Integrated Database System with Spatial Information for Disaster Risk Management

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***Abstract*—Despite availability of various image sources for specific areas, a new disaster management system is likely to be implemented by using only one of them. Thus, its applicability and extensibility are severely limited. In addition, real-time update for the disaster area is one of the crucial functions for search and rescue activities. To meet the aforementioned requirements, in this paper, we propose a new spatial data infrastructure by defining the methodological scheme for the raster information. The proposed system has four respective layers to reduce the management cost as well as provide a flexible architecture. In each layer, various open source software or standard technologies are employed to perform the given tasks. The experimental results reveal that the proposed scheme accommodates the requirements for disaster risk management and meets the performance requirements in an efficient way.**

***Index Terms*—database, geographic information systems, terrain mapping, software, image processing.**

I. Introduction

When a natural disaster happens in a territory, people who live in the affected area are vulnerable to these events in most cases. Therefore, activities in disaster risk management need to be performed in an effective way. Since such actions are undertaken in different geographical areas, they mostly depend on technological tools and resources that improve the territorial analysis by capturing, processing, and disseminating accurate information. In many cases, several image or data sources are preferred rather than a single one. Good image sources include satellite images, aerial photographs captured by an unmanned aerial vehicle (UAV), and ground observation sensors. However, in most cases, an integrated system under technological and geospatial criteria for a spatial database was not well organized or developed yet. Under these circumstances, the user cannot obtain proper geographical information at the required time, making it impossible to quickly organize search activities. In addition, there is another demand for new integrated systems. Real time data obtained from certain areas should be processed to analyze the situation of the vulnerable population. This implies that the information obtained by different types of capture devices is integrated with the cartographic information of the place and subsequently used for search and rescue activities. Despite these demands, the existing systems are not qualified to provide real-time updates for multiple source images.

To meet aforementioned requirements, in this paper, we propose a spatial data infrastructure that allows the collection, storage, and timely distribution of raster and vector geospatial data from different sources, to support activities of disaster risk management quickly and efficiently. By providing the suitable information at the proper time, particularly as the prevention step, the proposed system is suitable for an adequate estimation of the risk. Moreover, it helps to reduce the level of vulnerability of the exposed populations. From technical point of view, a four-layered software architecture and a data model are explained and implemented using various standards and tools.

The remainder of this paper is organized as follows. In section II, an overview of system components and related research work are described. The methodology for processing spatial data is presented in section III. In section IV, we present the spatial data infrastructure architecture for search and rescue actions in each layer. The functioning of the architecture is proven by case studies in section V. Finally, we conclude the paper in section

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II. Overview of System Components

A. Disaster Risk Management

Disaster risk is a latent condition that announces the probability of damages and losses. Disasters caused by natural hazards are currently a major threat that affects both developed and developing countries. Contemporary aspects such as faster population growth, denser urban areas, economic crises, and global warming have intensified the effects and the potential negative consequences of natural disasters [1].

Fig. 1 shows an interaction between the hazards and the vulnerabilities. The hazards are the external risk factors with the potential to cause social, environmental, and economic damage to a community over a period of time. Vulnerability is the internal risk factor of a population exposed to a hazard depending on its predisposition to be damaged.

Disaster risk management is applied to the assessment of hazards and vulnerabilities. In general terms, risk management is the integral action to handle a disaster situation. It allows determining the risks and intervening to modify, reduce, or eliminate the risks. Thus, this is an appropriate preparation for the search and rescue (SAR)

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actions. SAR are the operations carried out by emergency services in order to find and rescue people who are affected by the occurrence of hazards and who are in remote or poorly accessible vulnerable areas. The search is often carried out in wide open spaces, mountain regions, oceans, and deserts [2].

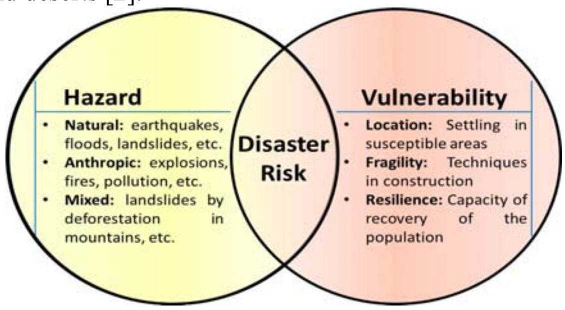

Figure 1. Interaction of elements in the risk of disasters

B. Geographic Information System

Geographic Information System (GIS) is a technology to manage geographic data and composed of computer equipment, software, methods, and rules that manage the spatial data and perform complex analysis. GPS works with spatial locations in a given geographical space. There are five elements of GIS: software, hardware, geographic database, functionalities, and users. Although all of them contribute to making the system effective, there are slight differences in their relative importance [3].

In addition, GIS manages the geographical element by handling the spatial and the thematic component of the data. Fig. 2 shows an example of a map developed with GIS: the levels of precipitation (thematic component) in a study area (spatial component).

