Software Development Report

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Document Version History

Version	Date	Description of change
1.0	30-Jul-2015	First draft

Abstract

This document is to describe the development of the web system 'RiskChanges'. It explains how the requirements have been implemented, which software and tools have been used and how they are integrated to the others. The achievements can be observed by the services offered and the solutions demonstrated in the following sections.

1. Introduction

RiskChanges is a web-based spatial Decision Support system for the analysis of changing risk to natural hazards as a consequence of risk reduction planning and/or possible future scenarios for climate change and land use change. The development was funded by the EC through two EU FP7 projects (CAHNGES and IncREO). There are four different possible uses of the system, as illustrated below:

- **Analyzing the current level of risk (both physical and population) for multi-hazards**

  This is done by integrating hazard intensity and spatial probability maps for different hazards and multiple return periods, elements-at-risk maps (building footprints, land parcels, lines or points) with associated attributes (type, value, number of persons), vulnerability curves, and administrative units. First losses are calculated for each combination of hazard return period and elements-at-risk, and then multi-hazard risk is calculated by considering all return periods and all hazard type. Also the interdependency of the hazards is taken into account. The system also allow to calculate the uncertainty by using average and standard deviation values for all parameters.

- **Analyzing the best risk reduction alternative**

  Different risk reduction / planning alternatives can be defined in the system in the form of projects. For each of these alternatives the user can define whether this alternative requires new hazard maps, elements-at-risk maps, and./or vulnerability data. New data can be uploaded, and the losses and risk can be re-analyzed. The difference between the average annual risk before and after the implementation of the alternative gives the annual benefit which can be used in a cost-Benefit analysis, together with information on the investment and management costs of the alternatives. The cost-Benefit analysis provides several indicators to determine the most cost-effective alternative. Also other indicators can be incorporated which are not directly risk based or based on cost-benefit, such as social, environmental and political indicators, and the users can use a Multi-Criteria tool to determine the optimal alternative.

- **Analyze how risk could change under possible future scenarios**

  Another type of use of the system is the evaluation how the physical and population risk might change given one or more possible future scenarios. These scenarios are defined by experts, and could incorporate the effects of climate change, land use change,

demographic change and/or socioeconomic change. New status maps have to be produced for one or more future years. This means that hazard maps and elements-at-risk maps have to be updated for these specific scenarios and future years. The system allows to re-analyze the risk for these combinations and make a comparison of the changing risk under different scenarios.

- **Determine the best "change-proof" risk reduction alternative**

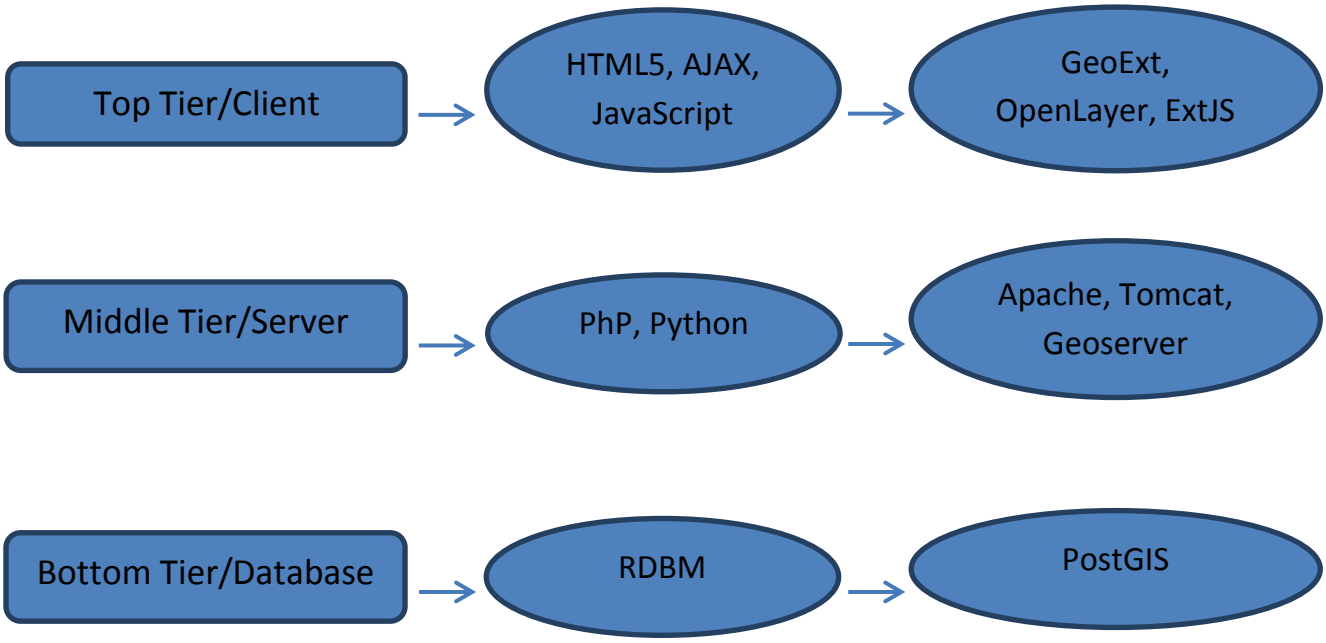
  The most complicated use of the system is to combine the above uses into one, that determines which of a set of possible risk reduction would produce the lowest risk under different possible future scenarios. Here, specific combinations of risk reduction alternatives, possible future scenarios and future reference years are defined and for each combination the expert should upload the expected hazard intensity maps and elements-at-risk maps. The system then allows to calculate the difference between the current level of risk and the risk for a given combination of alternatives and scenarios for a given year. This benefit which is changing in the future is then used in a cost-benefit analysis to determine the best risk reduction alternative. Also other indicators can be incorporated in the Multi-Criteria Evaluation.

