# ELECTRONIC REGIONAL RISK ATLAS: DEVELOPMENT, STRUCTURE AND APPLICATION PRACTICE IN REPUBLIC OF ARMENIA

**Arshavir Avagyan, Radovan Hilbert, Hayk Yeritisian, Hasmik Manandyan, Aleksandr Arakelyan, Artak Piloyan, Anna Elbakyan**

Ph.D., Arshavir Avagyan; Institute of Geological Sciences of the NAS of RA; 24a M.Baghramyan ave., Yerevan, Armenia; +374 10 564504; avagyan@geocom.am

Ph.D., Radovan Hilbert; ConsultITPro s.r.o.; Dolná 27, 96901, Banská Štiavnica, Slovakia; radovan.hilbert@gmail.com

M.Sc., Hayk Yeritisian; Institute of Geological Sciences of the NAS of RA; 24a M.Baghramyan ave., Yerevan, Armenia; hayk.yeritsian@gmail.com

Ph.D., Hasmik Manandyan; Institute of Geological Sciences of the NAS of RA; 24a M.Baghramyan ave., Yerevan, Armenia; hayuhin@yahoo.com

Ph.D., Aleksandr Arakelyan; Institute of Geological Sciences of the NAS of RA; 24a M.Baghramyan ave., Yerevan, Armenia; alex.arakelyan@outlook.com

M.Sc., Artak Piloyan; Masaryk University, Faculty of Sciences, Department of Geography; Kotlarska 267/2, bld. 4, 611 37 Brno, Czech Republic; +420 607 619 337; artakpiloyan@mail.muni.cz

M.Sc., Anna Elbakyan; Institute of Geological Sciences of the NAS of RA; 24a M.Baghramyan ave., Yerevan, Armenia; anushelbakyan@gmail.com

***Abstract***

*Initially ERRA was developed as a web-service presenting natural (landslides, flooding, earthquake, wildfire, strong winds) and man-made hazards and risks.*

*Further elaboration of ERRA resulted in development of methodological, analytical and informational environment for using spatial data in scientific research in Earth sciences and related disciplines. Spatial Data Infrastructure (SDI) has been developed, which includes:*

- *Spatial data for Armenia and partially for neighbouring countries. These include spatial datasets of Armenia at scale 1:100000 and larger (basemaps, administrative, geological, geomorphological, hydrological, land use, environmental layers),*
- *Set of research methods and applications, such as multi-factor mapping of occurrences of natural events and phenomena (landslides, erosion processes, critical discharge of surface waters) through overlay of spatial layers.*
- *SDI for scientific applications*
- *GIS for creating and publishing web maps and GeoPortal for providing access to spatial data through meta-data catalogues.*
- *Methodology and software for carrying out research on spatial objects in GIS environment.*

***Keywords**: GIS, Hazard assessment, mapping, web mapping, cartography, disaster management*

## INTRODUCTION

Digital maps, map-based information systems, simulations, and web-technology are increasingly applied in emergency management (EM) [Maclachlan et al. 2007, Hagemeier-Klose and Wagner 2008, Haubrock et al. 2008]. In this respect, spatial data and related technologies such as GIS, GPS, remote sensing (including visible, thermal and LIDAR imaging), photogrammetry and web mapping are crucial for effective EM. In fact, without spatial data, one cannot expect effective and efficient disaster management [Amdahl, 2002].

Investigations have shown that various user-needs for EM via Web exist [Rohrmann 2004]. Essential aspects are the design of visual components, easily understandable content, the offer of further information and a self-explaining, easy to use interface [Hagemeier-Klose and Wagner 2009]. In Sheppard and Blatchford [1995], the main benefits of visual information for EM are described:

- Speed of information access for the user.
- Provision of images (maps, photographs, video, diagrams, etc.) which allow people unfamiliar with the location to obtain a fuller more realistic picture.
- Cross-cultural, language, and professional discipline boundaries.
- Provision of a rich source of quantitative data and chronological documentation or updates.

This paper aims to describe the development of SDI conceptual model and a prototype entitled "Electronic Regional Risk Atlas" (ERRA) that facilitates spatial data collection, access, dissemination, management and use for proper emergency management.

The electronic regional risk atlas of the Republic of Armenia (ERRA) was developed as a set of maps, linked with each other by similar themes and methodology for assessing features of mapped objects and methods.

The functionality of atlas is organized as a web service, providing access to the spatial content through Geo-portal as it is defined in Inspire Directive Article 11 [Directive 2007/2/EC, 2007]. Other functions of Geo-portal (metadata, spatial data services and large spatial data sets) are also organized according to these requirements. Along with the layers, the development of which is described in this article and base topographic and geographic datasets, ERRA includes spatial information representing relief, geological structure, vegetation, soil coverage, water resources and climate for the country. Also, data describing demographic, social, economic situation of the country has been used. Thus, during the process of Atlas development the main components of country infrastructure for spatial information have been created.

Existing spatial datasets of ERRA are mostly developed by authors of this article and it allows planning a future extension of thematic and application areas of Atlas. Spatial data organization for scientific research in field of Earth Sciences, natural resources, environmental studies and other related topics are the core datasets. But the main content of this article is dedicated to description of hazard and risk assessment and mapping of main disasters of Armenia using ERRA functionality and GIS applications.

Structure of Atlas (ERRA Skeleton) has been developed by an expert team during the first phase of EU-funded Programme for the Prevention, Preparedness and Response to Man-made and Natural Disasters in the ENPI East Region (PPRD East).

