Developing open geographic data model and analysis tools for disaster management: landslide case

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Abstract

Disaster Management aims to reduce catastrophic losses of disasters. Geographic information technologies support disaster management activities for effective and collaborative data management considering complex nature of disasters. This study with an original conceptual approach aims to develop interoperable geographic data model and analysis tools to manage geographic data sets coming from different sources. For landslide disaster, 39 scenario-based activities were analyzed with required data according to user needs in a cycle of activities at mitigation, preparedness, response, and recovery phases. Interoperable geographic data model for disaster management (ADYS), enabling up-to-date exchange of geographic data, was designed compliant with the standards of ISO/TC211 Geographic Information / Geomatics, Open Geospatial Consortium (OGC), and Turkey National GIS (TUCBS). Open source and free analysis toolbox was developed and tested in the case study of the activities such as landslide hazard analysis and disaster warning system to support Provincial Disaster Management Centers of Turkey. Open data models and analysis tools make effective activity management and data sharing possible. However, transforming data sets to the data exchange formats is laborious.

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1 Introduction

Disaster is a natural, manmade, or technological event which causes physical, economics, and technological losses for the community and suspends the daily life of people with great destruction, ecological problems, loss of human life, and deterioration of health (UNISDR, 2009; WHO, 2005; FEMA, 1990). Landslides, amongst the most damaging disasters in mountainous regions especially, cause loses of lives and affects economy. In Turkey, the annual economic loses of landslides are about US $80 million, the second most common natural disaster after earthquakes. The majority of the losses are in the Eastern Black Sea region of Turkey that is subjected to heavy precipitation in mountainous topographical features (Yalcin, 2007; Ildir, 1995).

Disaster management aims to reduce potential losses, to provide essential assistance to victims, and to achieve rapid recovery. Disaster management works in a cycle of activities at mitigation, preparedness, response, and recovery phases. Prior to disaster, mitigation phase activities analyze risks and reduce possible impact of disasters, and then preparedness phase activities plan to ensure a rapid and more effective response. Response phase activities include emergency operations for minimizing effects during the disaster event and recovery phase returns life to normal after the disaster (Orchestra 2008; OASIS, 2005).

Geographic Information Systems (GIS) has an important role for effective disaster management. Considering complex nature of disasters, GIS can manage base geographic data sets such as buildings, roads, and topography and real-time data sets such as rainfall, earthquake, and water flow. In cases of disasters, actors and decision makers need up-to-date, accurately and timely geographic data from different data providers. The data sets need to be used for collaborative decision-making in disaster management activities. However, the lack of up-to-date exchange of the data sets hampers effective use of GIS in the activities. The delays and problems access to qualified data affect decision processes in disaster management activities (Abdalla and Tao, 2005; Zhang et al. 2010). The availability of the data sets is restricted by legal issues and limited by differences in data models and specifications (Aydinoglu and Yomralioglu, 2010).

Towards GIS, Geospatial Data Infrastructure (GDI) as a framework encompasses policies, access networks, standards, and human resources necessary for the effective management and the sharing of geographic data sets on web services. It provides multi-participant environment for the actors to support decision-making in disaster management activities (Mansourian, et al., 2006; Molina and Bayarri 2011). In this regard, data content standards supporting interoperability should be defined independent from any software and hardware for the successful functioning of the disaster management system. Otherwise the system working with inconvenient data will be ineffective in the case of disasters (Aubrecht et al., 2013).

GIS is mostly implemented for generating hazard and risk maps of disasters by using spatial analysis tools and visualizes the maps on the web environment for the planning purposes (Armenakis and Nirupama, 2013; Yalcin et al., 2011). As a part of National GDI initiatives, Federal Geographic Data Committee (FGDC) Department of Homeland Security (DHS) developed the DHS data model to support data interoperability in disaster management community with allies (FGDC, 2009). Hazus is a national methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes especially (Schneider and Schauer, 2006). Geo-spatial Data Infrastructure for Disaster Management (GDI4DM) project develops open national data models to manage preparedness and response phase of disasters. Information Model for Safety and Security (IMOOV) compliant with other national data specifications of the Netherlands provides a general approach for disaster or event management, similar to GDI4DM (Geonovum, 2008; Zlatanova et al., 2010). As well as these projects, integrated disaster management and developing data models compatible with National GDI are current research topics.

This study aims to determine an original conceptual model for harmonized and integrated disaster management. According to the conceptual model of disaster type-activity-task-data relations with landslide case, this paper offers a method to develop open/general data specifications based on the requirements of all disaster management activities at different phases and to understand how open data sets can be analysed with open software tools. As the first case of Turkey National GIS (TUCBS) infrastructure following GDI vision, the interoperable data model for disaster management (ADYS) that makes up-to-date exchange of geographic data sets from different sources possible was designed. The ADYS analysis tools that are open, flexible, and independent from any software and hardware were developed.

In Section 2, within the scope of fight against landslide disaster, the activities were analysed at mitigation, preparedness, response, and recovery phases to lead operations of Disaster Management Centers in provinces of Turkey. According to the standards of ISO/TC 211 Geographic Information/Geomatics Committee, application schemas of the ADYS data model were designed with Unified Modeling Language (UML) and encoded to Geographic Markup Language (GML) data exchange format. Considering the activities for landslide, ADYS analysis toolbox requiring open geographic data sets was developed with the using of open-source GIS software tools. In Section 3, these application schemas were tested in case

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activities such as landslide analysis, disaster warning system, and disaster effect analysis. This study was examined for effective disaster management in the last sections.

