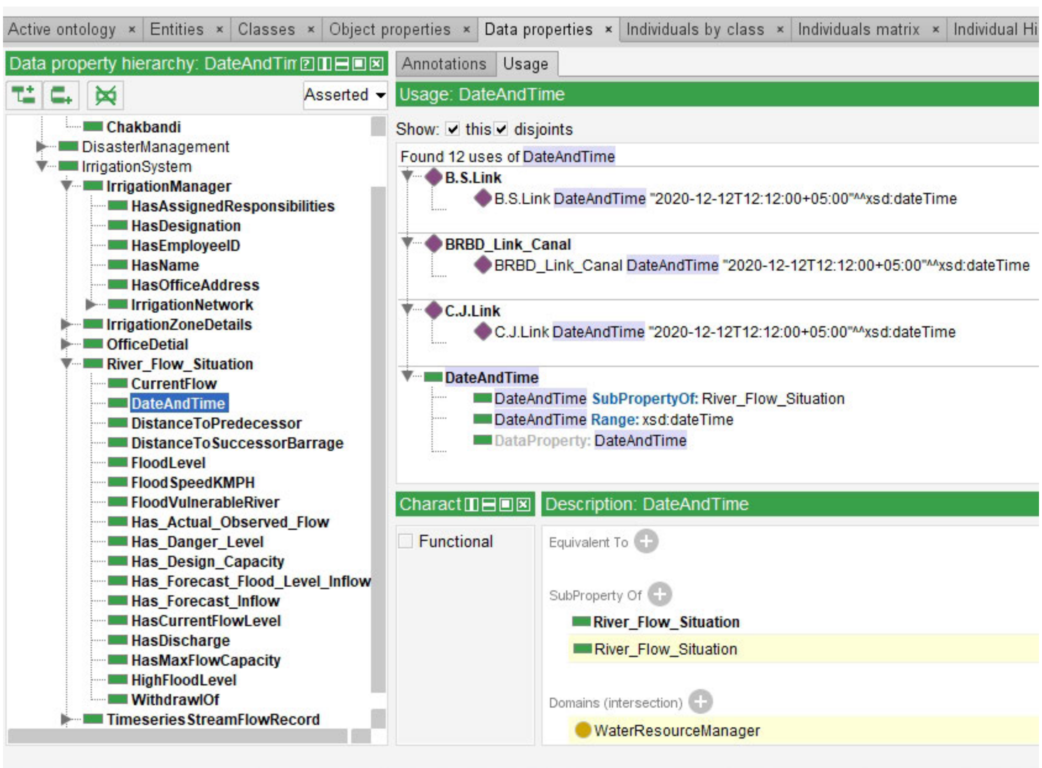
TABLE 7. SPARQL query for competency questions.

CQ#	Competency Question	SPARQL query
Q1	List of Channel with discharge river and Barrage or Headworks?	SELECT DISTINCT ?Channel ?River ?Barrage WHERE ?Barrage sm:OffTakingChannel ?Channel . ?Channel sm:CanalDischargeFromRiver ?River
Q2	List of Canal with discharging barrage, river, division, and province?	SELECT ?canal ?Division ?Province ?Barrage ?River WHERE ?canal sm:LocatedInDivision ?Division . ?canal sm:LocatedInProvince ?Province . ?canal sm:CanalDischargeAt ?Barrage . ?canal sm:CanalDischargeFromRiver ?River .
Q3	What is barrages sequences on rivers from top to down elevation level?	SELECT ?Barrage1 ? Barrage2 ? Barrage3 ? Barrage4 ? Barrage5 . WHERE ?Barrage1 sm:HasPredecessorBarrage ? Barrage2 . ? Barrage2 sm:HasPredecessorBarrage ? Barrage3 . ? Barrage3 sm:HasPredecessorBarrage ? Barrage4 . ? Barrage4 sm:HasPredecessorBarrage ? Barrage5 .
Q4	what are canals, discharging barrages, management authority of Indus River water?	SELECT ?Canals ?FromBarrage ?UnderManagementOfIrrigationAuthority WHERE ?Canals sm:CanalDischargeFromRiver <https://sites.google.com/view/smfis#IndusRiver> . ?Canals sm:CanalDischargeAt ?FromBarrage . ?Canals sm:IsManagedBy ?UnderManagementOfIrrigationAuthority
Q5	What is the administrative regional hierarchy?	SELECT ?Tehsil ?District ?Province ?Country WHERE ?Tehsil sm:TehsilInDistrict ?District . ?District sm:DistrictInDivision ?Division . ?Division sm:DivisionInProvince ?Province . ?Province sm:ProvinceInProvince ?Country

into primitive. The necessary and sufficient conditions to transformed into a defined class. Besides the class representing semantic relation among the classes on the same level, enriched by the SWRL. The new knowledge is inferred from explicit knowledge using rules. OWL 2 DL is compliant with the description logic that has a subset of the First Order