## SPATIAL DATASETS OF ERRA

Besides the hazard and risk maps, ERRA contains a number of other spatial datasets of Armenia, which are grouped as follows:

### Group 1. Basic Maps

- *Administrative* - State borders of Armenia, Marz borders, District borders, Settlements, Demography;
- *Infrastructures* - Railways, Roads

### Group 2. Maps of natural conditions

- *Geomorphology and geomorphometry* – Geomorphology zones, DEM, Slope, Aspect, Elevation zones, landscape types
- *Hydrology* - Main river basins, River network, Lakes, Reservoirs
- *Geology*
- *Soil types*

### Group 3. Maps of natural hazards and risks

- *The earthquake hazard and risk thematic layers* – Recent earthquakes, Historical earthquakes, Seismic zones

- *Landslide hazard and risk layers* – Landslide location, Landslide slope, Landslide risk map, Land use in landslide areas, Landslide bed rock geology, Landslide hazard per region.
- *Flood hazard and risk layers* – Historical flood events (point and polygon), Embankments, Restrictions to water flow (canals), Flood hazard by river basins, Flood hazard by regions, Flood hazard by marzes.
- *Forest fire hazard layers* – Wildfire hazard in June, July and August, Wildfire hazard distribution by elevation zones, Wildfire hazard distribution by forest types.

### Group 4. Industrial events hazard and risk

*Technological event hazard and risk layers* – Location layers of installations which may trigger risks, Technological event hazard layers and risk layers by regions, Industrial event hazard layer by administrative divisions (marz).

### Group 5. Critical Infrastructures

*Spatial data for the following assets*: Administrative buildings, Airports, Health facilities, Roads, Tunnels, Bridges, Railway, Power plants, High–voltage power lines, Electric substations, Telecommunication stations, Industrial buildings, Water use, Water extraction, Water discharge, Drinking water, Ore deposits, Chemical factories, Petrol stations, Reservoirs, Tailing dams, Solid waste, ARS divisions, Fire rescue centres, Mines, Enrichment plants.

### Group 6. Regional Disaster Vulnerability Index

*Vulnerability index layer by marz* – Vulnerability index layer, Social vulnerability layer

### Group 7. Natural resources

Non-metallic deposits, Ore deposits (operated), Ore occurrence, Tailing dams, Fresh drinking groundwater deposits, Hydro-geological wells, Soil types, Landscape types, Forests.

In order to achieve interoperability of ERRA with other Geo-portals and support services, each of layers is equipped with Metadata according to ISO 19115/19119/19139 standards. Discrete units of metadata are: map title, keyword, spatial resolution, responsible organization, source, author(s) and short description.

## METHODOLOGY OF HAZARD AND RISK ASSESSMENT AND MAPPING

### Methodology Summary

The extent of mapped hazards and risks in all of the resulting layers included in Atlas depends on a number of co-influencing factors of natural and man-made character. Hence, for the development of hazard and risk (as spatial variables) maps, a spatial multi-criteria evaluation method have been used. The theoretical background of this method is based on Analytical Hierarchical Process (AHP) developed by Saaty [Saaty, 1980].

This method allows to estimate hazard and risk quantitatively using the following principle: Hazard/risk formation factors are presented as a set of raster layers, and each of these layers' grid-cells are presented with specific standardised mean of factor. Then target layers of hazard/risk are created by summation of weighted means of criteria in spatially corresponding grid – layers of all cells [Van Westen et al., 2013].

In some cases target variable (hazard/risk) is caused by one or more compound factors which depend on subfactors. In this case a criteria “tree” is compiled. An example of this is the calculation of vulnerability index which consists of five sublevels.

Weighting coefficients which were used in described example were derived by experimental method and need to be continuously verified by correction of hazard/risk formation factors.

In this article the following methodologies are described:

- Flood, landslide, wildfire hazard assessment and mapping;
- Development of specific technological event hazard layer
- Asset characterization and mapping

- Assessment and mapping of population / community vulnerability

## Spatial multi-criteria evaluation

The input data are a set of maps spatially representing the criteria, which subsequently were grouped, standardized and weighted in a “criteria tree”. The outputs are “composite index map(s)”, which indicate the realization of the model implemented.

The value of each cell in the matrix is composed of the multiplication of the standardized value (between 0 and 1) of the criterion for the particular alternative, multiplied by the weight (W1 to Wn) related to the criterion. Once the matrix has been filled, the final value can be obtained by adding up all cell values of the different criteria for the particular alternative (e.g. a11 to a1n for alternative A1).

For implementing this matrix according to the AHP, three important steps need to be considered. The first one divides the problem (and the weights) into a hierarchical structure. The second one considers the weighting process, employing the pairwise comparisons of the criteria, and the synthesis is related to the multiplications among the hierarchical levels. Additionally, in the spatial implementation of this procedure, every criterion (Cj) becomes a raster layer, and every pixel (or set of pixels) of the final composite index map eventually becomes an alternative Aj. The goal (risk index) has been decomposed into criteria levels CL1 and CL2

## Flood Hazard Assessment and Mapping

This methodology has been developed to evaluate the flood hazard assessment within country based on the principles defined within the Flood Directive [DIRECTIVE 2007/60/EC, 2007]. The purpose of the EC directive is to establish a framework for the assessment and management of flood risks, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community. This methodology has been developed to consider the initial stages of the directive, and will allow flood prone areas to be identified and mapped onto a GIS.

The objectives of this methodology are to:

- Estimate the potential flood hazard based on hydro-meteorological, geo-ecological and geomorphometric parameters,
- Determine the settlements with high potential flood risk based on evaluation of past flood events,
- Develop flood hazard map / GIS layer.