Based on the services it offers, the system consists of a number of modules:

- A **data management module** where users can upload hazard maps, elements-at-risk maps and vulnerability curves for their own area of interest. Users can also define risk reduction alternatives and future scenarios and upload the hazard maps, elements-at-risk maps and vulnerability data for these;
- A **risk assessment module** which allows the users to calculate the losses for specific combinations of hazard maps and elements-at-risk maps, and combine these into a quantitative risk assessment both for economic as well as population risk;
- A **cost-benefit module** where users can analyze the CBA for different risk reduction measures that are proposed to reduce the risk;
- A **multi-criteria decision making module** where users can evaluate the best risk reduction option based on the quantitative information calculated from the risk and CBA modules, and from user defined additional criteria;
- A **visualization module** where users can visualize input map, loss maps and risk maps;
- A **user management module** where users can manage their roles within the system.

2. System Architecture

Enterprise applications are usually designed using a Three-Tier Client-Server Architecture (see figure below). This architecture provides three layers in which each layer deals with a different level of responsibilities. The three-tier architecture is used in the web-based spatial decision support system. The top tier or presentation layer constitutes the user interface, the middle tier is the core of the system for business logic and the bottom tier handles the data storage. One of the advantages of this architecture is easier to make changes in the layers without influencing the other layers.



As it is now, the RiskChanges is an open source platform that comprises of a Geoserver, PostGIS and JavaScript client side (OpenLayers and GeoExt based on ExtJS). The system employs HTML, JavaScript and CSS on the client side with a combination of Python/PHP scripting language and a PostGIS database on the server side. All the maps and all the data are stored in the PostGIS database. Analytical components for risk are implemented using SQL in the spatial database and decision analysis calculations are carried out in JavaScript on the client side. Finally, all the results are stored into the database. The whole system is running on a single Linux system. For an overview of the used software components see the Fig.2.1 below.

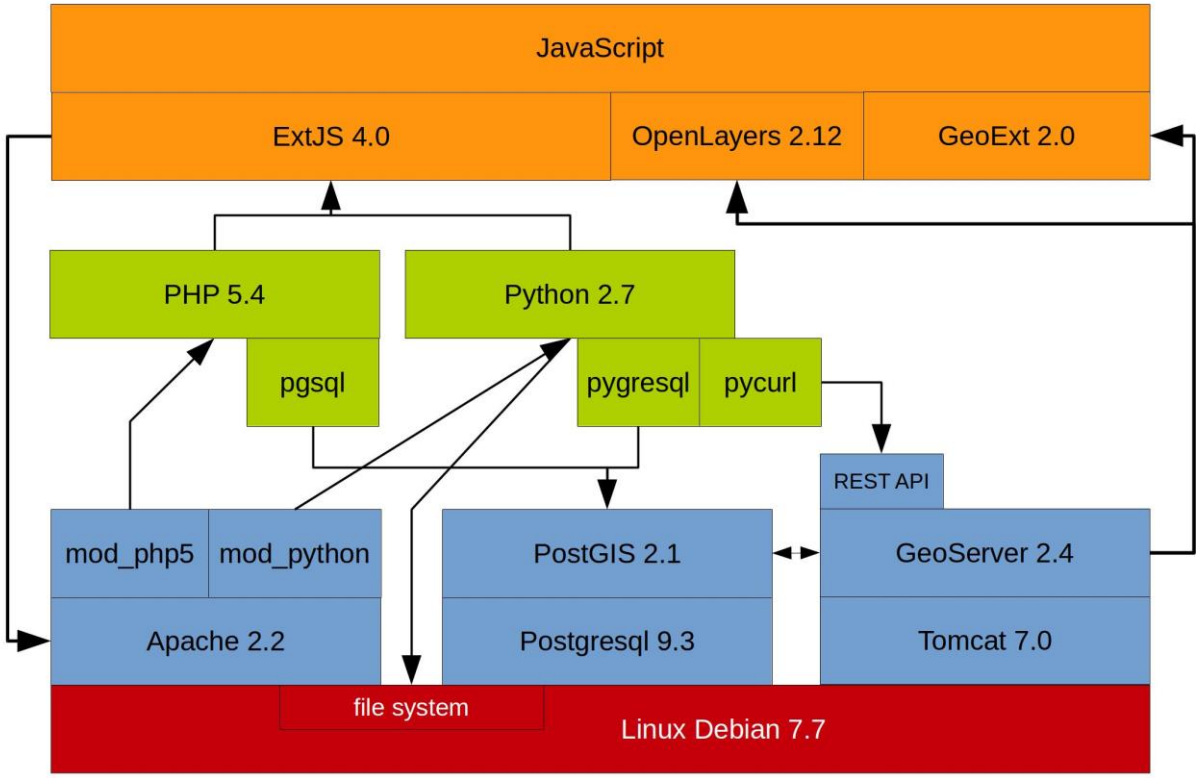


Figure 2.1: Software and libraries used in the system development

- **Linux operating system**

Linux is a Unix-like and mostly POSIX-compliant computer operating system assembled under the model of free and open-source software development and distribution. The defining component of Linux is the Linux kernel, an operating system kernel which was first released on 5 October 1991 by Linus Torvalds.

Typically, Linux is packaged in a form known as Linux distribution, for both desktop and server use. Some popular mainstream Linux distributions include Debian, Ubuntu, Linux Mint, Fedora, openSUSE, Arch Linux, and the commercial Red Hat Enterprise Linux and SUSE Linux Enterprise Server. Linux distributions include the Linux kernel, supporting utilities and libraries and usually a large amount of application software to fulfill the distribution's intended use.