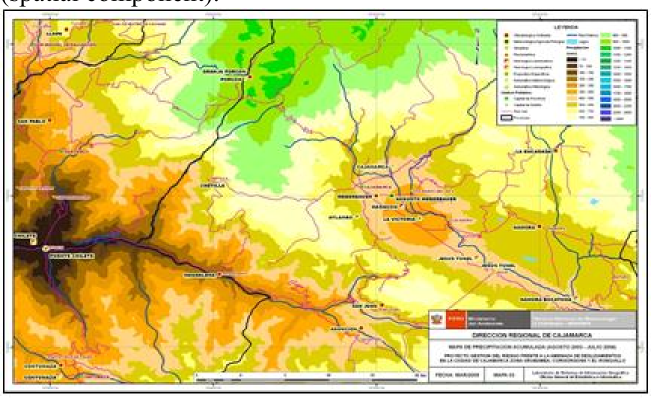

Figure 2. Map developed with the geographic information systems

Therefore, GIS works with both pieces of information: the location perfectly defined in the map and its associated thematic attributes. In more detail, GIS uses cartography and databases simultaneously by linking both parts and creating a single geographic database by using them. This ability to associate thematic databases together with the precise spatial description of geographic objects and their relationships (topology) is the major difference between GIS and other systems [4].

C. Spatial Data Set

A spatial data set is organized as a matrix with the information related to geographical places in the columns (the spatial component) and the attributes of these places in the rows (the thematic component). Thus, we can quantitatively process the information to check the spatial variation of a variable by analyzing a row. The spatial component refers to the geographic location of the objects, either geometrically or absolutely in relation to some external reference systems and the topological qualitative relationships (such as: to the left of, under, inside, etc.) This topological referencing facilitates the development of complex analysis and operations with spatial data, which distinguishes a GIS from a digital mapping system using absolute referencing [5]. The thematic component of the data represents patterns of variation that have certain regularities in both space and time.

D. Data Models

The data model refers to the rules used to create a real-world model. Principles of the integrated data model creation involve the description of spatial objects, their attributes and properties, topological details, and spatial relationships between them [6]. The two main data models in GIS are the vector and raster model. Whereas the former emphasizes the properties, the latter emphasizes the location. Vector model employs vectors (points, lines, and polygons) defined by pairs of coordinates relative to some cartographic projection system for the description of geographic objects. Raster model is an implicit conception of neighborhood relations between the geographic objects. Divide the study area of the database into a regular mesh of small cells (pixels) and assign a numerical value to each cell as a representation of its thematic value. Since the mesh is regular (the pixel size is constant) and the coordinate position of the center of each cell is known, then all pixels are georeferenced.

E. Spatial Data Infrastructure

The spatial data infrastructure (SDI) is defined as an architecture providing a configuration for optimal creation, management, and dissemination of geographic information at various organizational tiers with unanimous participation of public and private institutions. It is the result of the integration of access mechanisms, policies, standards, metadata, and institutional capacity to achieve an adequate management of the data that represent the geographic space [7]. Basically, SDI includes the definition and schematization of the following five components: institutional framework, technical standards, fundamental data, clearinghouse, and spatial database. In addition, the term geodatabase is frequently used to name a relational database containing geographic information [8], and also it works like a data mart that is a specific version of data warehouse [9].

F. Related Work for Disaster Risk Management

Previous studies for disaster risk management proposed various systems and architectures. Architecture of three-dimensional geographic information system along with its map service protocol [10] was realized as maps for aircraft simulation route during search and rescue operations. However, it was not integrated with information captured from satellites or UAVs. In [11], a real-time satellite data auto-processing system was developed. Using the proposed system, a massive enhancement of the raster images in database were set up. However, its applicability is only limited to satellite images.

In addition, building remote sensing images database and the architecture working on web service technology was presented in [12]. In [13], integrated Cloud-GIS and supporting technologies for a fast multisensor data fusion were used to describe the general target of the architecture. However, similarly to previous cases, its application is limited to risk assessment in power systems. Moreover, new process and architecture for remote sensing image data mining based on data warehouse and a prototype system were studied in [14].

Apart from aforementioned systems, specialized system implementations were also presented recently. These systems are employed to evaluate geospatial data for decision makers in emergency response. In case of GEODec [15] have three-tier architecture by blending techniques developed in the fields of databases, artificial intelligence, computer graphics, and computer vision. A system to support the earthquake disaster response was also presented in [16]. Finally, an interesting work was presented in [17] about a distributed geospatial data processing functionality to be applied in emergency response. However, the existing systems do not provide integration of various image sources, as well as capability to include real-time update yet.