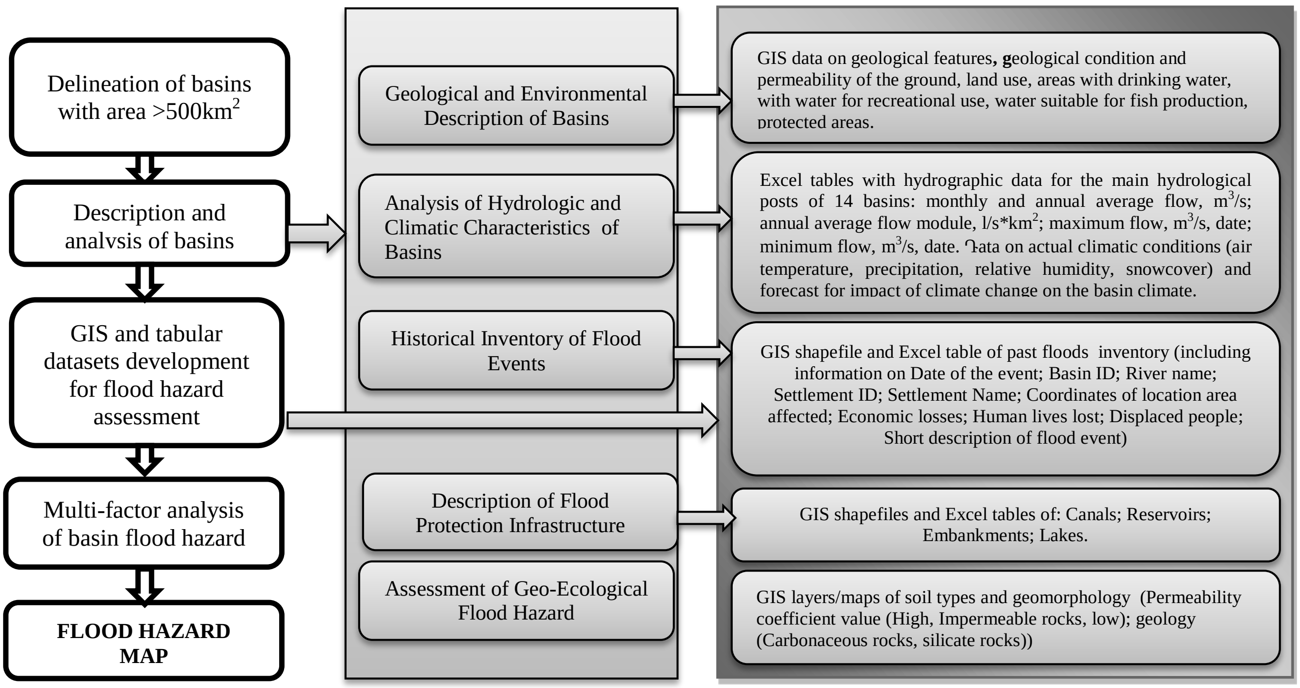


*Fig. 1. Flood Hazard Assessment and Map Development Flowchart*

The results of this methodology are:

- A register of locations on rivers where there is a known probability of a floods within the defined structure,
- Description of basins,
- Metadata records about all existing hydrologic models available in country along with other flood maps,
- Hazard map based on the register and analysis of records,
- Understanding of flood hazard potential based on morphometric and geo-ecological characteristics.

Necessary data for flood hazard assessment has been collected for the 14 basins of Armenia with an area of more than 500km$^2$. As a result of applying this methodology, these basins have been classified by the flood hazard level into 4 categories: *extreme, high, middle, low*.

Flowchart of flood hazard assessment and mapping procedure is presented below (Fig. 1).

## Landslide hazard map/ GIS layer development

The methodology used by authors (Georisk Company) to prepare the landslide hazard map of the territory of Armenia provides an index approach based on the selection of specific factors that lead to landslide activation. The core of this method is the combined analysis of factors of different nature and value, which requires one to standardize them and convert to values ranging from 0 to 1. The following factors are considered for landslide Hazard assessment: Geology, Seismicity, Slope Gradients, Precipitation and Land use. The standardized values for each of these factors, and the GIS layers derived by these values, are presented below (Tables 1 to 5).

*Table 1. Slope gradients (in degrees) and standardized values assigned to them*

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Standardized | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 | 0.5 | 1 | 0.8 | 0.1 |

*Table 2. Land use classes and standardized values assigned to them*

| ***Land use*** | *Yerevan city* | *Arable land* | *Crops* | *Pastures* | *Grassland* | *Forest, shrubland* | *Lake Sevan* | *Reservoir* |
|---|---|---|---|---|---|---|---|---|
| ***Standardized values*** | *1.000* | *0.500* | *0.500* | *0.181* | *0.181* | *0.065* | *0.042* | *0.042* |

*Table 3. Geological complexes, their description and standardized values assigned to them*

| ***Geological complex/ Description*** | A. *Strongly weathered fractured formations of rocks* | B. *Formations with sandstone, conglomerates, clays and marls, both weathered and fractured* | C. *Ultra-mafic rocks, tectonically discontinuous, lutites, calcarenites and aleurolites* | D. *Different lithology in the formations that have been well preserved and contain rocks less affected tectonically* | E. *Massive and compact formations, Quaternary sediments in plain areas. High-resistant volcanic rock* |
|---|---|---|---|---|---|
| ***Standardized Values*** | *1.000* | *0.565* | *0.348* | *0.196* | *0.089* |

*Table 4. Maximum amounts of daily precipitation and the standardized values assigned to them*

| ***Amount of precipitation in mm*** | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 85 |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Standardized values*** | *0.44* | *0.50* | *0.55* | *0.61* | *0.66* | *0.72* | *0.77* | *0.83* | *0.88* | *0.94* |

*Table 5. Peak ground accelerations (pga) and the standardized values assigned to them*

| ***P.g.a., in fractions of g*** | *0.1-0.2g* | *0.21-0.3g* | *0.31-0.4g* | *0.41-0.5g* |
|---|---|---|---|---|
| ***Standardized values*** | *0.3* | *0.5* | *0.7* | *0.9* |

Landslide hazard index is calculated as a weighed sum of standardized values of considered factors as presented in the expression bellow:

Landslide Hazard index=0.8(0.5(Slope gradient) +0.2(Land use) + 0.3(Geology)) + 0.2(0.7(Rains) + 0.3(Earthquake)).