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2 Material and methods

Conceptual approach for disaster management is defined to cope with the complex nature of disasters. This approach helps integrated management of disaster types such as earthquake, floods, landslides, fire, and transportation accident. The activities at different phases of disaster management were analyzed with required data to understand requirements of landslide case. According to this analysis, an open geographic data model for disaster management was designed and then open analysis tools were developed for the activities.

2.1. Conceptual approach for disaster management

The conceptual approach (Figure 1) of disaster management was defined with upper classes; DisasterType, Actor, Activity, Task, and Data (Aydinoglu et al., 2012);

- "DisasterType" defines disasters causing loss of life and property, such as landslide, earthquake, and fire.
- "Activity" is the applications to fight against the disasters at mitigation (Z), preparedness (H), response (M), and recovery (I) phases. For example, landslide risk analysis at mitigation phase, determining response units for fire at preparedness phase, determining earthquake effect area at response level, and restructuring works following flood at recovery phase are some examples of disaster management.
- "Actor" is responsible for managing the activities of any disaster type as S.Actor and works in response activities as F.Actor. The actors as example are disaster management centers under the responsibility of governorships, civil defense, fire fighters, ambulances, and police. In addition to this, rescue team and wreck removal unit are the actors responding to landslide hazard.
- "Task" is a part of the activity. Actors perform these tasks respectively for the response activity of any disaster type such as registering incident, directing rescue team, and evacuating area.

- "Data" is required and produced during a task. It is supposed that a task requires existing data from TUCBS base database and requires and produces static/dynamic data from ADYS disaster management database.

2.2. Activity analysis for landslide

As a result of a fieldwork applied to the experts and the actors and examining academic research, for landslide, 39 sub-activities of 15 activity group were defined at all disaster management phases (Aydinoglu, et al., 2012). As well as landslide hazard and vulnerability analysis studied often at mitigation phase, the activities at preparedness, response, and recovery phases were analysed.

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As the beginning phase of disaster management, mitigation phase contains the activities for the reduction of losses prior to disaster event. This phase consists of three parts; analysis, planning risk reduction, and re-planning as seen on Table 1. HEY.Z.01 landslide analysis activities comprise works for determining landslide potential, risky buildings and infrastructures. HEY.Z.02 risk reduction activities contain works for the elimination and the reduction of risks determined in the analysis works. In HEY.Z.03 activity, residential areas are planned depending on landslide risk determined in landslide analysis works. GIS techniques were implemented in these activities to determine measures to be taken before landslides (INSPIRE 2011; Muthukumar, 2013; Sudmeier et. al., 2013; Holcombe et. al., 2012; Jaiswal and van Westen, 2013).

As seen on Table 2, preparedness phase as pre-disaster activity contains activities to determine and to coordinate resources during disaster. After determining landslide risk in the analysis activities, HEY.H.01 activity anticipates response areas when landslide occurs. While response units are planned in HEY.H.02 activities, resources in response phase are examined in HEY.H.03 activities. HEY.H.04 activities estimate evacuation requirements when landslide occurs. It is envisaged which buildings may be damaged and should be evacuated prior to the disaster. In this way, these activities help to save people from disaster effect area quickly. HEY.H.05 activity determines warning locations for disaster warning system. These outputs are used in the activities of response phase (Bittencourt et.al., 2013; Venkatesan et.al., 2013; Ko and Kwak, 2012).

Response activities include tasks immediately after disasters as seen on Table 3. HEY.M.01 activity determines affected area after disaster occurs and its location is defined. Affected buildings and infrastructures are determined in the HEY.M.02 activity important for response units and evacuation process of victims. HEY.M.03 activity directs response units such as police, health response, and civil defense by using network analysis functions of GIS. While HEY.M.04 activity identifies buildings for evacuation, HEY.M.05 activity delivers base and health supplies determined in the preparedness phase (Parentale and Sathisan, 2007; HS, 2008; Saadatseresht et.al., 2009; Keim 2008).

Recovery phase includes activities for the reduction and elimination of disaster losses. As seen on Table 4, HEY.I.01 activity detects debris and plan debris removal by defining convenient location and logistics facilities. HEY.I.02 activity plans new settlements to update zoning plans after the disaster brought about destruction. Thus, risk reduction and elimination will be provided in the long term (Beck 2005; Wiles et.al., 2005).

2.3. Requirement analysis example for landslide activities

Each activity has various tasks respectively that were managed by the actors. These tasks need static and real-time geographic data. Base data sets such as buildings, roads, and topography are included in static data category. Furthermore, meteorological data, earthquake data, and traffic density data can be defined in real-time data category.

For landslide disaster, the sub-activities were analyzed to define data requirement. These analyses were carried out based on expert opinion after examining academic publications and projects, and then completed with the assessment of the actors in disaster management sector. The data requirement analysis defines produced and used geographic data sets with detailed information including data types, geometry, attributes and values, associations and topological rules, and possible functions.

For example; at mitigation phase, HEY.Z.01.01 Landslide Hazard Analysis produces landslide hazard raster datasets by using spatial analysis techniques on data sets such as topography, land cover, stream, road, and lithology. Topography, as example, with line geometry was defined with the attributes such as elevation height, type, and accuracy.

At response phase, HEY.M.O3.05 Directing Emergency Management Units as a sub-activity of HEY.M.03 Directing Response Units produces transportation route data sets by using GIS network analysis techniques. The tasks in this analysis require response area, road, emergency response unit, affected building, and response source data sets. Response source location, as example, with point geometry was defined with the attributes such as emergency response material list, material amount, responsible person, and communication information.