III. Methodological Scheme for Raster Information

As indicated in the previous section, there are vector and raster data models. Whereas the spatial information in the vector model is stored in the database, raster model is processed prior to being converted to the other model. The benefit of storing information in a vector model is to manage complex data tables with more information called primary attribute tables. These tables work under a relational entity model within the spatial database. Fig. 3 shows the methodological schema for the processing of spatial data. The methodology performs numerous operations on a raster image and generates an answer to specific geographical questions. By manipulating imagery data values and positions, it is possible to get invisible features. The process of the methodological scheme is described in the following subsection.

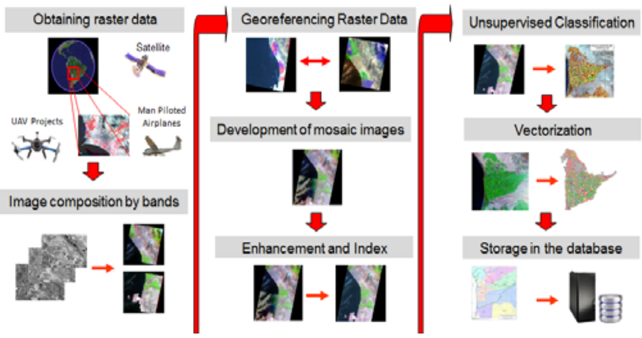

Figure 3. Methodological scheme for processing of raster information

A. 3.1 Obtaining Raster Data

The images in raster format are obtained from the data capture equipment, such as satellites, airplanes, or UAVs. Depending on the characteristics of equipment, such as its position relative to the ground, amplitude and coverage of the lens, or data processing capacity, the resolution of the information is determined. On the other hand, raster data is also obtained from official web sites of the space programs. In all cases, the metadata are verified prior to usage.

B. Image Composition by Bands

After obtaining the raster images from the date of analysis, in case of satellite images, the combination is performed in a single file for all bands under the fact that each band contains information captured within a specific range of the electromagnetic spectrum, and previously they are separated in different files. Whereas LANDSAT satellite image has seven bands, ASTER satellite image does a total of fourteen bands. All these spectral bands are grouped into a single file. Moreover, a group of three bands is selected according to the analysis to perform. In case of RGB bands, combinations for true color terrain visualization for Landsat 7 or Landsat 5 are likely to employ bands 7, 4, 2, whereas Landsat 8 does 7, 5, 3 bands.

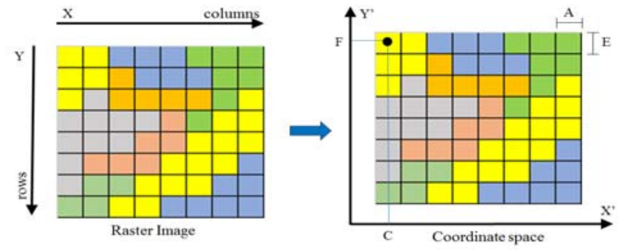

Figure 4. Application of general equations according to the least squares fitting (LSF) algorithm

C. Georeferencing Raster Data

If the raster data has no predefined cartographic parameters such as the coordinate projection system and reference ellipsoid, it makes use of checkpoints previously identified in the study area to locate the raster image spatially. To realize this, we perform a polynomial transformation, in which it uses a polynomial based on checkpoints and the algorithm of least squares fitting (LSF). Through LSF, we derive general equations (1) and (2) that are applied to all points (as Fig. 4 shows) to represent a slight movement of the positions of the control points. Table 1 shows a description of the parameters to be analyzed.

$$X' = AX + BY + C \tag{1}$$

$$Y' = DX + EY + F \tag{2}$$

TABLE I. PARAMETERS OF THE LEAST SQUARES FITTING (LFS) ALGORITHM

Variable	Description
X	Column count in the raster image.
Y	Row count in the raster image.
X’	Horizontal value in the coordinate space.
Y’	Vertical value in the coordinate space.
A	Width of the cell in the map units.
B	Rotation term.
C	X’ value of the center of the upper left cell.
D	Rotation term.
E	Negative height of the cell in the map units.
F	Y’ value of the center of the upper left cell.

D. Development of Mosaic Images

This process matches two or more raster images containing areas of land spatially continuous. The method we employed in this process is principal component analysis (PCA). Principal component analysis is a statistical procedure concerned with elucidating the covariance structure of a set of variables. Specifically, it allows us to identify the main directions in which the data varies. The process in two dimensions of the PCA method is shown in Fig. 5, where (μz1, μz2) are the mean values of the variables. Let Σ be a covariance matrix: a 2 x 2 matrix for all data points. We calculate the eigenvectors of the co-variance matrix, as well as get the direction of vectors indicated by Φ = [φ1, φ2]. Moreover, we build a transformation matrix that transforms our data points from the [x1, x2] axis system to the axis [φ1, φ2] system, according to the equation (3). Table II shows a description of the parameters to analyze.

$$P\phi = (Px - \mu x).\phi \tag{3}$$

TABLE II. PARAMETERS OF THE PRINCIPAL COMPONENT ANALYSIS (PCA) METHOD

Variable	Description
Px	Any point in the [x1, x2] axis system
μx = (μz1,μz2)	Data mean
PΦ	Coordinate of the point in the [φ1, φ2] axis system