Due to the flexibility and the free and open-source nature of Linux, it becomes possible to highly tune Linux for a specific purpose. The distributions often used for this purpose include Debian, Ubuntu (which is itself based on Debian). The Debian Stable distribution is one of the most popular for personal computers and network servers, and has been used as a base for

several other Linux distributions.

For the system, the Debian distribution was selected. Debian is the most stable and popular non-commercial Linux distribution. Software is easy to install and upgrade, because Debian has the best packaging system in the world. It is fast and easy on memory. It has good system security. And remote maintenance is easy.

The original RiskChanges system ran on a quad core CPU running at 2.40GHz with an approximate speed of 6600 bogomips, a total memory of 8 GB and a two 1 TB disks configured as one Linux software RAID of 1 TB. At the time of writing the version of the operating system is Debian 7.7, which was released on 18 October 2014.

- **PostGIS**

PostGIS is an open source software program that adds support for geographic objects to the PostgreSQL object-relational database. PostGIS follows the Simple Features for SQL specification from the Open Geospatial Consortium (OGC). Maintenance on the PostGIS database on the RiskChanges system can be done using different tools. One tool that can be used everywhere is the web-interface through phppgadmin. The web-interface can be reached via the following url: http://changes.itc.utwente.nl/phppgadmin/

- **Geoserver**

In computing, the GeoServer, which is an open-source server written in Java, allows users to share, process and edit geospatial data. Designed for interoperability, it publishes data from any major spatial data source using open standards. The Geoserver of the RiskChanges system runs on top of the Tomcat web server. It can be accessed via the following url: http://changes.itc.utwente.nl:8080/geoserver

- **Git**

The software versions of RiskChanges system are maintaining on a Git server on the Linux machine. The Git server can be reached through the SSH protocol (on port 2222) on the following url: ssh://changes.itc.utwente.nl:2222/home/git/changes.git. After inputting your username and password, remember to retrieve the ‘SDSS Master’ branch.

- **Apache2, Tomcat7**

The Apache HTTP Server, normally called just Apache, is the world's most widely-used Web server software. Apache Tomcat, or simply Tomcat, is an open source web server and servlet container. Tomcat implements several Java specifications including Java Servlet, JavaServer Pages (JSP), Java EL, and WebSocket, and provides a "pure Java" HTTP web server

environment for Java code to run in.

- **Python, PHP**

Python is a widely used general-purpose, high-level programming language. Its design philosophy emphasizes code readability, and its syntax allows programmers to express concepts in fewer lines of code than would be possible in languages such as C++ or Java. The language provides constructs intended to enable clear programs on both a small and large scale. Python can serve as a scripting language for web applications. The Python scripts on the RiskChanges system run via mod_python on the Apache web server. Python scripts use the Python module pg to talk to the database. The required GIS processing for the RiskChanges system is all done on the PostGIS spatial database. Python scripts construct SQL statements for this functionality.

PHP (Hypertext Preprocessor) is a server-side scripting language, designed for web development also used as a general purpose programming language. PHP code can be simply mixed with HTML. PHP code is usually processed by a PHP interpreter, which is usually implemented as a web server's native module or a CGI (Common Gateway Interface) executable. After the PHP code is interpreted and executed, the web server sends the resulting output to its client, usually in the form of a part of the generated web page.

3. User Management Module

There are five user roles within the RiskChanges system, namely, study area administration, project manager, expert, decision maker and visitor.

- **Study area administration**: owns the right to manage all the data within the study area he/ she created.
- **Project Manager**: is assigned by a study area administration to manage a specific project within the study area.
- **Expert**: is assigned by a study area administration or a project manager to input data and conduct analysis within a particular project.
- **Decision maker**: is assigned by a study area administration or a project manager to make multi-criteria decision analysis within a particular project.
- **Visitor**: a user who does not login the system using his/her own account. As a visitor, he or she is limited to access the study area 'demo' which is for demonstration purpose.

3.1. Data Model

The Entity Relationship diagram (fig 3.1) illustrates the physical data model of the data input module within the system, followed by a list of table schema where more detailed description is provided.