2.4. Designing interoperable geographic data model of Turkey with landslide case

Disaster management projects of Turkey have been initiated after devastating Marmara earthquake in 1999. Turkey Disaster Information System (TABİS) project developed a database structure and GIS standards for disaster management. These standards were implemented for Istanbul in a project (Bilgi et al., 2008). Hazturk project based on Hazus developed an earthquake loss estimation for Turkey. Various projects more have been triggered, such as meteorological early warning system, seismic risk mitigation, emergency transportation network planning, and disaster information system projects especially focused on earthquake (Korkmaz, 2009). In 2009, the Prime Ministry of Turkey established Disaster and Emergency Management Presidency according to the law N.5902. It aims to coordinate all disaster events under a central administration structure and provincial administrations are responsible for managing disaster events (Gazette of Republic of Turkey, 2009). However, data management and coordination approach have not been determined yet to manage disaster types, actors, and disaster activities (Aydinoglu, et al., 2011; Erden 2012).

Turkey National GIS (TUCBS) base data specifications were designed to enable geographic data interoperability between data providers and users, after General Directorate of GIS was built in 2012. However, TUCBS data models have not put into practice yet and stakeholders have met with problems such as the usability of data models, and data sharing problems, and repetitive data production. Data interoperability is required between sector data models like disaster management and national data models like TUCBS (GDGIS, 2012-1).

In this study, The ADYS data model titled as disaster management data model was designed with landslide case according to the data requirement in the activity analysis. As conceptual approach, The ADYS data model is compliant with TUCBS and Urban GIS (KBS) data models. TUCBS base data themes such as Address (*AD.Adres*), Land Cover (*AO.Arazi Örtüsü*), Building (*BI.Bina*), Administrative Unit (*IB.Idari Birim*), Hydrography (*HI.Hidrografya*), Geodesy (*JD.Jeodezik Altyapı*), Orthophoto (*OR.Ortofoto*), Land Registry-

Cadastre (*TK.Tapu- Kadastro*), Topography (*TO.Topografya*), and Transportation (*UL.Ulaşım*) are used as base static data in disaster management activities (GDGIS, 2012-2). It is supposed that data interoperability will be possible at logical level because public institutions accepted TUCBS standards for the exchange of geographic data sets (Figure 2).

ADYS is as an object-oriented geo-data model. ISO 19103 Conceptual Schema Language (ISO/TC211, 2005a), ISO 19109 Application Schema Rules (ISO/TC211, 2005b), and other related standards of ISO/TC211 define rules to model feature types, relations between these, attributes, geometries, and other properties. UML as a modeling language is used for object modelling.

The ADYS data model includes feature types defined in the disaster management activities for the disaster types like Earthquake (*Deprem*), Landslide (*Heyelan*), Flooding (*Sel*), Forest Fire / Fire (*Orman/Kent yangını*), Transportation Accident (*Ulaşım Kazası*), and disaster general (*Afet Genel*). This model includes disaster related feature types not defined in TUCBS and KBS data models. For example, beside other geo-data themes, landslide theme includes feature types; plantation area (*AgaclandirmaBolge*), barrier area (*BariyerUygulamaBolge*), retaining walls (*IstinatDuvari*), slope regulation region (*SevDüzenlemeBölge*), drainage arrangement (*DrenajDuzeneleme*), landslide hazard (*HeyelanTehlike*), and so on.

According to the requirement analysis of landslide activities, the used and produced feature types were modelled for the activities. For example:

In the activity HEY.Z.01 Landslide Analysis Works as seen on Figure 3, HEY.Z.01.01 requires digital elevation model, slope, and aspect *(<<featuretype>> YukseklikGrid, Egim, Baki*) from TUCBS.TO, stream *(<<featuretype>> Akarsu*) from TUCBS.HI, land cover *(<<featuretype>> AraziOrtusuNesnesi*) from TUCBS.AO, road *(<<featuretype>> Karayolu*) from TUCBS.UL, and lithology *(<<featuretype>> Litoloji*) from TUCBS data themes. Landslide hazard *(<<featuretype>> HeyelanTehlike*) of the ADYS data model is produced with analysing these inputs according to the method.

HEY.Z.01.02 requires building *(<<featuretype>> Bina*) from TUCBS.BI, transportation base class *(<<featuretype>> Ulasim*) from TUCBS.UL, infrastructure base class *(<<featuretype>> Ulasim*) from TUCBS data themes. According to the method, landslide vulnerability (*<<featuretype>> HeyelanZarar*) of the ADYS data model is produced with analysing these inputs.

A risk zone is the spatial extent of a combination of a hazard and the associated probability of its occurrence. A risk zone must be associated with one or more vulnerability coverage including exposed elements such as building and infrastructure (INSPIRE, 2011). For HEY.Z.01.03, landslide risk (<<*featuretype*>> *HeyelanRisk*) of the ADYS data model is associated with a landslide hazard when landslide hazard is in vulnerability feature types.

In the activity HEY.H.05 Landslide Warning System, required data is Building (<<*featuretype*>> *Bina*) from TUCBS.BI and Disaster Risk (<<*featuretype*>> *AfetRisk*) from ADYS general data theme. Disaster warning area (<<*featuretype*>> *AfetUyarıAlanı*) depending on disaster risk and disaster warning point (<<*featuretype*>> *AfetUyariNoktasi*) feature types are defined with address, geometry, ownership, and megaphone model attributes in the ADYS data model (Figure 4).

HEY.M.01 Determining Disaster Effect Area is the first activity at response phase to identify areas where the disaster occurs and to determine affected structures. Figure 5 presents feature types of this activity defined in the ADYS model. The location of the disaster is defined in event (<<*featuretype*>> *Olay*) feature type with point geometry. If an event covers wide-area and threaten human life and environment, disaster is called and the estimated disaster effect area *(*<<*featuretype*>> *TahminiAfetEtkiAlani*) is defined with polygon geometry.