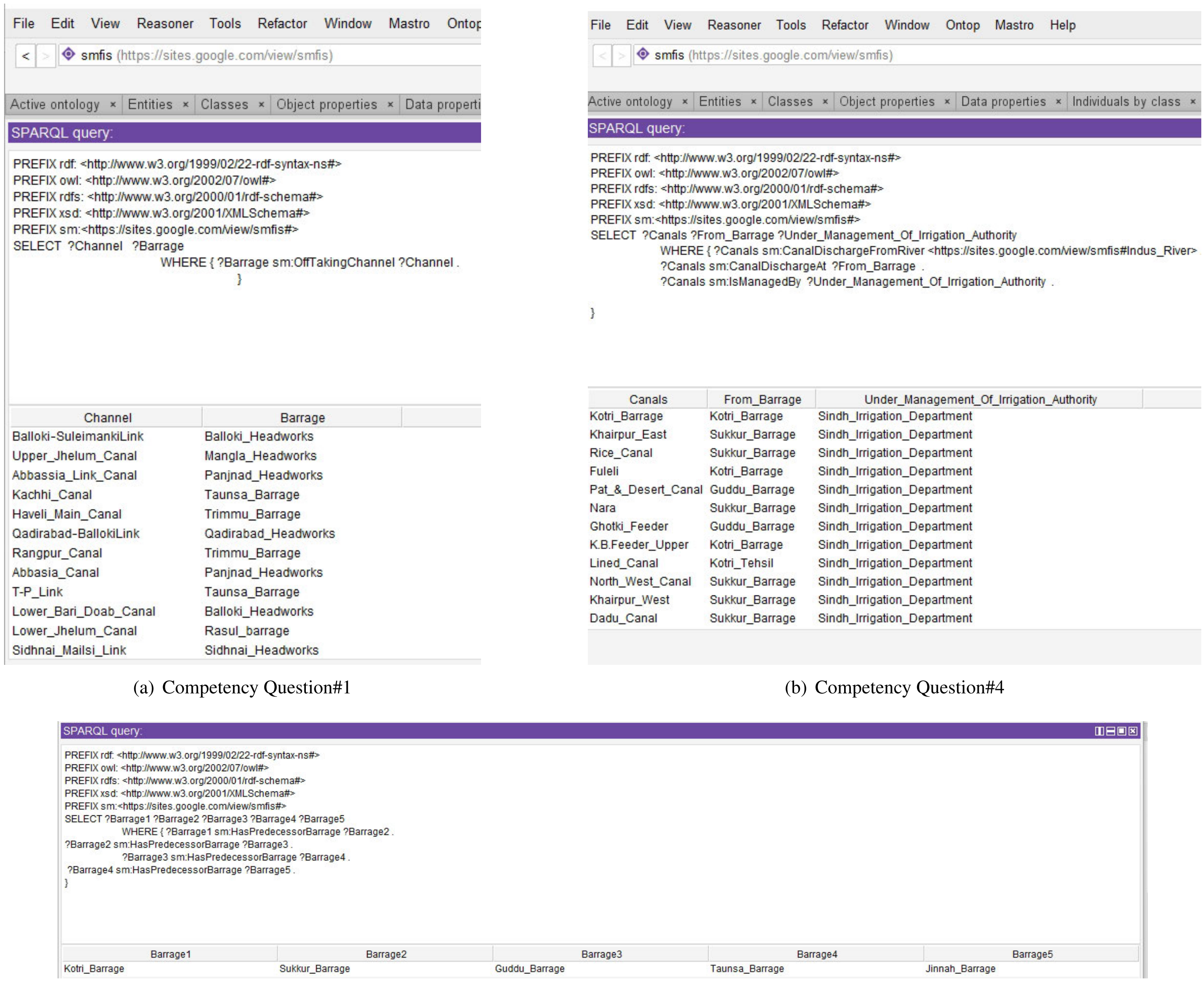


(a) Object Properties.