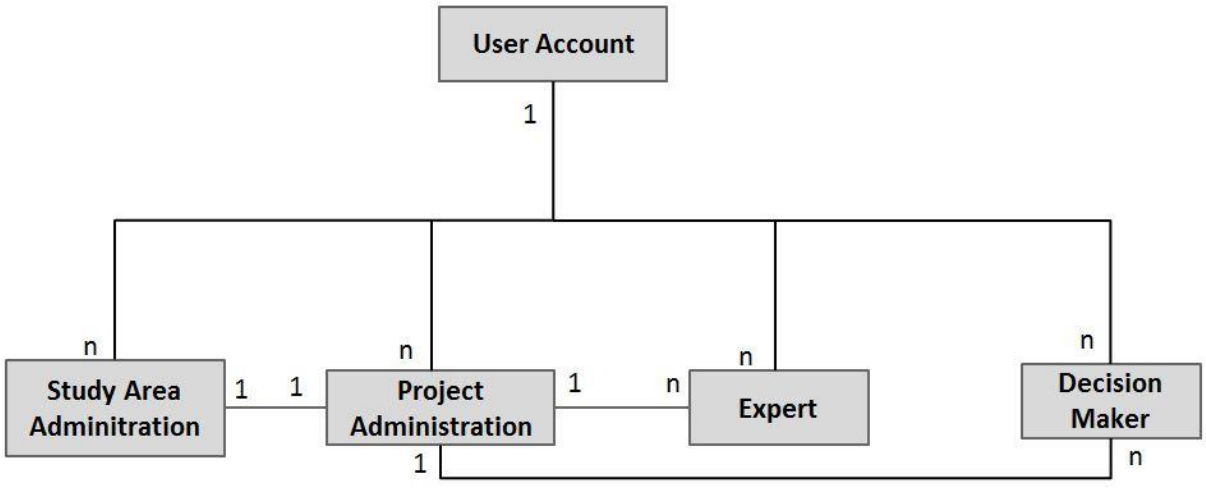


Figure 3.1: Entity Relationship graph of User Management Module

- **User Account table in schema 'public'**

UserAccount			
Description	This table contain all the user account information		
Attribute	**Description**	**Type**	***Examples of values***
UserAccountID	ID of users	serial	1,2,3…
Account	Email address of users	Character varying	xxxx@xx.com
Password	The account password	Character varying	Cs33c34s
GivenName	The user's given name	text	John
Surname	The user's surname	text	John
Primary Key	**UserAccountID**		

- **Study Area administration table in schema 'public'**

StudyAreaAdmin			
Description	This table contain all the study area administration info		
Attribute	**Description**	**Type**	***Examples of values***
ID_StudyAreaAdmin	ID of the study area administration	serial	1,2,3…
fk_UserAccountID	ID of the user account	integer	1,2,3…
fk_studyAreaID	ID of the study area	integer	1,2,3…
Primary Key	**ID_StudyAreaAdmin**		
Foreign Keys	**fk_UserAccountID** reference the table 'UserAccount'. **fk_studyAreaID** reference the table 'studyarea'.		

- **Project administration table in schema 'public'**

ProjectAdmin			
Description	This table contain all the project administration info		
Attribute	**Description**	**Type**	***Examples of values***
ID_ProjectAdmin	ID of the project	serial	1,2,3…

	administration		
fk_UserAccountID	ID of the user account	integer	1,2,3…
fk_StudyAreaAdminID	ID of the study area administration	integer	1,2,3…
fk_ProjectID	ID of the project	integer	1,2,3…
Primary Key	**ID_StudyAreaAdmin**		
Foreign Keys	**fk_UserAccountID** reference the table 'UserAccount'. **fk_StudyAreaAdminID** reference the table 'StudyAreaAdmin'. **fk_ProjectID** reference the table 'studyarea'.		

- **Expert table in schema 'public'**

ExpertAdmin			
Description	This table contain all the project administration info		
Attribute	**Description**	**Type**	***Examples of values***
ID_ExpertAdmin	ID or the expert	serial	1,2,3…
fk_UserAccountID	ID of the user account	integer	1,2,3…
fk_ProjectAdminID	ID of the project administration	integer	1,2,3…
Primary Key	**ID_ExpertAdmin**		
Foreign Keys	**fk_UserAccountID** reference the table 'UserAccount'. **fk_ ProjectAdminID** reference the table 'ProjectAdmin'.		

- **Decision Maker table in schema 'public'**

DecMakingAdmin			
Description	This table contain all the project administration info		
Attribute	**Description**	**Type**	***Examples of values***
ID_DecMakingAdmin	ID or the decision maker	serial	1,2,3…
fk_UserAccountID	ID of the user	integer	1,2,3…

	account		
fk_ProjectAdminID	ID of the project administration	integer	1,2,3…
Primary Key	**ID_ DecMakingAdmin**		
Foreign Keys	**fk_UserAccountID** reference the table 'UserAccount'. **fk_ ProjectAdminID** reference the table 'ProjectAdmin'.		

3.2. Use Case

The table below lists the actions each role could perform within each module in the RiskChanges system.

	Study Area Admin	**Project Manager**	**Expert**	**Decision Maker**	**Visitor (Demo)**
Data Input Module					
Study Area					
Create/Delete/Edit Study Area	√				
View Study Area Info	√	√	√	√	√
Input/Delete/Edit Admin data	√				
View Admin info	√	√	√	√	√
Visualize/Download Admin layer	√	√	√	√	√
Input/Delete/Edit hazard data in current situation	√				

View hazard info	√	√	√	√	√
Visualize/Download hazard layer	√	√	√	√	√
Input/Delete/Edit EaR in current situation	√				
View EaR info	√	√	√	√	√
Visualize/Download EaR layer	√	√	√	√	√
Create/Delete/Edit Project	√				
Project					
View Project Info	√	√	√	√	√
Create/Delete/Edit Scenario	√	√			
View Scenario Info	√	√	√	√	√
Create/Delete/Edit Future Year	√	√			
View Future Year Info	√	√	√	√	√
Create/Delete/Edit Alternative	√	√			
View Alternative Info	√	√	√	√	√
Create/Delete Loss Parameter	√	√	√		

combinations					
Input/Delete/Edit (new) hazard data	√	√	√		
View new hazard info	√	√	√	√	√
Visualize/Download hazard layer	√	√	√	√	√
Input/Delete/Edit (new) EaR	√	√	√		
View new EaR info	√	√	√	√	√
Visualize/Download EaR layer	√	√	√	√	√
Vulnerability Curve					
Search/Visualize Vul Curve	√	√	√	√	√
Input/Delete Vul Curve	√	√	√		
Risk Analysis Module					
Loss computation					
Compute loss	√	√	√		√
Delete loss data	√	√	√		√
Visualize/Download loss map	√	√	√	√	√