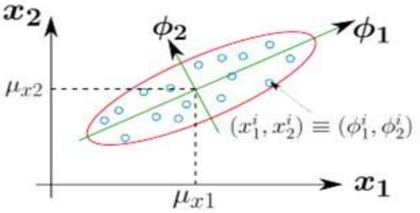

Figure 5. Process in two dimensions of the PCA method

E. Enhancement and Index

This process generates a combined result of bands where the spatial attributes related to the physical and chemical characteristics of the land are highlighted. Moreover, it allows us to identify the common geographical features of the concerned area. Specific features include the areas of vegetation, geological structure and composition of the soil. One of the most important cases is to determine areas with vegetation, because it is possible to evaluate the areas of the terrain that have large resistance to the effects generated by mass movements as the action of internal and external geodynamic phenomena based on location awareness.

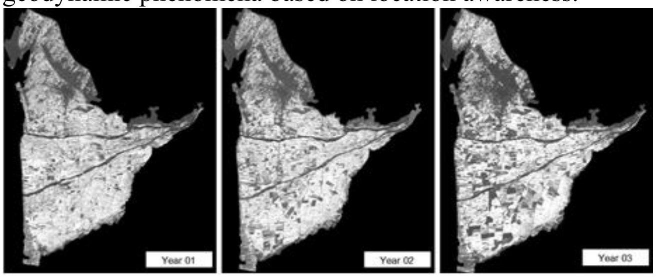

Figure 6. Results of multitemporal images processed using the NDVI method

For this subject, we propose to use the normalized difference vegetation index (NDVI). In case of satellite images, the raster data acquired in visible and near infrared spectral bands are adequate to determine the large differences in the reflectance of plants, and group them according to their similarity in order to set up their spatial distribution in these satellite images. The *NDVI* is calculated through these individual measurements with the equation (4), where *NIR* represents the data captured in infrared band and *VIS* does the data captured in visible band. *NDVI* is obtained from the visible and near-infrared light reflected by vegetation. In addition, the areas are distinguished by changed vegetation. In Fig. 6, we can observe the vegetation in this area is decreasing.

$$NDVI = \frac{(NIR - VIS)}{(NIR + VIS)} \tag{4}$$

F. Unsupervised Classification

This method performs grouping of pixels in ranges based on stored reflectance data. Each range is recognized as a color for better differentiation, and then monitoring sample points are identified. The algorithm has some further refinements by splitting and merging the clusters. The objective function to be minimized is the sums of square distances (errors) between each pixel and its assigned cluster center. This is represented in the equation (5), where C(x) is the mean of the cluster to which pixel x is assigned.

$$SS_{distances} = \sum\nolimits_{\forall x} [x - c(x)]^2 \tag{5}$$

Minimizing the $SS_{distances}$ is equivalent to minimizing the mean squared error, which is a measure of within-cluster variability given in the equation (6), where *N* is the number of pixels, *c* indicates the number of clusters, and *b* is the number of spectral bands.

$$MSE = \frac{\sum\nolimits_{\forall x} [x - c(x)]^2}{(N - c)^b} = \frac{SS_{distances}}{(N - c)^b} \tag{6}$$

G. Vectorization

In this process, the raster information (consisting of an array of pixel data) is converted into a vector format (based on geometric elements such as points, lines and polygons). The pixels that are classified as the same group in the previous step are consolidated to generate the vector elements.

H. Storage in the Database

This is the final process to store the raster information. Once this information is converted to vector elements, it is stored under the concept of spatial data tables. Each vector element linked to a record with data from this feature stores geometric data such as position (coordinate pairs), and location based on the projection system and reference ellipsoid (spatial georeferencing).

IV. NEW SDI ARCHITECTURE

Raster information captured from different sources (satellite, aircraft, UAVs) is integrated into a flexible system that allows the user to access this information immediately to organize search and rescue actions in case of natural disasters. The proposed SDI architecture for search and rescue consists of four layers. Each layer is divided considering the elements of hardware and software necessary for its technological operation in the collection, processing, and storage of data, as well as technical details of the integration of spatial data (raster, vector, and other ground data) within the SDI. In addition, the services of distribution and publication of the information are made by using the application corresponding to the standards of the Open Geospatial Consortium (OCG) and open software templates for visualization through the Web. The methodological schema of the architecture is illustrated in Fig. 7. Further, we will explain details for each layer.