(b) Data Properties

FIGURE 13. Object properties and Data Properties of ORFFM.



(a) Competency Question#1

(b) Competency Question#4

(c) Competency Question#3

FIGURE 14. Results of Competency Questions and mapped SPARQL Query displayed in Table 3.

Predicate Logic. OWL 2 is based on $\mathcal{SROIN}^{(D)}$discussed in the previous section on semantic formalism has an issue of decidability, for valid SWRL rules, the language is decidable but for invalid rules, the tableaux algorithm may take infinite time. To resolve the decidability issue, the reasoner implements DL-safe rules and is only implemented to named individuals. The rules to infer assertion for implicit knowledge are added in ORFFM. We developed ORFFM ontology in Protégé 5.5 environment has SWRL Tab [46] for new rules with ease and assurance of valid syntax and selection of atomic statement for rules. Some of these rules illustrating the indirect relationships among the spatial regions, disaster managers are presented here. Tehsil relation with district and district relation with division enables to form tehsil relation with the division as in (19).

$$\begin{aligned} &Tehsil(?t) \wedge Located\ InDistrict(?t, ?d) \\ &\quad \wedge Located\ InDivision(?d, ?v) \\ &\quad -> LocatedInDivision(?t, ?v) \end{aligned} \tag{19}$$

The river having current flow greater than max flow may generate flood and marked as flood vulnerable river. The early warning system may be initiated for associated Union Councils for proactive mitigation measures stated in (20) and (21)

$$\begin{aligned} River(?r) &\wedge HasMaxFlowCapacity(?r, ?m) \\ &\wedge HasCurrentFlowLevel(?r, ?c) \\ &\wedge swrlb : greaterThan(?m, ?c) \\ &-> FloodVulnerableRiver(?r, true) \end{aligned} \tag{20}$$

$$\begin{aligned} &FloodVulnerableRiver(?r, true) \\ &\quad \wedge VulnerableUnionCouncils(?v) \end{aligned}$$

TABLE 8. Ontology metrics of ORFFM.

Base metrics	Axioms:	5382
	Logical axioms count:	3608
	Class count:	410
	Total classes count:	410
	Object property count:	413
	Total object properties count:	413
	Data property count:	308
	Total data properties count:	308
	Properties count:	721
	Individual count:	625
	Total individuals count:	625
	DL expressivity:	$SROIQ^{(D)}$
Class axioms	Axioms:	5382
	SubClassOf axioms count:	452
	Equivalent classes axioms count:	3
	Disjoint classes axioms count:	33
	GCICount:	0
	HiddenGCICount:	4
Object property axioms	SubObjectPropertyOf axioms count:	429
	Equivalent object properties axioms count:	4
	Inverse object properties axioms count:	33
	Disjoint object properties axioms count:	3
	Functional object properties axioms count:	24
	Inverse functional object properties axioms count:	8
	Transitive object property axioms count:	2
	Symmetric object property axioms count:	5
	Asymmetric object property axioms count:	30
	Reflexive object property axioms count:	2
	Irreflexive object property axioms count:	18
	Object property domain axioms count:	329
	Object property range axioms count:	244
Data property axioms	SubDataPropertyOf axioms count:	160
	Disjoint data properties axioms count:	4
	Functional data property axioms count:	61
	Data property domain axioms count:	128
	Data Property range axioms count:	247
Individual axioms	Class assertion axioms count:	623
	Object property assertion axioms count:	531
	Data property assertion axioms count:	230
Schema metrics	Attribute richness:	0.75122
	Inheritance richness:	1.102439
	Relationship richness:	0.498335
	Equivalence ratio:	0.007317
	Axiom/class ratio:	13.126829
	Inverse relations ratio:	0.086498
	Class/relation ratio:	0.45505
Graph metrics	Absolute root cardinality:	12
	Absolute leaf cardinality:	332
	Absolute sibling cardinality:	410
	Absolute depth:	2096
	Average depth:	3.790235
	Maximal depth:	6
	Absolute breadth:	553
	Average breadth:	5.701031
	Maximal breadth:	41
	Ratio of leaf fan-outness:	0.809756
	Ratio of sibling fan-outness:	1.0
	Tangledness:	0.102439
	Total number of paths:	553
	Average number of paths:	92.166667

$$- > GenerateEWSforUCs(true) \tag{21}$$

VII. ONTOLOGY EVALUATION

The evaluation of the proposed model proves the effectiveness and quality of the model. There are various techniques of ontology evaluation. We evaluate the ORFFM by ontology matrix, competency questions, and from a result of SPARQL query language queries.