After response units work, the actual impact of the disaster is defined with disaster effect area (<<*featuretype*>> *AfetEtkiAlani*). This area aggregates affected buildings, infrastructures, transportation, and vehicles feature types that are inherited from the TUCBS data model. Response areas (<<*featuretype*>> *MudahaleBolgesi*) are determined and response units are directed to the structures in the disaster effect area.

2.5. Approach for Geographic Data Exchange

After modelling UML application schemas, these models were transformed to ISO 19136 Geography Markup Language (GML) format that is a XML based encoding standard for geographic data interoperability and developed by Open Geospatial Consortium (OGC). It is supposed if different geographic data sets produced by different users are converted into these TUCBS and ADYS data exchange format, these data sets can be used in the disaster management activities effectively (OGC, 2012; OGC, 2011; Li et al. 2008). Geographic data sets, therefore, should be transformed from a system to another system by using these application schemas as a data exchange format.

However public institutions used to work with their familiar software and database environment. Extract-Transform-Load (ETL) tools, therefore, were developed to overcome interoperability challenges by providing accurate and defined geographic data sets to the users. ETL tool extracts data from a source database, transforms the data to the format defined in TUCBS and ADYS application schemas, and loads the data into application database for disaster management activities.

2.6. Developing Open Spatial Analysis Tools for the Activities

Free and Open Source Software (FOSS) desktop GIS programs were used to develop the ADYS toolbox due to most GIS functions can be accomplished in desktop environment. Quantum GIS, GRASS GIS, and SAGA GIS as mature desktop GIS projects were used in this study. These are licensed by General Public License (GPL) and free as alternative of commercial software (Steiniger and Hunter, 2013; Teeuw, et al. 2013).

Processing steps of the analysis tools were developed in Quantum GIS (QGIS) open source platform. QGIS performed extremely well under the existing conditions and its functionalities are adequate for general applications. As user interface of ADYS toolbox, the Sextante toolbox is a Java-based framework and processes vector and raster data with several desktop GIS tools. Its functionalities can be enhanced with GIS functions of other programs (Chen et al., 2010; Hugentobler, 2008).

GRASS GIS has become a high quality cutting edge GIS, represents a collaborative development model, and supports the free spread of knowledge. Users are encouraged to download the underlying code, customize and enhance all algorithms and methods. Since it is a modular system it may be implemented in various environments (Neteler et al., 2012; Steineger and Hay 2009; Neteler and Mitasova, 2008; Casagrande et. al., 2012).

Beside these, System for Automated Geoscientific Analysis (SAGA GIS) come forward with powerful and various spatial analysis tools (Cimmery, 2010; Conrad, 2007). GDAL (raster) and OGR (vector) are two libraries that import and convert between different geographic data formats. Their Python bindings play a significant role in current FOSS developments.

The ADYS analysis toolbox was developed to manage landslide activities according to the activity analysis explaining task steps. The framework provides templates for the custom construction of model components arranging the schedule of the integrated model. The high-level Python language, allowing domain experts without in-depth knowledge of software, was used for model construction of the activities (Schmitz et. al., 2013).

Figure 6 shows ADYS toolbox including landslide activities as example. As the activities of mitigation phase, HEY.Z.01.03 Landslide Risk Analysis tool can be run after HEY.Z.01.01 Landslide Hazard Analysis and HEY.Z.01.02 Landslide Vulnerability Analysis tools. These tools use input GML data sets from TUCBS database as explained on Figure 3. GRASS GIS and SAGA GIS functions were utilized in the processing steps of this tool as seen on Figure 8. Besides r.slope.aspect for generating slope and aspect and r.buffer for creating a raster euclidan distance from GRASS GIS; shapes to grid, reclassify grid values, and raster calculator were used from SAGA GIS.

In the HEY.Z.01.01 tool, raster calculator is used to produce landslide hazard map (<<*featuretype*>> *Heyelan Tehlike*) from the input data sets. Analytic Hierarchy Process (AHP) improved by Saaty (1980), one of the multi-criteria decision analyses (MCDA), deals with complex decision-making and help to determine weights of selected criteria for each input data set (Saaty and Vargas, 2001; Chen, et al., 2013; Erden and Karaman, 2012). Pair-wise comparison matrix, factor weights and consistency ratio of the data sets were determined after reviewing academic publications, Yalcin et al. (2011) especially.

Figure 7 shows the Phyton code of processing steps for the activity HEY.H.05.01 disaster warning system. This activity requires GML data sets from TUCBS database and aims to define warning points and covering area in the best way. Locations of warning points should be the optimum number and cover more population depending on effect area. Thus, open analysis functions such as creategraticule from SAGA GIS, polygoncentroids, extractnodes and fixeddistancebuffer from QGIS, and v.select from GRASS GIS were used.

3. CASE STUDY

The activity tools of HEY.Z.01.01 Landslide Hazard Analysis and HEY.Z.01.02 Landslide Vulnerability Analysis were tested to produce HEY.Z.01.03 Landslide Risk Analysis. Data sets defined in Figure 3 were collected from various public institutions for Macka county of

Trabzon province of Turkey, such as elevation and stream data sets from General Command of Mapping (GCM), transportation data sets including road from Ministry of Transportation, lithology data set from General Directorate of Mine Research, infrastructure and building data sets from local government, and LANDSAT image.

By designing ETL tool developed in FME software, these data sets were converted to GML-based data exchange format of TUCBS and ADYS and then applicable database format because of different formats and contents.