Risk computation					
Create/Delete/Edit Risk Analysis	√	√	√		√
Compute Risk	√	√	√		√
Visualize Risk curve and AAL value	√	√	√	√	√
Visualize/Download risk map	√	√	√	√	√
Cost Benefit Analysis Module					
Create/Delete/Edit Cost Benefit Analysis	√	√	√		√
Add/Delete Cost/Benefit Indicator	√	√	√		√
Compute Cost-Benefit	√	√	√		√
Visualize Cost-Benefit Result	√	√	√	√	√
Multiple Criteria Decision Making Module					
Create/Delete decision Session	√	√	√	√	√

Add / Remove /Select Indicator	√	√	√	√	√
Criteria Definition (Standardization)	√	√	√	√	√
Weight Indicator	√	√	√	√	√
Compare and Visualize	√	√	√	√	√
Visualization Module					
Search/Visualize/Compare/Download Input Data	√	√	√	√	√
Search/Visualize/Compare/Download Loss Map	√	√	√	√	√
Search/Visualize/Compare/Download Risk Map	√	√	√	√	√
Time slides to show temporal data series	√	√	√	√	√
User Management Module					
Assign/Delete Project	√				

Manager					
Assign/Delete Expert	√	√			
Assign/Delete Decision Maker	√	√			

4. Data Input Module

The system has the following types of input data.

Type	Raster/Vector	Description
Study Area	None	Definition of a study area
Project	None	Definition of a project within a study area
Administrative units	Vector	Administration unit where the risk will be calculated.
Alternative map	Vector	These maps are used for visualization purpose only to show risk reduction measures.
Vulnerability file	None	Text files for each combination of EaR type and intensity unit. The file contains intensity classes, and columns with vulnerability values (average value and /or standard deviation value)
Hazard maps	Raster	Intensity value maps for different hazards and return periods. Spatial probability maps or values for different hazards and return periods
EaR maps	Vector	Attribute data relates to the EaR type, value and population
Loss parameter set	None	User should choose which EaR map and which hazard map for later loss computation

4.1. Data Model

The Entity Relationship diagram (fig 4.1) illustrates the physical data model of the data input module within the system, followed by a list of table schema where more detailed description is provided.

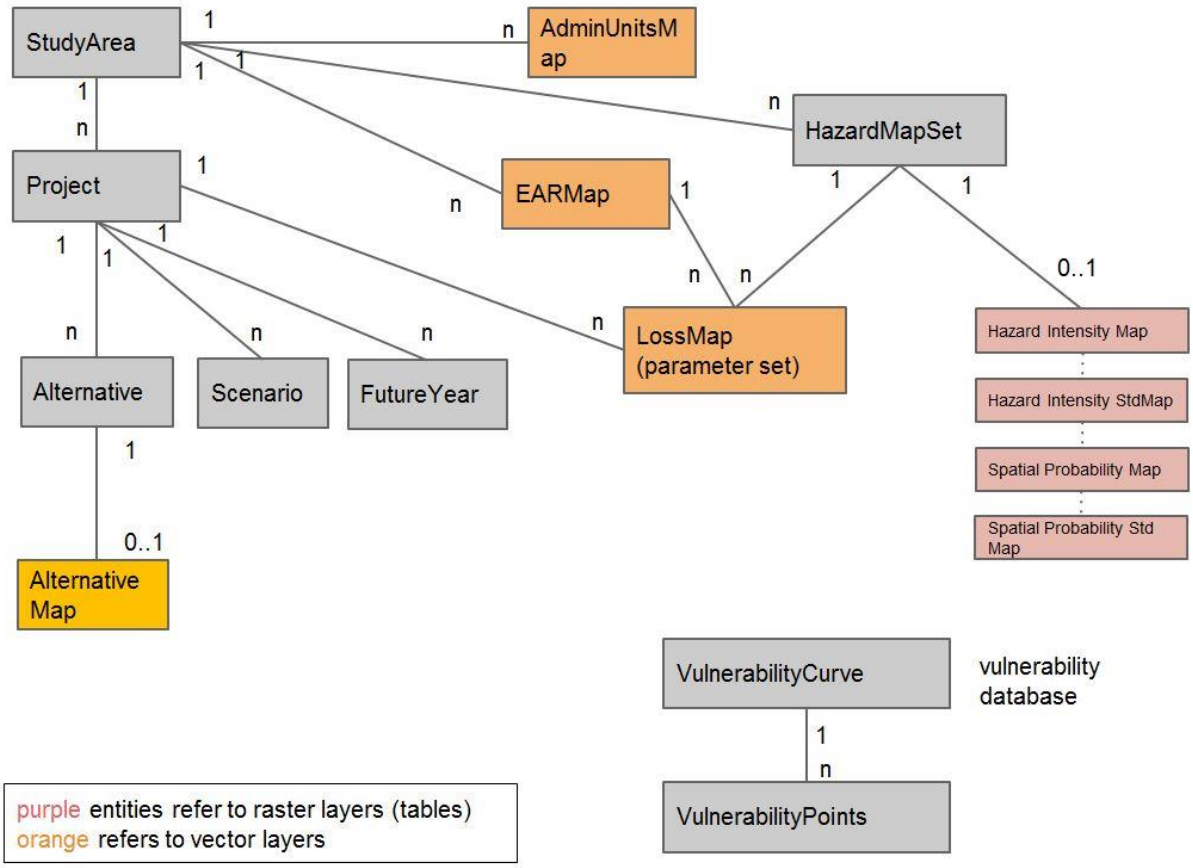


Figure 4.1: Entity Relationship graph of Data Input Module

- **Study Area table in schema 'public'**

studyarea			
Description	This table is used for storing all the information related for a particular study area.		
Attribute	**Description**	**Type**	***Examples of values***
areaID	ID of the study area	serial	1,2,3,.....
areaName	Name of the study area	Character varying	Nocera
description	Additional description for the study area	Character varying	Nocera is an Italian study area which…
Primary Key	**areaID**		