A. SPARQL QUERY FOR COMPETENCY QUESTIONS

The quality of the knowledge base is estimated from satisfaction on the knowledge retried as per requirement. The preciseness, flexibility, and semantic interoperability qualities of a knowledge base enable easy change for collaboration. The competency questions results are obtained by the SPARQL query Language from the ontology of River Flow and Flood Mitigation(ORFFM). The SPARQL was designed for RDF [27] and extended for OWL language by World Wide Web Consortium (W3C)[10] with more expressiveness.The OWL direct semantic entailment regimes discussed by Kollia *et al.* in [32]. They also assessed query improvements and optimization techniques with HermiT reasoner for query answering from a knowledge base. We evaluated our semantic ORFFM for competency questions of stakeholders. Table 7 displays the five competency questions as a sample and SPARQL query language for results. The results of CQ1, CQ3, and CQ4 are displayed in Fig. 14, as Fig. 14(a), Fig. 14(b) and Fig. 14(c) using Protégé.5.5. Following namespaces are used in each query and omitted from Table 7 for brevity.

```
PREFIX owl:
<http://www.w3.org/2002/07/owl#>
PREFIX rdfs:
<http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd:
<http://www.w3.org/2001/XMLSchema#>
PREFIX sm:
<https://sites.google.com/view/smfis#>
```

The ontology shared for extension and feedback from stakeholders and researchers on GitHub repository at following link. https://github.com/muhammadhussainmughal/SM4ORFFM

B. ONTOLOGY METRICS

Ontology metrics are used to assess the complexity and expressiveness of an ontology. OWL 2 language used $SROIQ^{(D)}$, which has 2N exponential time completeness complexity [23] for inference reasoner. We have applied HermiT 1.4.3.456 reasoner [64] for OWL 2 ORFFM in Protégé 5.5 Environment. The complete ontology metrics for ORFFM presented in Table 8 covering Base metrics, Class axioms, Object property axioms, Data property axioms, Individual axioms, Schema metrics, and Graph metrics.

C. COMPARATIVE ASSESSMENT WITH EXISTING FLOOD ONTOLOGIES

Comparative assessment of existing flood ontologies discussed in section II-A revealed that ontology-based approach applied by various esteemed researchers in the last two

[10]https://www.w3.org/

TABLE 9. Comparative assessment of ORFFM with existing flood ontologies.

Name of Ontology	Creaters	Year	Reference	Operations	Ontology Design Pattern	Class examples	Properties examples	Classes (Aprox.)
Flood Ontology	Norwawi *et al.*	2002	[3]	Integration	Non modular	HydrologyNetwork, HydrologyData, FloodAnalysis,EmergencyCommittee, ContactPerson,	AccessFrom, CollabrateWith	8[a]
Coastal Flood Ontology	García-Castro *et al.*	2012	[21]	Integration, extension	Modular	OceanRegion, FloodPlain, FloodZone, FloodDefencePol, Duties, Organizations, Roles	OceanRegion Properties, locatedInRegion, appliesTo	47
Flood Risk Ontology	Yi and Sun	2013	[78]	Extension	Modular	WaterSystem, Watershed flood, Watershed, drought, Waterquality, Climate, Precipitation	HasAssociated WatershedRealm, hasAssociated EarthRealm	10[a]
Flood Risk Assessment Ontology	Scheuer *et al.*	2013	[61]	Extension	Modular	Flood, EventIntensity, RecurrenceInterval, SusceptibilityFunction, ElementAtRisk, DamageRatio, Stakeholder, Authority	intensityOf, hasSusceptibility	24
FloodOntology	Agresta *et al.*	2014	[4]	Integration	Modular	Drainage_Component, Motion_Related_Quantity, Sensing_Device	is_measured, is_quantity_of	55[a]
Crisis Management Ontology	Roller *et al.*	2015	[58]	NA	Non modular	WaterLevel, ElectricityComponent, ElectricalAsset, ElectricalSupply, WaterSupplyArea, WaterResistanceThreshold	isResponsibleFor, isLocatedIn	11[a]
Dynamic Flood Ontology	Kurte*et al.*	2017	[34]	integration	Modular	GeoSpatialRegionTime, Slice,timeSlice, GeoSpatialRegion, Timeinterval, ImageSegment,	hasFloodFiliation, isSubmergedBy, hasBeginning	8[a]
Flood Scene Ontology	Potnis *et al.*	2018	[51]	Extension	Modular	FloodWater, Road Vehicle	hasVehicle	4[a]
Flood Ontology	Wang *et al.*	2017	[73]	Extension	Modular	WaterLevel, WeatherStation, HydrologcalStation, RainGuage, WaterLevelGauge, Waterbody, HyrdrologicalMonitorPoint	isHostedBy, isObservedBy	10[a]
Flood Ontology	Sermet and Demir	2019	[63]	Extension and integration	Modular	NaturalHazard, Instrument, EnvironmentalPhenomena, RiverineFlood,	flowDirection, flowRate, hasWaterSource, measuredBy	42[a]
ORFFM	Mughal *et al.*	2021	This article	Extension and integration	Modular	SpatialRegion, AdminstrativeAuthority, DisasterManager,CanalCircle	WithdrawalFrom, DischargeTo, HasDataSource, HasFloodCommissioner, VulenerabilityAssessementOf	410