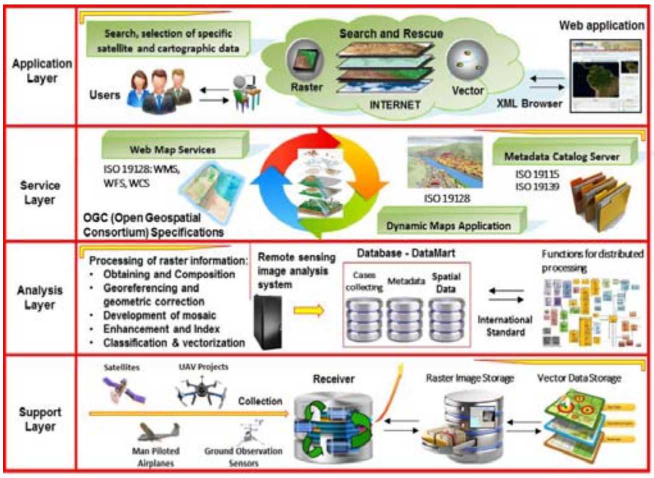

Figure 7. Methodological scheme for spatial data infrastructure architecture

A. Support Layer

One of the main characteristics of a spatial data infrastructure is the possibility of processing information from different sources and obtaining the appropriate attributes and data of the study area. It gives the stakeholders an opportunity for a more detailed analysis of the actions of search and rescue. As the lowest layer, the support layer deals with the sources of information such as satellites, main piloted airplanes, UAV projects, and ground observation sensors. In addition, the detailed architecture for infrastructure is determined in this layer. Fig. 8 illustrates the systems in this layer and the relationships between them. Moreover, the support layer includes a function to handle vector and raster cartographic information from different storages in an integrated way.

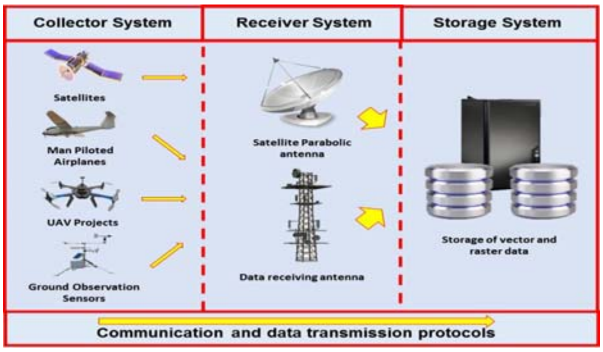

Figure 8. Interaction between the systems in the support layer

B. Analysis Layer

In this layer, the mechanisms and structures to manage massive raster data and geographic information for the system as a whole with the security integration are defined. In order to convert the raster data to vector data, the spatial data processing is applied. In addition, tools and internal processes to manage the data under the concept of data mart are implemented in this layer. The proposal of data mart for this layer has three main topics:

- Case collecting: It collects specific cases to meet user's requirements as well as obtains good analytical data. Requests come from users' need to find answers about the occurrence of an external or internal geodynamic event and work under the sequence shown in Fig. 9. Additionally, Table III explains the sequence diagram.
- Metadata: Metadata is the information about the data that allows its interpretation. Thus, users know about what information exists in the database and can specify their requests more adequately. According to the information needs of the data and accuracy of interpreted data, the metadata is classified and structured. It includes a description, inventory and so on. In the scheme presented in Fig. 7, the link from the metadata catalog server to the spatial database is considered, where the metadata tabs are stored and queried according to the ISO 19115 standards.

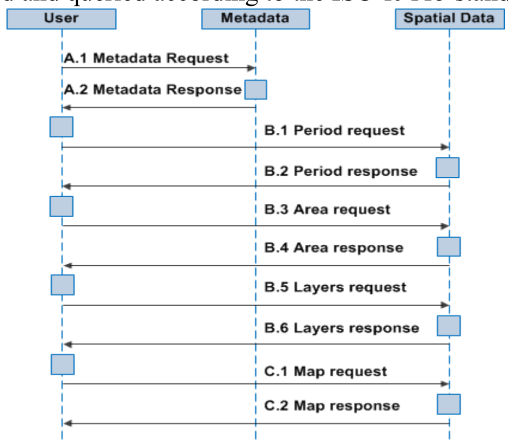

Figure 9. Request and response sequence diagram

TABLE III. SEQUENCE DIAGRAM

Step	Explanation
A	Metadata
A.1	User requests the register of metadata catalog, to review the available information.
A.2	Metadata catalog provides the metadata of available information to the user.
B	Data
B.1	User selects the period of data and sends the request to the spatial data server.
B.2	Spatial data server provides a response on available data period to the user.
B.3	User selects the area, using a coordinated pair, administrative or hydrographic boundaries, or a previously delimited place.
B.4	Spatial data server processes the request, overlapping the area with the available information, and sends a response to the user.
B.5	User selects the layers of information from the spatial data server.
B.6	Spatial data server processes the raster information, extracts the vector data elements of the selected layers, and sends a response to the user.
C	Map
C.1	User requests a map image with the desired layers from the spatial data server.
C.2	Spatial data server returns the mapping result and data records through web map services to the user.