- **Vulnerability curve table in schema 'demo'**

vulnerabilityCurve			
Description	This table is used for storing the information of vulnerability curves.		
Attribute	**Description**	**Type**	***Examples of values***
vulnID	ID of the vulnerability curve	serial	1,2,3,.....
hazTypeID_fk	ID of the hazard type	integer	1,2,3,.....
hazIntTypeID_fk	ID of the hazard intensity type	integer	1,2,3,.....
units_fk	ID of the hazard intensity type	integer	1,2,3,.....
vulnType_fk	ID of the vulnerability type	integer	1,2,3,.....
earType_fk	ID of the EaR type	integer	1,2,3,.....
earCodeType	EaR type	Character varying	Wood, Park,…
source	Source of the vulnerability curve	Character varying	This curve is produced by…
description	More detailed description about the vulnerability curve	Character varying	This curve contains…
fk_UserID	ID of the hazard intensity type	integer	1,2,3,.....
Primary Key	**vulnID**		
Foreign Keys	**hazTypeID _fk** reference the “hazardType” table. **hazIntTypeID _fk** reference the “hazardIntensityType” table. **units _fk** reference the “units” table. **vulnType _fk** reference the “vulnType” table. **earType _fk** reference the “earType” table. **fk_ UserID** reference the “UserAccount” table.		

- **Vulnerability Points table in schema ‘demo’**

vulnerabilityPoints			
Description	This table is used for storing the vulnerability values of a vulnerability curve.		
Attribute	**Description**	**Type**	***Examples of values***
vulnPointID	ID of vulnerability point	serial	1,2,3…
vulnID_fk	ID of the vulnerability curve	integer	1,2,3…
hazIntensity_from	The lower limit of hazard intensity value	double	0.28, 0.34…
hazIntensity_to	The upper limit of hazard intensity value	double	0.42, 0.52…
vulnAVG	Average vulnerability value	double	0.1,0.3….
vulnSTD	Standard deviation vulnerability value	double	0.02,0.06…
Primary Key	**vulnPointID**		
Foreign Keys	**vulnID_fk** reference the “vulnerabilityCurve” table.		

- **Unit Map table in study area schema**

unit Map			
Description	This table is used for storing all the information related for a particular (administration) unit.		
Attribute	**Description**	**Type**	***Examples of values***
unitID	ID of the unit	serial	1,2,3,.....
unitLayerName	The name of the Spatial Table generated by the system	Character varying	NoceraUnit001

fileName	Shape file name as the user has inputted	Character varying	NoceraUnit.shp
unitDisplayName	Easy remembered name defined by the user	Character varying	Nocera
type	The type of the unit	Character varying	Neighbourhood, census track…
adminUnitNameField	Column name within the shapefile containing the information of unit label	Character varying	Enschede, Hengelo
Primary Key	**unitID**		

- **Project table in study area schema**

project			
Description	This table is used for storing all the project related information.		
Attribute	**Description**	**Type**	***Examples of values***
projectID	ID of the project	serial	1,2,3…
projectDisplayName	Project name defined by the user	character varying	Urban planning
name	Name of the Project	Character varying	Nocera Project One
goal	Goal of the project	Character varying	Reduce the risk to roads
organization	The organization responsible for the project	Character varying	ITC
contactPerson	name of the person in charge	Character varying	Jos

email	email of the person in charge	Character varying	Jos@utwente.nl
phone	phone of the person in charge	integer	0031572455
description	More detailed description about the project	Character varying	Nocera Project One contains alternative
Primary Key	**projectID**		

- **Alternative table in study area schema**

alternative			
Description	This table is used for storing the information related to the particular alternative.		
Attribute	**Description**	**Type**	*Examples of values*
altID	ID of the alternative	serial	1,2,3…
projectID_fk	ID of the project	integer	1,2,3…
altDisplayName	Name of the alternative defined by the user	Character varying	Dike
fileName	Shape file name as the user has inputted	Character varying	DikeConstruction.shp
altLayerName	The name of the Spatial Table, generated by the system	Character varying	DikeConstruction001
description	Additional description for this alternative	Character varying	By building a dike…

doc	The pdf document describing in more detail the alternative	Character varying	
isCurrent	If it is the current situation	boolean	True
lifetime	The period length of the alternative	integer	20
incrBenefits	If the benefits increase with year	boolean	True
benefitsStartYear	The start year of having benefits	integer	2020
Primary Key	**altID**		
Foreign Keys	**projectID_fk** reference the "project" table. The user can create multiple alternatives per project.		

- **Scenario table in study area schema**

scenario			
Description	This table is used for storing the information related to the particular scenario.		
Attribute	**Description**	**Type**	***Examples of values***
scenID	ID of the scenario	serial	1,2,3…
projectID_fk	ID of the project	integer	1,2,3…
scenDisplayName	Name of the scenario defined by the user	Character varying	Climate Change
description	Additional description for scenario	Character varying	Climate Change related description
doc	The pdf document describing in more	Character varying	

	detail the scenario		
isCurrent	If it is the current scenario	boolean	True
Primary Key	**scenID**		
Foreign Keys	**projectID_fk** reference the "project" table. The user can create multiple scenarios per project.		

- **Future Year table in study area schema**

futureYear			
Description	This table contain all the future years.		
Attribute	**Description**	**Type**	*Examples of values*
futYearID	ID of future year	serial	1,2,3…
projectID_fk	ID of the project	integer	1,2,3…
year	The year	integer	2015, 2020
isCurrent	If it is the current year	boolean	True
Primary Key	**futYearID**		
Foreign Keys	**projectID_fk** reference the "project" table. The user can create multiple future years per project.		