[a]Estimated classes from Partially available classes , Complete ontology is not available Publicly ; Few classes and properties examples are stated to reflect style and coverage aspect of ontology

decades and modeled flood domain with various aspects. Flood onology proposed in the context of urban flood, power cut issue due to flood, coastal flood, flood environment assessment, stakeholders preference, recede duration estimation inundated area, etc. These studies are summarized by capturing essential parameters of ontological models. Table 9 presents these studies with the Name of Ontology, creators, Year of proposal or development, Operations, Design pattern, few classes/subclasses examples, few properties examples, and the approximate total number of classes. Most of the ontologies are not publicly available, therefore the classes are estimated from the published articles of these studies. The last row of the Table 9 is our proposed and developed ORFFM semantic model. The studies are sorted by year in ascending order representing the evolution of semantic modeling approaches for the floods. We believe that optimizing streamflow in irrigation networks has a direct connection with flood mitigation. To the best of our knowledge, Our semantic model ORFFM has the highest number of classes, integrating irrigation domain and with publicly available ontology via VII-A.

VIII. CONCLUSION AND DISCUSSION

In this paper, we presented a novel approach for knitting the hierarchies of water-producing sources, water distribution, and diversion mechanisms. Flow monitoring and maintenance are connected to flood and it raises the phenomenon of context-awareness in terms of water overflow during streaming from one node to another. Precisely, it helps towards the improved distribution of water to the irrigation lands, and reduce wastage. We represented modular ontology to simplify the complexity of large-scale spatiotemporal systems. We contribute to interoperable information sharing for efficient water utilization for agricultural lands and avoidance, mitigation, and response mechanism for a flood disaster. We proposed the integration of technology through semantic modeling. Machine process-able data assists in improving the economy through better provision of irrigation to agricultural lands as well as household and industrial use.

Due to climate change performance of the forecasting model was degraded. A higher number of dimensions results in a computational trade-off. The contextual model is required for effective forecasting models considering local constraints and considering the variability of data. Another major issue of degraded performance and the reliability of the data. Non-reliability is itself a disaster for the decision-making system. A realistic model not only needs the contextual models but also requires data with acceptable accuracy, adequate frequency, a sufficient number of features to model the semantic model with reliability and interoperability.

IX. FUTURE WORK

We would develop the automation system based on ORFFM interoperable, consistent information repository of integrated domains, such as self-alarming system integrated with climatology, topology, agricultural, and population consensus data for water availability based adaptive model for crops. The autonomous system needs to develop that can consumes the information processed by WaterOnto after acquisition from WaterGird and then applying heuristic for combined human and machine intelligence for the optimal solution and proactive response strategies development. Towards an extension of the ORFFM model, we covered semantic formalism, inferring, rule language, and formal logic along with semantic interpretation. We extend this model for proof layer by integration and implementation of business logic, provenance for verification of activities performed, and Blockchain consensus-based modification of workflow and water distribution mechanism to resolve the conflict among provinces triggered by the scarcity of fresh surface water.

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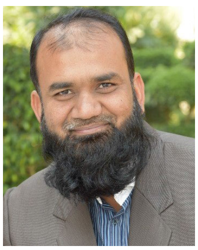

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