For Landslide Hazard Analysis, the HEY.Z.01.01 tool use digital elevation model (DEM), lithology, stream, road, and satellite image (Figure 8). Processing steps with additional analysis tools;

- All input data sets were converted to raster format for analysis processes.
- Using surface analysis techniques produces slope and aspect data sets (<<featuretype>> Egim / Baki) from digital elevation data sets (*<<featuretype>> YukseklikGrid*).
- Calculating Normalized Difference Vegetation Index (NDVI) in red and near-infrared (nir) band of satellite image determines vegetation as land cover object *(<<featuretype>> AraziOrtusuNesnesi*).
- Using euclidean distance analysis tool produces distance to road and stream data sets from base data sets (*<<featuretype>> Karayolu / Akarsu*).
- Reclassifying raster data sets determines normalized factor weights for lithology, slope, aspect, land cover, elevation, distance to stream, distance to road. For example; factor weights of slope are 0.043 for % 0-10, 0.068 for %10-20, 0.123 for %20-30, 0.288 for %30-50, 0.479 for bigger than %50 (consistency ratio: 0.038). Factor weights of distance to road are 0.394 for 0-25m, 0.234 for 25-50m, 0.124 for 50-75m, 0.124 for 75-100m, and 0.124 for 100-125m (consistency ratio: 0.016).
- The last process of this tool is to analyse the data sets by Weighed Linear Combination (WLC) method depending on weight values of the each factor. Weight values between the factors were calculated as 0.386 for lithology, 0.230 for slope, 0.129 for aspect, 0.098 for elevation, 0.083 for land cover, 0.037 for distance to stream, and 0.037 for distance to road (consistency ratio: 0.038, acceptable).
- As a result, Landslide Hazard Map (*<<featuretype>> HeyelanTehlike of ADYS*) was produced with low, medium, and high hazard level as seen on Figure 8.

For Landslide Vulnerability Analysis, the HEY.Z.01.02 tool use building data sets, infrastructure data sets including linear engineering structures, and transportation data sets including road, railway, and related structures. Similar to processing steps above, these data sets were analysed by WLC method depending on the weight values of each factor. As a result of this case study, vulnerable areas (<<*featuretype*>> *HeyelanZarar)* of ADYS were determined to analyse with landslide hazard map.

To test the HEY.H.05.01 activity tool, Selver and Osman Gazi Districts of Meram county of Konya province of Turkey were determined as case area. Input building data set was collected from local government and analysed by using the interface on Figure 9. Processing steps defined on Figure 7;

- Graticule was created with 500m, depending on building data sets. Centroids and nodes were extracted from graticule. Duplications were eliminated and then the data were merged.
- Graticule was created for building area again. Warning points were selected in these areas. Then, covering area was defined with buffer function.
- After processing steps of this analysis tool, it is supposed that each warning point announces an area of 250m. As output of this tool, GML data sets of disaster warning points (<<*featuretype*>> *AfetUyariNoktası*) and disaster warning area (<<*featuretype*>> *AfetUyariAlani*) were produced in the ADYS database.
- As a result, 21 disaster warning points covering %97.3 of buildings were assigned by using this analysis tool.

4. RESULTS

The ADYS, disaster management data model, was designed as open and object-oriented geographic data model and compatible to ISO/TC211 standards and national data models. It is supposed that if data providers produce geographic data sets depending on these data models, data sharing and cooperation will be possible between actors for disaster management activities at mitigation, preparedness, response, and recovery phases. This model, therefore, is a new approach for geographic data interoperability in Turkey.

The ADYS data model with landslide case can be implemented in any geographic database because it was designed independent from any software and hardware. In general, accepted and familiar methods have been determined for each activity because the model was prepared according to analysis results of the activities and background of available projects. It is supposed that 39 activities at all disaster management phases of landslide can be managed with this approach and determines a new approach for integrated disaster management in the public institutions.

Using a standardized geo-data model provides the interoperability of geographic data sets. GML data sets were used and produced as open data exchange format in case study. However, intensive process was required to collect the data sets coming from different sources, to convert open data model defined, and then to use in any database environment. A new data conversion is required for each activity because source data sets have not been standardized yet in Turkey. If each public institution had shared the data sets according to the standard of TUCBS and ADYS model, these open data sets could have been used in the activities automatically.

ADYS activities such as landslide analysis works and disaster warning system were tested with developed open-source analysis tools. Modeller environment of QGIS provides opportunities for using various open source software tools in the processing steps of the same activity. Multi-criteria decision analysis techniques and tools were implemented in the activities and aimed composing an automated analysis system. Compared with commercially available software, open source functions and tools tested with case study can be used in the disaster management activities and provides accurate results.

In this way, using these analysis tools with open geographic data sets provide costless and improvable solutions for the landslide activities of Disaster Management Centres in any province of Turkey.

5. DISCUSSION

Disaster management is a multi-disciplinary activity. The most fundamental asset is the data itself that needs to be shared between different actors. It is important to reach real and accurate geographic data sets on time. Geographic data sets used by actors have great importance to perform the tasks of the activities at different phases of disaster management. Therefore, ADYS conceptual model can be accepted as practical approach for integrated management of different disaster types like landslide.

Building GDI, named as TUCBS in Turkey, provides the tools giving easy access to distributed databases for disaster management actors who need data sets for their own activities. Activities with tasks were formalized sequentially while required data for each task was obtained from TUCBS mechanism compliant with ADYS model.

It will be possible to manage and to use dynamic geographic data on electronic communication networks when web interface developed with Service Oriented Architecture (SOA) is configured on the web and data servers. Related stakeholders can manage and update geographic data at a place where the data is maintained effectively. It is supposed that web services can have their interfaces generated automatically from the models. That is, UML-specified interfaces should be translatable into the specifications written in the Web Services Description Language (WSDL).