- **Hazard Map Set table in study area schema**

hazardMapSet			
Description	This table is used for storing the hazard information.		
Attribute	**Description**	**Type**	*Examples of values*
hazardMapSetID	ID of the Hazard Map Set	serial	1,2,3…
hazMapSetName	Name defined by the user to reference a particular hazard map set	Character varying	floodmax

hazardIntensityLayerName	Name of the intensity Layer	Character varying	FloodIntensity001
hazardIntensitySTDLayerName	Name of the Standard deviation intensity Layer	Character varying	FloodIntensitySTD 001
spatialProbLayerName	Name of the spatial probability Layer	Character varying	FloodSpatialProb0 01
spatialProbSTDLayerName	Name of the Standard Deviation Spatial probability Layer	Character varying	FloodSpatialProbS TD001
spatialProbValueAVG	Average value of the spatial probability	Double	0.75
spatialProbValueSTD	Standard deviation value of the spatial probability	Double	0.15
hazType_fk	ID of the hazard type	integer	1,2,3…
returnPeriodAVG_fk	ID of the average return period value	integer	1,2,3…
returnPeriodSTD	ID of the standard deviation return period value	integer	1,2,3…
description	Description related to this hazard map set	Character varying	This hazard map set contains intensity and spatial probability maps…
isCurrent	If it is hazard map set in current situation	boolean	True

Primary Key	**hazardMapSetID**
Foreign Keys	**hazType_fk** references the "hazardType" table. **returnPeriodAVG_fk, returnPeriodSTD** reference the "returnPeriod" table.

- **Hazard type table in study area schema**

hazardType			
Description			
Attribute	**Description**	**Type**	*Examples of values*
hazTypeID	The ID of the hazard type	serial	1,2,3…
hazType	The hazard type	Character varying	Flood, debris flow…
Primary Key	hazTypeID		

- **Hazard return period table in study area schema**

returnPeriod			
Description			
Attribute	**Description**	**Type**	*Examples of values*
retPerID	The ID of the return period	serial	1,2,3…
retPeriod	The return period value	integer	10,20,500…
Primary Key	**retPerID**		

- **Hazard Intensity Map table in study area schema**

hazardIntensityMapInfo	
Description	

Attribute	Description	Type	*Examples of values*
hazardIntensityLayerName	Name of the Hazard Intensity Layer/Table	Character varying	FloodIntensity001
fileName	File name of the raster file uploaded by the user	Character varying	FloodIntensity
hazIntDisplayName	Name of intensity layer defined by the user	Character varying	FloodIntensity
description	Description of hazard intensity map	Character varying	This hazard intensity map is …
source	The source of the hazard intensity map	Character varying	This hazard intensity map is created by XXX group in ITC
hazIntType_fk	The ID of hazard intensity type	integer	1,2,3…
units_fk	The ID of the units/ scale of measurements	integer	1,2,3…
hazMapSetID_fk	The ID of the hazard map set	integer	1,2,3…
Primary Key	**hazardIntensityLayerName**		
Foreign Keys	**hazIntType_fk** references the 'hazardIntensityType' table. **units_fk** references the 'units' table. **hazMapSetID_fk** references the 'hazardMapSet' table.		

- **Hazard Intensity type table in study area schema**

hazardIntensityType			
Description			
Attribute	**Description**	**Type**	***Examples of values***
hazIntTypeID	The ID of hazard intensity type	serial	1,2,3…
hazIntType	the hazard intensity type	Character varying	Water depth, impact pressure….
Primary Key	**hazIntTypeID**		

- **Hazard Intensity unit table in study area schema**

units			
Description			
Attribute	**Description**	**Type**	***Examples of values***
unitID	The ID of the unit	serial	1,2,3…
unit	The unit	Character varying	cm, kpa…
Primary Key	**unitID**		

- **Hazard Intensity STD Map table in study area schema**

hazardIntensitySTDMapInfo			
Description			
Attribute	**Description**	**Type**	***Examples of values***
hazardIntensitySTDLayerName	Name of the Hazard Intensity STD Layer/Table	Character varying	FloodIntensitySTD001
fileName	File name of the raster file uploaded by the user	Character varying	FloodIntensitySTD
hazIntDisplaySTDName	Name of intensity STD layer defined	Character varying	FloodIntensitySTD

	by the user		
description	Description of hazard intensity STD map	Character varying	This hazard intensity STD map is …
hazMapSetID_fk	The ID of the hazard map set	integer	1,2,3…
Primary Key	**hazardIntensitySTDLayerName**		
Foreign Keys	**hazMapSetID_fk** references the 'hazardMapSet' table.		

- **Spatial Probability Map table in study area schema**

spatialProbMapInfo			
Description			
Attribute	**Description**	**Type**	***Examples of values***
spatialProbLayerName	Name of the spatial Probability Layer/Table	Character varying	SpatialProb001
fileName	File name of the raster file uploaded by the user	Character varying	SpatialProb
spProbDisplayName	File name of spatial probability layer defined by the user	Character varying	SpatialProbability
description	Description of hazard spatial probability map	Character varying	This hazard spatial probability map is …
hazMapSetID_fk	The ID of the hazard map set	integer	1,2,3…

Primary Key	**spatialProbLayerName**
Foreign Keys	**hazMapSetID_fk** references the 'hazardMapSet' table.