Name of factors in parenthesis refers to their standardized value in the same grid cells of appropriate thematic layers.

At the last stage, all calculated values of the landslide hazard index are reduced to the three values of “high”, “moderate” or “low” for creation of resulting layer for ERRA.

The analysis of results produced for the territory of Armenia demonstrates a good correlation between the Map of Landslide Hazard and the distribution of landslides. In the meantime, the correlation shows that geological structure and seismic impacts have determinative influence on landslide activation. Slope gradient is a less important factor and landslides associated with it are mainly those surrounding the Aragats mountain. Precipitation has even smaller effect, which is explained by its low rate, considering that Armenia is situated within an arid climatic zone. The impact of land use is almost indiscernible, which might be explained by the small scale of 1:500,000, which doesn’t include any man-made features.

## Development of Wildfire Hazard Map

Country wildfire hazard as a thematic layer of ERRA has been created by developing sub layers and using the appropriate weighting scores. The information used for base – layer development covers data on Population distribution, Land use, Topography (Digital Elevation Models), Transportation networks, River channels and basins.

Methodology of creating the wildfire hazard layer identifies individual fire hazard factors and groups them in sub-layer which share similar characteristics. The sub-layers developed are static in nature and conform to preliminary regional base model for Armenia. These are fuel condition and weather triggers. A final fire hazard output is produced by combining these sub-layers using a weighted approach.

In order to construct the static wild fire hazard map the variables for each sub-layer are converted into a hazard index. The hazard factor obtained has been normalized with standardized values varying between 0.00 to 1.00. For the territory of Armenia, the following variables have been used to develop the equations below:

Fuel hazard = 0.54(Fuel type) + 0.32 (Slope) + 0.09 (Aspect) + 0.06 (Elevation); Weather hazard = 0.74 (Temperature) + 0.26 (Precipitation) and finally Wild fire hazard = 0.81 (Fuel) + 0.19 (Weather).

The fuel hazard type takes into account land cover classified by the International Geosphere-Bioshere Programme (IGBP) on 16 land cover or fuel type – each one with specified hazard standardized value.

*Table 6. Land cover classification and hazard indices according to International Geosphere-Bioshere Programme*

| **Land Cover Type** | Evergreen Needle leaf Forest | Evergreen Broadleaf Forest | Deciduous Needle Leaf Forest | Deciduous Broadleaf Forest | Mixed Forest | Closed Shrub land | Open Shrub land | Woody Savannahs |
|---|---|---|---|---|---|---|---|---|
| **Hazard Index(0-low, 16-high)** | 11 | 10 | 15 | 12 | 10 | 15 | 14 | 9 |
| **Standardized Value** | 0.688 | 0.625 | 0.938 | 0.750 | 0.625 | 0.938 | 0.875 | 0.563 |

| Savannas | Grassland | Permanent Wetland | Croplands | Urban and Built up Lands | Cropland/ Natural Vegetation Mosaic | Snow and Ice | Barren | Water Bodies |
|---|---|---|---|---|---|---|---|---|
| 8 | 16 | 1 | 4 | 3 | 5 | 0 | 2 | 0 |
| 0.500 | 1.000 | 0.063 | 0.250 | 0.188 | 0.313 | 0.000 | 0.125 | 0.000 |

The slope hazard index has been established according to several rules relatied to wildfire behaviour. Since steep slopes tend to increase the rate of fuel burning, higher values will be given to those, compared with flat surfaces or lower slope gradients. Slope hazard fire index is based on the following classification and standardization. Slope gradient from flat up to 40 degree and more was divided into 9 classes from very low up to very high fire hazard probability. Classes have been assigned to hazard indices and then their values were standardised from 0.022 – very low to 0.8 high.

The aspect factor is the most important because it has effect on wind conditions, air moisture and is related to how dry the fuel is and spread of fire.

Four Aspects have been considered for this layer: North, West, East and South with standardized value of hazard index from 0.1 to 1.0.

The elevation impact is based on the following assumptions: higher elevations are known to experience greater rainfall and an impact on the vegetation type, humidity and temperature. Five Hazard classes have been defined as a follows:

*Table 7. Elevation ranges and fire hazard indices*

| Elevation (m ) | 0 – 483 | 484 – 1074 | 1075 – 1709 | 1710 – 2435 | >2436 |
|---|---|---|---|---|---|
| Fire Hazard | High | Medium | High Medium | Medium Low | Low |
| Fire Hazard Index | 5 | 4 | 3 | 2 | 1 |
| Standardized value | 1.000 | 0.667 | 0.200 | 0.400 | 0.067 |

Weather factors have influence on fuel moisture and fire spread. The main factors are temperature and precipitation which are considered for fire hazard assessment.