On the other hand, each GIS system works independently and can communicate with each other using agreed standards and exchange format. Even if TUCBS is implemented, this study will have some disadvantages about model conversion from UML to GML. This model-driven conversion causes the loss of some modelling content. The model, therefore, should be kept as simple as possible for the consistency of the data exchange format instead of complex systems and databases. In this study, most of these problems were tested and eliminated by reasonable changes.

Open source ADYS software tools can be implemented to develop complex analysis for different activities. These analysis tools are open source so users can modify them for their applications. However, expertise is required to build and manage open source tools. Eliminating bugs takes time if it is compared with commercial GIS software.

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Table 1. Landslide Activities for Mitigation Phase

HEY.Z.	**Landslide Activities for Mitigation Phase**
HEY.Z.01	Landslide analysis works
HEY.Z.01.01	Landslide hazard analysis
HEY.Z.01.02	Landslide vulnerability analysis
HEY.Z.01.03	Landslide risk analysis
HEY.Z.02	Planning landslide risk reduction
HEY.Z.02.01	Regulating natural slopes
HEY.Z.02.02	Identifying areas for the barrier
HEY.Z.02.03	Improving the ground of the slopes
HEY.Z.02.04	Reforestation of the slopes
HEY.Z.02.05	Establishment of drainage systems
HEY.Z.02.06	Determining areas for the construction of retaining walls
HEY.Z.02.07	Strengthening the buildings
HEY.Z.03	Landslide re-planning
HEY.Z.03.01	Planning new construction areas
HEY.Z.03.02	Making changes in plans

Table 2. Landslide Activities for Preparedness Phase

HEY.H.	**Landslide Activities for Preparedness Phase**
HEY.H.01	Planning landslide response
HEY.H.01.01	Determining response areas
HEY.H.02	Determining response units
HEY.H.02.01	Determining police response units
HEY.H.02.02	Determining fire response units
HEY.H.02.03	Determining health response units
HEY.H.02.04	Determining civil defense units
HEY.H.02.05	Determining emergency management units
HEY.H.03	Determining response resources
HEY.H.03.01	Determining locations for food and clothing supplies
HEY.H.03.02	Determining locations for health supplies
HEY.H.03.03	Determining locations for appliance supplies
HEY.H.04	Planning evacuation
HEY.H.04.01	Landslide evacuation analysis
HEY.H.04.02	Determining evacuation staff
HEY.H.05	Landslide warning system
HEY.H.05.01	Determining locations for warning system

Table 3. Landslide Activities for Response Phase

HEY.M.	**Landslide Activities for Response Phase**
HEY.M.01	Determining disaster effect area
HEY.M.01.01	Defining disaster location
HEY.M.02	Disaster effect analysis
HEY.M.02.01	Determining affected buildings
HEY.M.02.02	Determining affected infrastructures
HEY.M.03	Directing response units
HEY.M.03.01	Directing police response units
HEY.M.03.02	Directing fire response units
HEY.M.03.03	Directing health response units
HEY.M.03.04	Directing civil defense units
HEY.M.03.05	Directing emergency management units
HEY.M.04	Evacuations works
HEY.M.04.01	Identifying buildings for evacuation
HEY.M.04.02	Routing evacuation
HEY.M.05	Delivery of help resources
HEY.M.05.01	Delivery of base and health supplies

Table 4. Landslide Activities for Recovery Phase

HEY.I.	**Landslide Activities for Recovery Phase**
HEY.I.01	Recovery in disaster area
HEY.I.01.01	Detection of debris
HEY.I.01.02	Planning for debris removal
HEY.I.02	Restructuring works
HEY.I.02.01	Detecting restructuring regions
HEY.I.02.02	Making changes in the environmental plan