- Spatial data: It is composed by the vector information obtained from the preprocessing of raster information. Additionally, this information is linked with the basic cartographic information available. For proper management of the spatial data, the database has the capacity to contain the elements such as object class, feature class, feature attributes, and so on. Finally, the set of spatial and nonspatial tables of the database are structured according to a data dictionary. An example of the data dictionary for towns is shown in Fig. 10. To generate the data dictionary, file names, indication of keys, column names, features of the fields (type, width), domains (field description), application of standards, remarks, and indication of null values are considered for each table.

C. Service Layer

The protocols and communication interfaces are defined in this layer. This service includes a function of evaluation of hazards for search and rescue activities. For this layer, OGC protocols to manage web services and dynamic maps are used. ISO 19128 is applied to define the web map services available by sending data from a remote server using Internet (Web Mapping Service WMS, Web Feature Service WFS and Web Coverage Service WCS).

File Name	PK	FK	Fields	Type	Width, Decimals	Field Description	Null? Y / N
SGMAP_PUEB							
	Y	Y	V_COD_PAIS	Varchar2	4	Country code	N
	Y	Y	V_COD_DEPA	Varchar2	2	Department code	N
	Y	Y	V_COD_PROV	Varchar2	4	Province code	N
	Y	Y	V_COD_DIST	Varchar2	6	District code	N
	Y		V_COD_PUEB	Varchar2	10	Town Code	N
			V_NOM_PUEB	Varchar2	50	Town name	N
			V_COD_CPUE	Varchar2	2	Code of town category	N
			V_CAT_PUEB	Varchar2	30	Town category	N
			V_CLA_PUEB	Varchar2	10	Town classification	N
			N_TOT_VIVI	Number	Total 6, Dec 0	Number of houses in the town	N
			N_CAP_DEPA	Varchar2	1	It is the capital of the department?	N
			N_CAP_PROV	Varchar2	1	It is the capital of the province?	N
			N_CAP_DIST	Varchar2	1	It is the capital of the district?	N
			N_LON_PUEB	Number	Total 10, Dec 6	Longitude in degrees	N
			N_LAT_PUEB	Number	Total 10, Dec 6	Latitude in degrees	N
			N_U18_XPUE	Number	Total 14, Dec 6	UTM 18 east coordinate	N
			N_U18_YPUE	Number	Total 14, Dec 6	UTM 18 west coordinate	N

Figure 10. Data dictionary structure example

- Web Map Service (WMS): It presents an easier type of interconnection of cartographic by Internet. It returns an image (gif format) that fits the destination map. It presents limited possibilities to consult the remote data and supports any format, although more appropriate in this case, because the layers of data have nothing to filter.
- Web Feature Service (WFS): This type of connection allows downloading vector data from remote points, and it has all the other functionalities described in the WMS.
- Web Coverage Service (WCS): It provides georeferenced data in a format such as multidimensional "cover" for access through the web.

In addition, ISO 19115 for metadata core and ISO 19139 for publishing metadata through the web are employed. The metadata configuration of the Web Services - WMS is defined according to the following template:

```
MAP
 NAME
 EXTENT
 WEB
   METADATA
          "wms_title"                         "Title of the map"
           "wms_abstract"                     "Descriptive of map service"
          "wms_onlineresource"                "Web link of online resource"
          "wms_accessconstraints"             "public"
          "wms_srs"                           "EPSG code"
          "wms_feature_info_mime_type"        "text/html"
          "wms_contactperson"                 "Name of contact person"
          "wms_contactorganization"           "Name of Institution"
          "wms_contactposition"               "Contact person position"
          "wms_contactmailaddress"            "Email"
          "wms_contactvoicetelephone"         "Contact phone"
          "wms_contactfacsimiletelephone"     "Contact fax"
          "ows_addresstype"                   "Type of address"
          "ows_address"                       "Address"
          "ows_city"                          "Capital"
          "ows_stateorprovince"               "Province"
          "ows_postcode"                      "Post code number"
          "ows_country"                       "Country name"
          "ows_contactperson"                 "Name of contact person"
          "ows_contactorganization"           "Name of Institution"
          "ows_contactposition"               "Contact person position"
          "ows_contactmailaddress"            "Email of metadata creator"
          "ows_keywordlist"                   "Keywords"
   END
 END
 LAYER
   METADATA
          "wms_title"                         "Title"
          "wms_abstract"                      "Summary"
          "wms_extent"                        "Geographical map extension"
          "wms_srs"                           "EPSG code"
          "gml_include_items"                 "all"
          "wms_contactperson"                 "Name of contact person"
          "wms_contactorganization"           "Name of Institution"
          "wms_contactposition"               "Contact person position"
          "wms_contactmailaddress"            "Email of metadata creator"
          "wms_contactvoicetelephone"         "Contact phone"
          "wms_contactfacsimiletelephone"     "Contact fax"
   END
 END
END
```

D. Application Layer

In this layer, a prototype system is generated by open source software for data dissemination that allows the user to obtain the necessary information in search and rescue activities. The software works in web environment, and its development follows the sequence shown in Fig. 11.