*Table 8. Temperature hazard indices*

| Temperature (Cº) | 0 – 3.2 | 3.3 – 6.4 | 6.5 – 9.5 | 9.6 – 12.9 | >12.9 |
|---|---|---|---|---|---|
| Weather Hazard | Low | Medium Low | Medium | Medium High | High |
| Weather Hazard Index | 1 | 2 | 3 | 4 | 5 |
| Standardized value | 0.067 | 0.200 | 0.400 | 0.667 | 1.000 |

Precipitation hazard index is considered according to its average per month values:

*Table 9. Precipitation hazard indices*

| Precipitation (mm) | 429-685 | 686-861 | 862-992 | 993-1,180 | >1.181 |
|---|---|---|---|---|---|
| Precipit. Haz. index | Low | Medium Low | Medium | Medium High | High |
| Weather Hazard | 5 | 4 | 3 | 2 | 1 |
| Standardized value | 1.00 | 0.67 | 0.4 | 0.20 | 0.67 |

Based on the described model, wildfire hazard layers per month for June, July, August, and layers of hazard distribution by elevation zones by forest types have been created.

## Development of Technological Event Hazard Layer

According the EU Council Directive 67/548/EEC, hazardous installations are divided to (a) explosive, (b) oxidising, (c) easily flammable, (d) flammable, (e) toxic, (f) harmful, (g) corrosive classes. For the development of Technological Event Hazard Layer, potentially hazardous installations which currently operate in Armenia have been identified, classified according to mentioned-above directive and the final spatial data compiled.

In case of man–made factors Industrial accident (e.g. fire, explosion, mechanical failure), Collision, Human error, Systems failure are considered as possible triggers.

Landslide, avalanche, flooding, earthquake and wildfire have been considered as natural disaster events that could impact the installation considered. Statistical and spatial data on natural hazard was analyzed to assess the risk level of installation location.

The following categories of baseline data have been identified for each installation which are assessed and mapped as hazardous.

1. Site Setting Category includes information on:

a) Geographic boundaries of that hazard, i.e. how far could the hazard extend in the case of a technological event. Different accident scenarios have been considered, such as: vessel rupture, pipe rupture, leak, fire, explosion, installation security (e.g. unauthorized personnel entry).
b) Existence of receptors at potential risk within anticipated boundaries of hazard. Existence of a credible hazard transport mechanism, such as air (wind direction, strength), surface water (rivers, canals, sea, drinking water supply) and groundwater.
c) Recurrence of a technological event by available qualitative or quantitative method.
d) Existence of evidence that installation owner/operator assesses consequences of industrial event.
e) Existence of evidence that installation owner/operator assesses measures preventing from industrial events.

The compiled information on Baseline Installation Categories have been classified according to intrinsic Hazard level (Table 10) and Frequency of Occurrence of Specific Type of installation (Table 11)

*Table 10. Hazard Categories by Installation type*

| **Category name** | **Hazard level** | **Hazard index** |
|---|---|---|
| Food, Beverage, Tobacco Products, Electrical and Electronics, Municipal solid waste | Low | 1 |
| Cement Works, Airports | Medium | 2 |
| Oil and gas processing, Animal and Animal Products, Metal Product Manufacturing, Electricity Generation | Fair | 3 |
| Organic and Inorganic Chemical Production, Mineral Extraction and Processing, Hazardous Waste Water supply, Mineral Extraction and Processing | High | 4 |

*Table 11. Frequency of Occurrence of Specific Type of installation*

| **Category Type name** | **Frequency of Occurrence of Specific Type of installation** | **Frequency Index of Specific Type of Installation** |
|---|---|---|
| Airports, Metal Products Manufacturing, Mineral Extraction and Processing, Water supply | Once in 50 years | 0 |
| Organic and inorganic Chemical Production | Once in 20 years | 1 |
| Hazardous Waste, Electricity Generation, Cement Works | Once in 10 years | 2 |
| Oil and gas processing, Food, beverage, tobacco products, Electrical and Electronics, Animal and Animal Products | Once in 5 years | 3 |
| Municipal solid waste | Once a year | 4 |

2. Risk Management Category includes the following information:

a) Existence of formal, documented Risk Assessment for each installation.
b) Planned and implemented measures in place to limit and mitigate consequences of an event
c) Training plans of personnel in the organization, responsibilities and emergency response procedures described and training conducted.

3. Preparedness and planning measures describing prevention policy:

a) Existence of a Major Accident Prevention Policy for the installation;
b) Existence of a Safety Management System for the installation;
c) Existence of an Emergency Plan for the installation.

4. Conclusion for each installation.

Consideration of the above for each installation, would indicate if:

a) An installation could present a potential hazard;
b) There is a credible set of conditions which could trigger a Technological Event;
c) Technological Event could adversely impact vulnerable receptors;
d) The installation Owner/Operator has put in place hazard mitigation measures which would eliminate or significantly reduce the impact of the event on the receptors

The preparedness extent of potentially hazardous installation by Baseline Data is shown in table 12.

*Table 12. Installation Preparedness*

| **Preparedness Baseline Data description** | **Preparedness Level** | **Preparedness index** |
|---|---|---|
| Complete absence of document on disaster risk reduction | None | 0 |
| Existence of regional plan of action in an emergency situation | Poor | 1 |
| Existence of regional plan of action in an emergency situation, Certificate of technical safety | Faire | 2 |
| Existence of regional plan of action in an emergency situation, Certificate of technical safety, Own plan of action | Good | 3 |
| Existence of regional plan of action in an emergency situation, Certificate of technical safety, Own plan of action, Emergency Drills regularly practiced | Prepared | 4 |

By summing up the factors according to tables 1, 2 and 3, industrial event hazard for an installation is calculated:

Installation Hazard = 0.4*[Installation Type Hazard Index] +0.2* [Occurrence Frequency Index of Specific Type of Installation] - 0.4*[Preparedness Index]

Using the above-mentioned equation, a value of technological hazard was assigned to each marz, which is equal to summary of hazard values for installations, which are located in each marz.