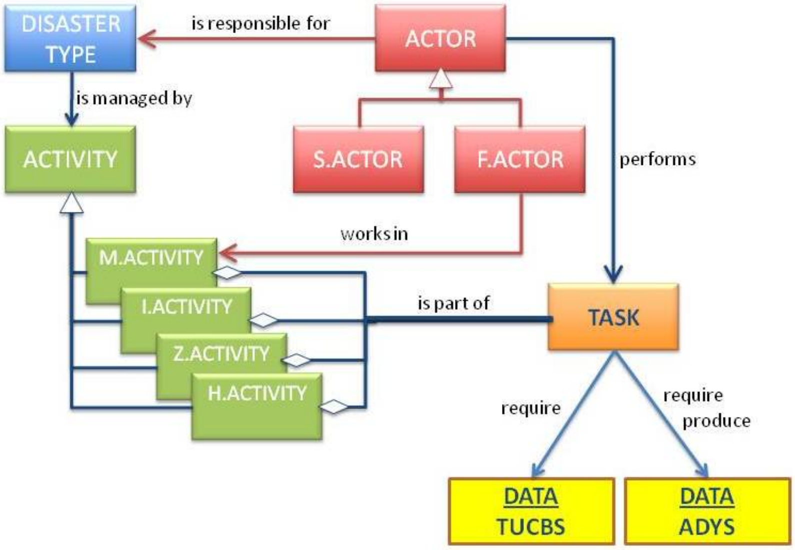

Figure 1. Conceptual Model Schema for Disaster Management

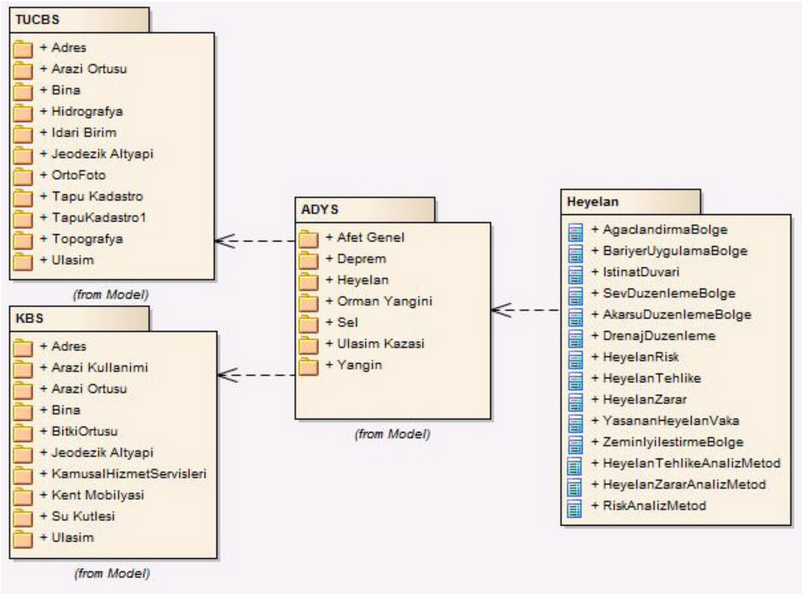

Figure 2. Data themes in TUCBS, KBS, and ADYS data models and feature types in Landslide theme