The cartographic processing and initial designs of the templates, legends and symbologies are developed in QGIS in client/server mode. The spatial database is created by the help of the PostgreSQL database management system, which has a PostGIS extension that supports tables of vector cartographic elements including their geometry. It also permits the management of functions through SQL commands for the development of queries to spatial tables and is compatible with the Geospatial Data Abstraction Library (GDAL), which is used to perform raster data conversions. The database was initially designed under the structure of the entity-relationship model, using the ERwin Data Modeler software.

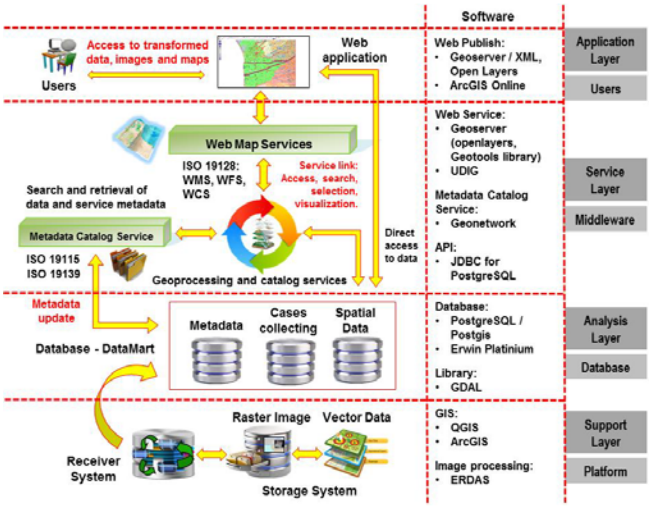

Figure 11. Software Architecture

The communication between the database and web publishing systems is accomplished by the JDBC API for PostgreSQL, because it manipulates the data directly. In addition, the specifications of the OCG are applied for the distribution of Web Map Service (WMS), WFS, and WCS using Geoserver with Geotools library and UDIG to create XML code for web templates and styles [18]. Metadata Catalog Service is implemented using Geonetwork [19]. The prototype is developed by the Geoserver working with Open Layer formats and the ArcGIS Online templates.

The vector based spatial information, which refers to the base cartography (political divisions, hydrographic network, road network, hypsography and villages) is obtained from the National Geographic Institute of Peru (IGN) and is at scale 1/100000. Moreover, the spatial vector information on hazards is obtained from the National Institute of Civil Defense of Peru (INDECI) and the meteorological information comes from the source of the National Service of Meteorology and Hydrology of Peru (SENAMHI). This information is used for visualization of the satellite images and provides more specifications on the study areas. All vector files are in shapefile format (.shp) and are inserted into the PostgreSQL database. The raster images are standardized to the format (.tiff) and connected to the database tables through the functions provided by GDAL [20].

Besides, SQL functions in the database are implemented using the PL/pgSQL language. These functions are developed to improve the organization of the information in the database as well as the spatial queries that are made by the users through the graphical interface.

V. Experimental Result through Case of Study

In this section, we present a prototype of the system that applies the proposed architecture extended by [21] in a case study. The location of the study area (Fig. 12) is the valley of the San Juan River, Ica Region, nearly 260 km from Lima, the capital of Peru. The San Juan River valley is formed between two buttresses at an altitude of 3,419 above sea level and descends from that altitude to the Pacific Ocean.

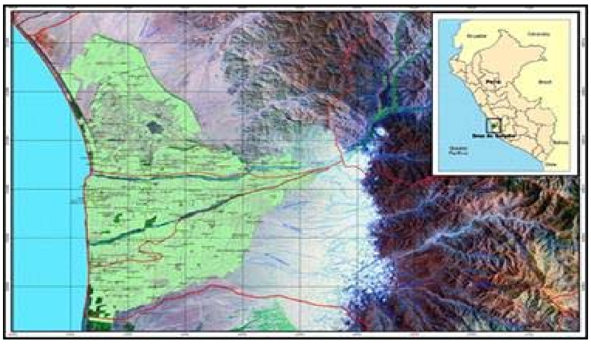

Figure 12. Location of the study area

Agricultural activities in this valley are important for the economic development of the region. One part of the valley was developed with a strong investment in this activity. However, in a considerable part of the valley, approximately 8000 families are engaged in agricultural activities for basic subsistence. In specific seasons, high-vulnerability situations happen in this valley: extreme precipitations in the high areas generate floods in the low agricultural zones where the population is settled. To perform the analysis of the study area, the base cartography, hazards, and meteorological data are collected and inserted into a PostgreSQL database. Furthermore, according to their spatial attributes, the tables are built under an entity-relationship model, as shown in Fig. 13.

The system receives input as the set of layers of the study area, which are imported from the spatial DB in the vector format. Moreover, it requests the raster formats from the repositories. For this case, we present a scenario where the availability of heterogeneous data sources from the same location allows a better understanding of the study area by expert and nonexpert users. The data used in the case are shown in Fig. 14.