### Asset characterisation and mapping

Asset characterisation and mapping was developed for assessment of national critical infrastructure and classification of asset elements at natural and man-made disaster risk. The purpose of characterization is identification of an asset and to determine the level (degree) of its importance to country's economy, environment and social well-being.

Individual assets are specified by following attributes: asset ID, Brief description, Category name (one of 9 categories), spatial type (point, line, area), coordinates, Perceived criticality or importance ((0) - None, (1) - Very low, (2) - Low, (3) - Medium, (4) - High, (5) - Very High), Interdependencies (Yes or No), Number of Interdependencies ((Not known), 1-8)), Number of dependencies ((Not known), 1-8)), Sub-assets (Does the asset have any crucial elements (Y/N)), Network (Is the asset being characterised a crucial part of a network comprising an important system (Y/N)), Consequence types (The type of direct consequence that would occur if asset were lost (top 3 only, 1-highest, 2-second, 3-thrid); Financial, Environmental, Life), Susceptibility to hazards (Asset susceptibility or vulnerability to hazard type (Y/N), Qualify susceptibility (For Each susceptible hazard selected the following degree of susceptibility 0) Negligible, 1) Low, 2) Moderate, 3) High), Hazard intensity required to significantly disrupt damage asset (Level or intensity of each hazard required to damage or cease functionality of the asset 1) Any, 2) Low, 3) Moderate, 4) High, 5) Very high), Ease of recovery (Following the degree of hazard above detail the maximum possible time to recovery or acceptable working level for each selected hazard 1) Week, 2) Month, 3) 3 Month, 4) 12 Month, 5) >12 Month, 6) Never).

Wherever Y/N answer was requested, it was replaced by 1/0. The following natural hazards were selected as specific to Armenia and assessed in format requested by PPRD: Earthquakes, Landslides, Floods.

Each of these hazards is given a specific field for Susceptibility to Hazard, Qualify Susceptibility, Hazard intensity required to significantly disrupt/damage asset and Ease of recovery categories. Hence, each category is divided into additional 3 fields for each hazard.

The final result of this exercise is an ESRI Geodatabase and an excel sheet with the list of all critical assets and mentioned-above variables.

### Assessment and mapping of population / community vulnerability

There are several definitions of vulnerability; therefore, there are various approaches of its assessment and mapping. Comparative analysis of widely used methods and approaches of vulnerability assessment has been carried out to select the most appropriate method.

The International Federation of Red Cross and Red Crescent defines vulnerability as "The characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural or man-made hazard" [Guidelines for emergency assessment, 2005]. Vulnerability and Capacity Assessment (VCA) method which uses participatory approach to assess people's exposure to and capacity to resist natural hazards (http://www.ifrc.org/en/what-we-do/disaster-management/preparing-for-disaster/disaster-preparedness-tools1/) is based on this definition. According to the United Nations International Strategy for Disaster Reduction (UNISDR), vulnerability is "The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard" [UNISDR, 2009]. The approach of the UNISDR) [ISDR, 2004] considers physical, social, economic, and environmental factors of vulnerability, which increase the susceptibility of a community to the impact of hazards. This approach of vulnerability assessment as a susceptibility of a system to hazards does not include coping capacities or exposure, being separate elements that contribute together to produce risk [N. J. Roberts et. al., 2007].

EU Framework Programmes, related to management of risks and emergency situations due to natural and technological hazards, consider quantitative and qualitative approaches of risk assessment [Wood Maureen and Jelínek Róbert, 2007]. Therefore, vulnerability presents:

- The degree of loss (from 0% to 100%) resulting from a potentially damaging phenomenon in the quantitative (probabilistic) approach of risk assessment;
- The degree (e.g. high, medium, low) to which a system is susceptible and unable to cope with damage or harm in the qualitative approaches of risk assessment.

The qualitative approach of vulnerability assessment and mapping is presented below. It provides opportunity for both visualization of spatial distribution of population vulnerability at regional level, and use of the vulnerability map for natural and technological hazards' risk assessment and mapping. This approach considers vulnerability as a logical combination of three indicators – susceptibility, coping capacity and adaptive capacity. Each indicator (component) of vulnerability consists of several subcomponents representing a factor of vulnerability.

Subcomponents of vulnerability are combined by means of application of weights (as values of 0 to 1) to represent a component. Similarly, components are combined using weights for quantitative estimation of overall vulnerability index.

Values of weights are determined by expert judgment, and they need to be verified later.