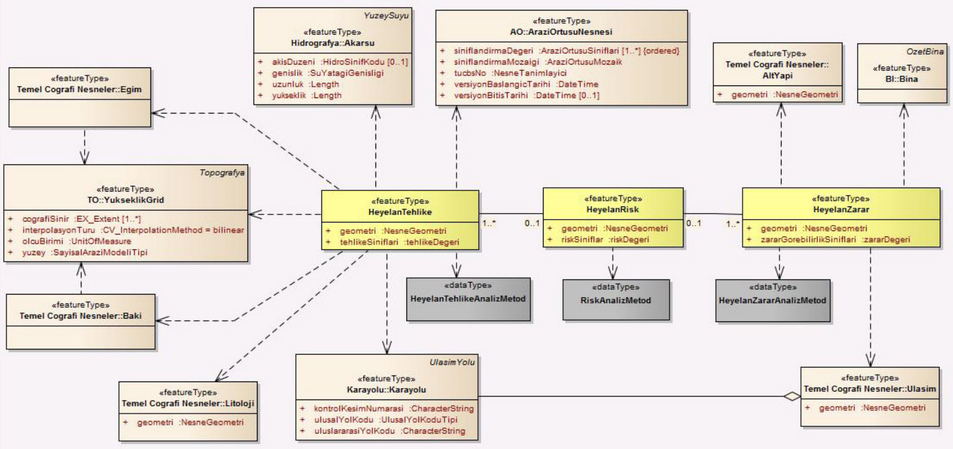

Figure 3. Relations between Hazard, Vulnerability, and Risk feature types

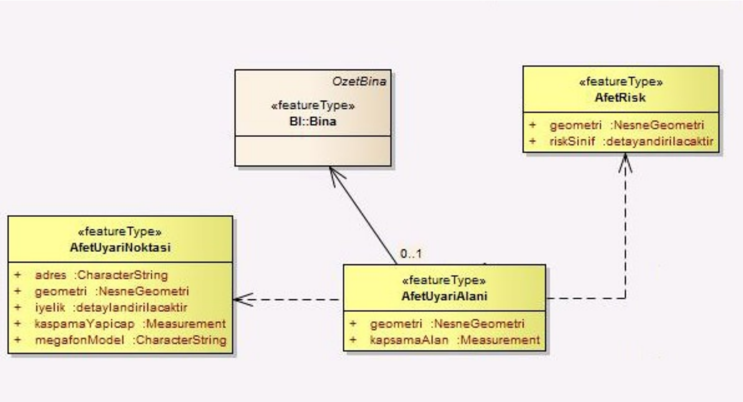

Figure 4. ADYS feature types concerning Disaster Warning System

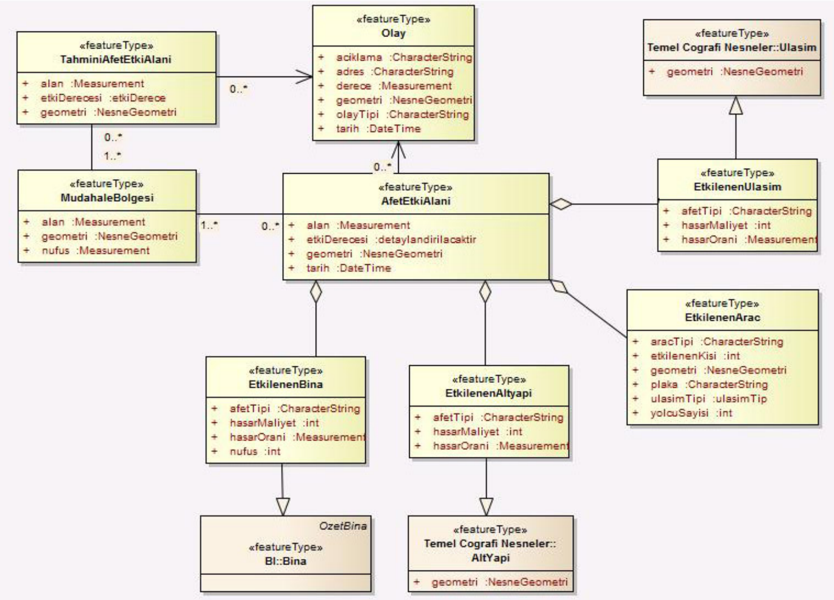

Figure 5. ADYS feature types concerning Disaster Effect Analysis

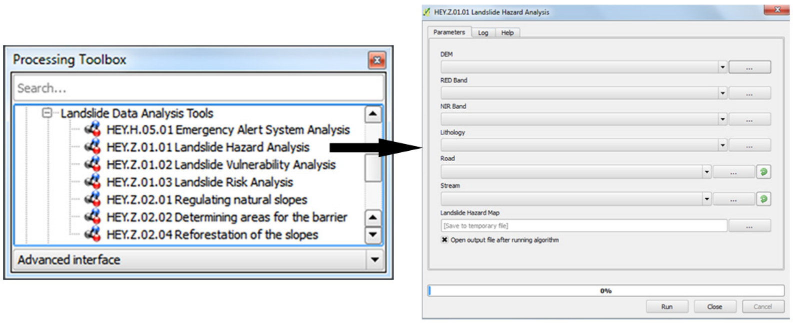

Figure 6. ADYS analysis toolbox and user interface of HEY.Z.01.01 activity

```
##HEY.H.05.01 Emergency Alert System Analysis=name
##Buildings=vector
##Warning_Point=output vector
##Warning_Coverage_Area=output vector
outputs_0=Processing.runalg("saga:creategraticule", Buildings, None, 500, 500, 1, None)
outputs_1=Processing.runalg("qgis:polygoncentroids", outputs_0['GRATICULE'], None)
outputs_2=Processing.runalg("qgis:extractnodes", outputs_0['GRATICULE'], None)
outputs_3=Processing.runalg("qgis:deleteduplicategeometries", outputs_2['OUTPUT'], None)
outputs_4=Processing.runalg("qgis:mergevectorlayers", outputs_1['OUTPUT_LAYER'], outputs_3['SAVENAME'], None)
outputs_5=Processing.runalg("saga:creategraticule", Buildings, None, 50, 50, 1, None)
outputs_6=Processing.runalg("grass:v.select", outputs_5['GRATICULE'], Buildings, 0, None, -1.0, 0.0001, 0, None)
outputs_7=Processing.runalg("grass:v.select", outputs_4['SAVENAME'], outputs_6['output'], 0, None, -1.0, 0.0001, 0, Warning_Point)
outputs_8=Processing.runalg("qgis:fixeddistancebuffer", outputs_7['output'], 250, 5, True, Warning_Coverage_Area)
```

Figure 7. Processing steps of HEY.H.05.01 activity

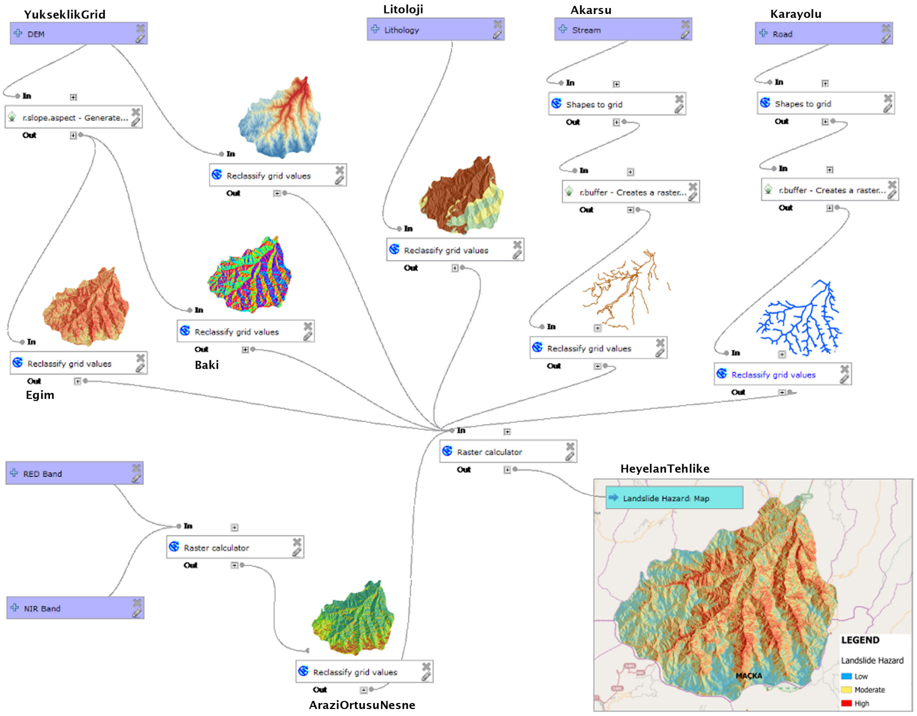

Figure 8. Processing steps and data sets for Landslide Hazard Analysis in Macka, Trabzon-Turkey

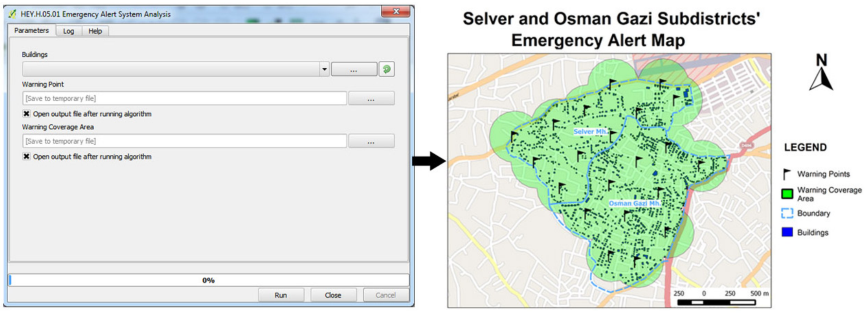

Figure 9. User interface and produced data sets for Disaster Warning System in Meram, Konya- Turkey