By analyzing the multispectral satellite image, as shown in Fig. 14(a), it is possible for both expert and nonexpert users to deduce the location of the agricultural area. Moreover, an expert user will probably infer the existence of several small villages located within the valley, judging by the color intensity of the pixels. Additionally, users have cartographic information available, as shown in Fig. 14(b). The map clearly identifies the main roads, rivers, and location of the villages, and shows more details such as the names, population, and area of the towns.

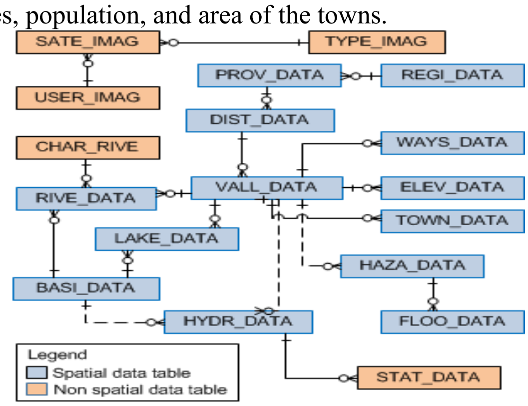

Figure 13. Model of the database

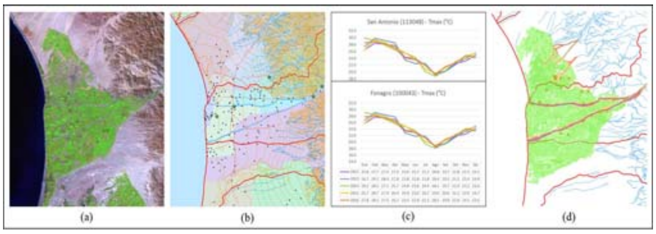

Figure 14. Heterogeneous data sources: (a) multispectral satellite image; (b) cartographic information; (c) graphical meteorological information; (d) hydrological simulation models and the previous occurrence of hazards.

The meteorological information is obtained from the web viewer, because the data are linked to the space layer of meteorological stations from where they are captured. The meteorological stations with geographic location in the terrain are represented to determine the weather conditions in the place. For a better visualization, the meteorological information is showed in time series graphs, because the historical period analysis requires a lot of data. Information of the main meteorological parameters (temperature, precipitation, humidity) is entered into the system. An example of graphical meteorological information is shown in Fig. 14(c). The information of previous disasters and locations of the hazards is also visualized. Moreover, the results of hydrological modeling of flood areas are carried out by using several previous conditions of analysis. Fig. 14(d) shows the results of hydrological simulation models and previous occurrence of hazards. In case that all this information is overlapping, it is possible to determine which areas are most vulnerable to the occurrence of a new disaster. Areas with low vulnerability are considered for evacuation and post-disaster relief activities. The open Geoserver web viewer is employed to not only publish information in the classic OpenLayers format, but also allow exporting the information to KML and GML formats to accommodate user requirements to use them in more complex web browsers such as Google Earth, Google Maps, among others. Fig. 15 shows an example of cartographic diffusion through this web viewer.

The ArcGIS Online web viewer also has the advantages of easy navigation and visualization of spatial and tabular data, where overlaying cartographic information from OpenStreetMap and other satellite formats are used as a background map. In Fig. 16, it is possible to recognize the overlapping results with the OpenStreetMap information within this web viewer.

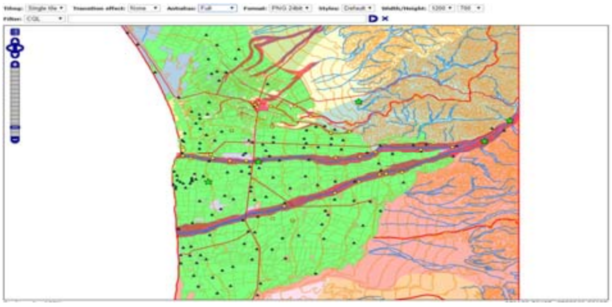

Figure 15. Results in Geoserver web viewer

Figure 16. Results in ArcGIS Online web viewer

During the short period after the occurrence of the disaster, satellite information and images of aerial photographs for the recent place are overlapped. This information, combined with the existing cartography, helps to identify affected areas where search and rescue activities are prioritized. It is also possible to generate route maps for the development of these actions, because it contains a printing module. In addition, using GPS monitoring, it is possible to indicate the position and movement of rescue brigades, movement and protection of affected people to safe areas, and the provision of essential resources to vulnerable populations.

VI. Conclusion

In this paper, we proposed and explained new system architecture of spatial data infrastructure for search and rescue activities, which is based on a layered structure. We explained the results using a case study of including geospatial data from different sources, according to geometric characteristics. Experimental results of the system architecture revealed that the processed geospatial information is accessed using web viewers connected directly to the integrated database whereas meeting the requirements.

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