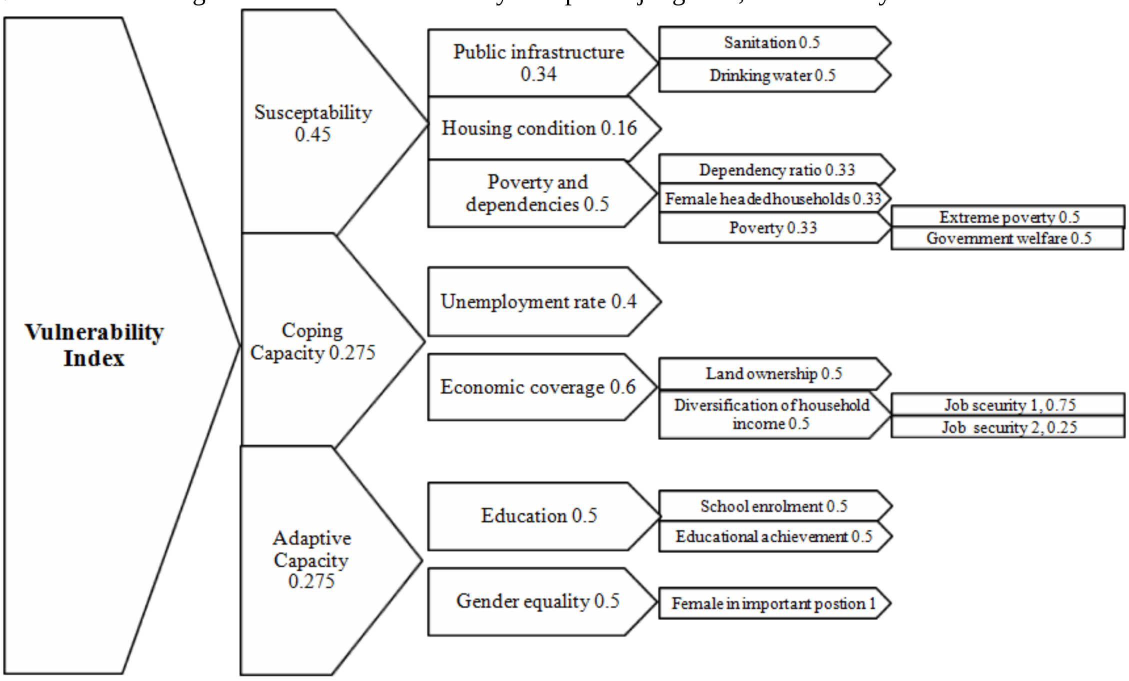


Fig. represents the weights of different components of the vulnerability index.

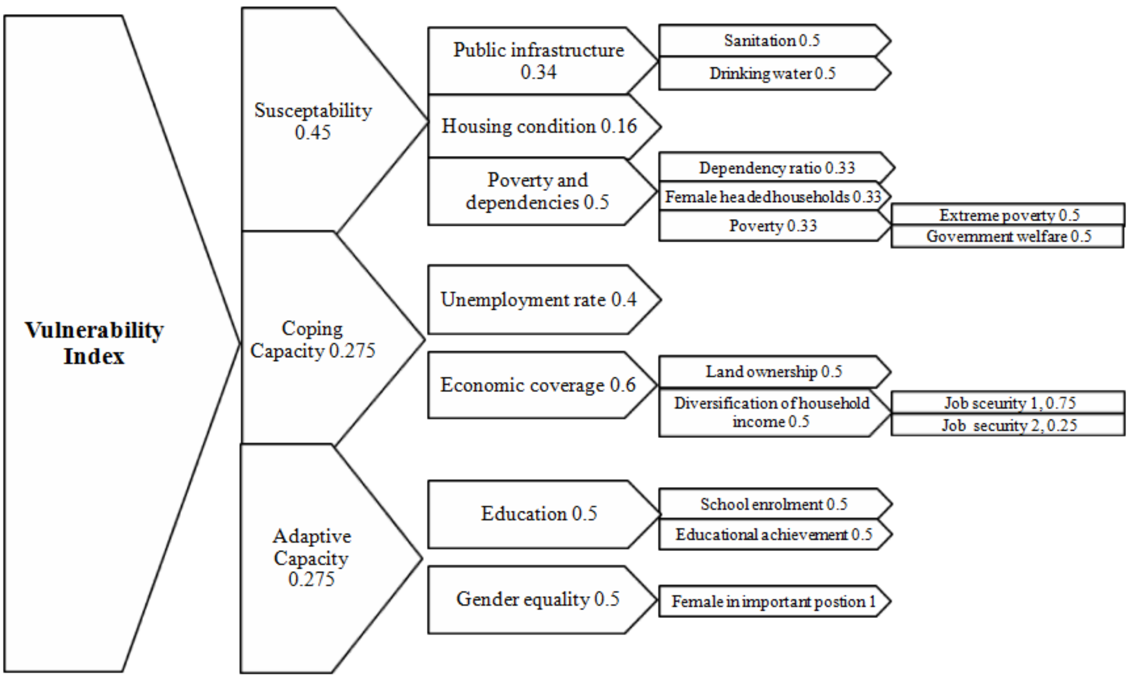


*Fig. 2. Weighting values of vulnerability index and its components*

Susceptibility is determined by public infrastructure, housing conditions, poverty and dependencies. Coping capacity is determined by unemployment rate and economic coverage (land ownership and diversification of household income). Adaptive capacity is determined by education level and gender equality. Eventually, the vulnerability is assessed quantitatively and represented by an index varying from 0 to 100%. The value of this index is used for mapping population vulnerability at regional level.

Data collection from different governmental, public and private organizations has been implemented. Collected data have been compared and assessed based on their quality, reliability and relevance. Consequently, the most reliable and up to date data have been selected and organized as a database for vulnerability assessment and mapping.

A vulnerability relational database has been developed. The database includes 5 tables – “Regions”, “Vulnerability”, “Susceptibility”, “Coping capacity” and “Adaptive capacity” (Fig 3). Each table contains ID numbers, values of subcomponents and their respective weights, which have been used for calculation of vulnerability indicators and index for each region of RA. The table “Regions” contains name, area and population data for each region of RA.

The tables “Susceptibility”, “Coping capacity” and “Adaptive capacity” are connected to the table “Vulnerability”, which is connected to the table “Regions”. All tables are connected to appropriate digital layer of a geo-database included in the ERRA.

Based on the calculated values, 4 separate thematic maps representing vulnerability indicators (Susceptibility, Coping capacity and Adaptive capacity) and vulnerability index at regional level have been developed. “Susceptibility”, “Coping capacity” and “Adaptive capacity” maps show spatial distribution of vulnerability factors separately, while “Vulnerability” map shows distribution of overall vulnerability index in the territory of Armenia.

Spatial analysis of susceptibility, coping capacity, adaptive capacity indicators and the vulnerability index shows the trend of population vulnerability increase from the central part of the country to the north and south. This shows insufficient capability of population to anticipate, cope with, resist, respond and rehabilitate from the impact of hazards in the regions located far from the capital Yerevan.

The population of Yerevan and central regions of RA are relatively resistant to the impact of natural and technological hazards.

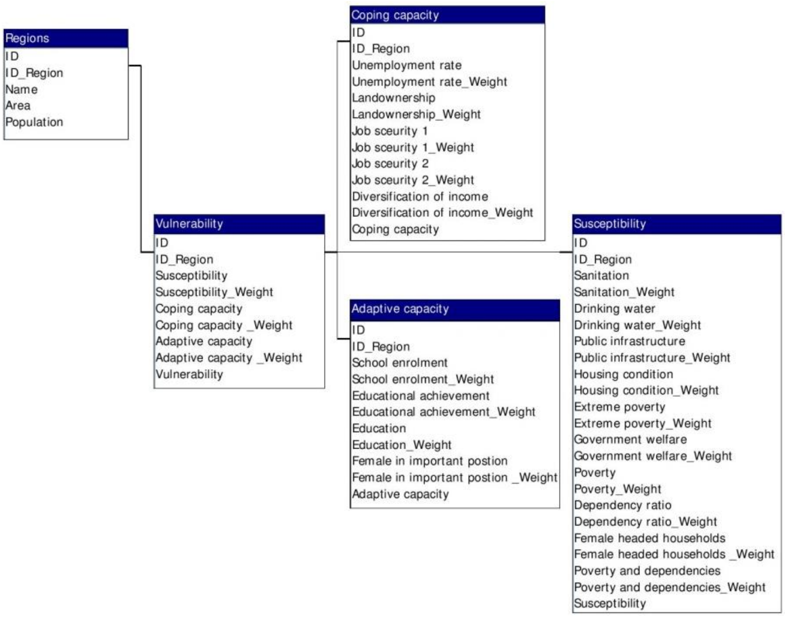


*Fig. 3. Vulnerability database structure and content.*

This approach of assessment and mapping of population vulnerability has been tested at local level (community level) for 10 communities of Tavush region. The structure of database and its relation to the thematic maps allows developing a set of vulnerability maps at local level for RA and including them in the ERRA.

## REFERENCES

Amdahl, G., 2002. Disaster Response: GIS for public safety. ESRI, Redlands California. Amdahl, G., 2002. Disaster Response: GIS for public safety. ESRI, Redlands California [online]. Available from: http://www.esri.com/news/arcnews/winter0102articles/gis-homeland.html

Flood Hazard Directive: DIRECTIVE 2007/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2007 http://eurex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32007L0060:EN:NOT

Guidelines for emergency assessment. International Federation of Red Cross and Red Crescent Societies. 2005. 103 p.

Hagemeier-Klose, M. and Wagner, K., 2008. Experten-evaluation von web-GIS-losungen und Internetkartendiensten zur Kommunikation von Hochwasserinformationen. Geographica Helvetica, 63 (2), 94-103.

Haubrock, S., Dransch, D., and Plattner, S., 2008. Maps in the natural disasters networking plattform NaDiNe - meeting the user's needs: form static images to highly interactive realtime information integration. In: M.P. Peterson, ed. International perspectives on maps and the Internet. Berlin: Springer-Verlag, 251-266.

INSPIRE Directive: Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE) 14.03.2007. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32007L0002:EN:NOT

ISDR. "Living with Risk, a Global Review of Disaster Reduction Initiatives", United Nations. 2004. 429 p.

Maclachlan, J.C., et al., 2007. Mapping health on the internet: a new tool for environmental justice and public health research. Health and Place, 13, 72-86

N. J. Roberts, F. Nadim, and B. Kalsnes. Quantification of vulnerability to natural hazards. ISGSR. 2007. First International Symposium on Geotechnical Safety & Risk. Oct. 18-19, 2007 Shanghai, Tongji University, China. 333-344 pp.

Rohrmann, B., 2004. The relevance of the internet for enhancing disaster preparedness of residents. Paper presented at 11th annual TIEMS conference the international emergency management society, Yarra Ranges.

Saaty, T.L. The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation (Decision Making Series). Mcgraw-Hill Publishing, 1980, 287 p.

Sheppard, S.R.J. and Blatchford, D., 1995. Visual information systems and GIS in crisis management [online]. Available from: http://ioscproceedings.org/doi/pdf/10.7901/2169-3358-1995-1-982

UNISDR Terminology on Disaster Risk Reduction. United Nations International Strategy for Disaster Reduction, 2009. 35 p.

Van Westen, C., Damen, M and Feringa, W. National Scale Multi-Hazard Risk Assessment. Theory Book. PPRD East Training Package on National Scale Multi-Hazard Risk Assessment. University of Twente, 2013, 183 p.

Wood Maureen and Jelínek Róbert. Risk Mapping in the New Member States. A Summary of General Practices for Mapping Hazards, Vulnerability and Risk. 2007. 29 p.