- **Spatial Probability STD Map table in study area schema**

spatialProbSTDMapInfo			
Description			
Attribute	**Description**	**Type**	*Examples of values*
spatialProbSTDLayerName	Name of the spatial Probability STD Layer/Table	Character varying	SpatialProbSTD001
fileName	File name of the raster file uploaded by the user	Character varying	SpatialProbSTD
spProbSTDDisplayName	File name of spatial probability STD layer defined by the user	Character varying	SpatialProbabilitySTD
description	Description of hazard spatial probability STD map	Character varying	This hazard spatial probability STD map is …
hazMapSetID_fk	The ID of the hazard map set	integer	1,2,3…
Primary Key	**spatialProbSTDLayerName**		
Foreign Keys	**hazMapSetID_fk** references the 'hazardMapSet' table.		

- **EaR Map table in study area schema**

EAR Map			
Description	The EAR spatial layer related information is stored here. This table is used as a description for the EAR Spatial layer table.		
Attribute	**Description**	**Type**	***Examples of values***
earLayerName	Name of the EAR Spatial Layer/Table generated by the system	Character varying	Buildings001
earDisplayName	Name of the EAR Spatial Layer defined by the user	Character varying	Building_footprint
fileName	File name of the shape file uploaded by the user	Character varying	Buildings.shp
earTypeID_fk	The ID of the ear type	integer	1, 2, 3, …
earCodeTypeAttr	Column name in EaR shapefile representing info of EaR structure type such as Wood	Character varying	type
description	Additional info for the EAR shapefile	Character varying	This EaR map is….
source	Source of the EaR shapefile	Character varying	This EaR map is produced by XXX group in ITC
isCurrent	If EaR map is the one in current situation	boolean	True
Primary Key	**earLayerName**		
Foreign Keys	**earTypeID_fk** reference the ‘earType’ table.		

- **EaR type table in study area schema**

earType			
Description			
Attribute	**Description**	**Type**	***Examples of values***
earTypeID	The ID of the ear type	serial	1,2,3…
earType	The ear type	Character varying	Building, land parcel, line element, point
Primary Key	**earTypeID**		

- **EaR Amount Type table in study area schema**

earAmountType			
Description	This table contains the information such as which column in the EaR shapefile contains the economic value or population number info		
Attribute	**Description**	**Type**	***Examples of values***
earAmountTypeID	The ID of the ear amount type	serial	1,2,3…
earLayerName_fk	The ear layer name	Character varying	Building_footprint
earAmountType	The amount type	Character varying	Physical, population
earAmountColumnName	The column name within the EaR layer	Character varying	People_number
Primary Key	**earAmountTypeID**		
Foreign Keys	**earLayerName_fk** reference the ‘earMap’ table.		

- **Loss Map Parameters table in study area schema**

lossMapParameters			
Description	This table contains the information of loss combinations made by users		
Attribute	**Description**	**Type**	***Examples of values***
lossMapParamID	ID of the loss map parameter	serial	1,2,3…
scenID_fk	ID of scenario	integer	1,2,3…
altID_fk	ID of alternative	integer	1,2,3…
futYearID_fk	ID of future year	integer	1,2,3…
hazMapSetID_fk	ID of hazard map set	integer	1,2,3…
earLayerName_fk	EaR layer name	Character varying	Building_footprint
earCodeTypeAttrName	Column name in EaR shapefile representing info of EaR structure type such as Wood	Character varying	type
earAmountAttrName	The column name within the EaR layer	Character varying	People_number
lossMapExist	If the loss map has already been calculated	boolean	True
Primary Key	**lossMapParamID**		
Foreign Keys	**scenID_fk** reference the ‘scenario’ table. **altID_fk** reference the ‘alternative’ table. **futYearID_fk** reference the ‘futureYear’ table. **hazMapSetID_fk** reference the ‘hazardMapSet’ table. **earLayerName_fk** reference the ‘earMap’ table.		

4.2. Codes

The table below shows the name of the file or folder which contains the codes of the functions in data input module.

	View (UI design) **/app/view/datainput**	**Controller (action)** **/app/controller/datainput**	**Python(server)** **/python/dataInput**
Create/Delete/Edit /View Study Area	/StudyArea/	/StudyArea.js	/StudyArea/
Input/ Edit /View/ Visualize/Download /Delete Admin data	/adminUnits/	/adminUnits/	/adminUnits/
Input/Delete/Edit /Visualize/Download hazard data in current situation	/hazardMaps/	/hazardMaps/	/hazardMaps/
Input/Delete/Edit / Visualize/Download EaR in current situation	/earMaps/	/earMaps/	/ear/
Create/Delete/Edit Project	/project/	/project/	/project/
Create/Delete/Edit Scenario	/scenario/	/scenario/	/scenario/
Create/Delete/Edit Future Year	/futureYear/	/futureYear/	/futureYear/
Create/Delete/Edit/ Visualize/Download Alternative data	/alternative/	/alternative/	/alternative/

Create/Delete Loss Parameter combinations	/LossMapParameters.js, /LossMapParametersGrid.js, /LossHazEarLink.js	/LossMapParamsCtrl.js	/lossParams/
Input/Delete/Edit/ Visualize/Download (new) hazard data	/hazardMaps/	/hazardMaps/	/hazardMaps/
Input/Delete/Edit/ Visualize/Download (new) EaR	/earMaps/	/earMaps/	/ear/
Search/Visualize/ Input/Delete Vulnerability curve	/vulnerability/	/vulnerability/	/vulnerability/

5. Risk Analysis Module

This module is to assess the current risk, analyze the risk after implementations of risk reduction alternatives, and analyze the risk in different future years when considering scenarios such as climate change, land use change and population growth. Not only the single-hazard but also the multi-hazard risk assessment is included in this component. As shown in Fig. 5.1, the outputs that can be generated by this component totally depend on what data they input within the system.

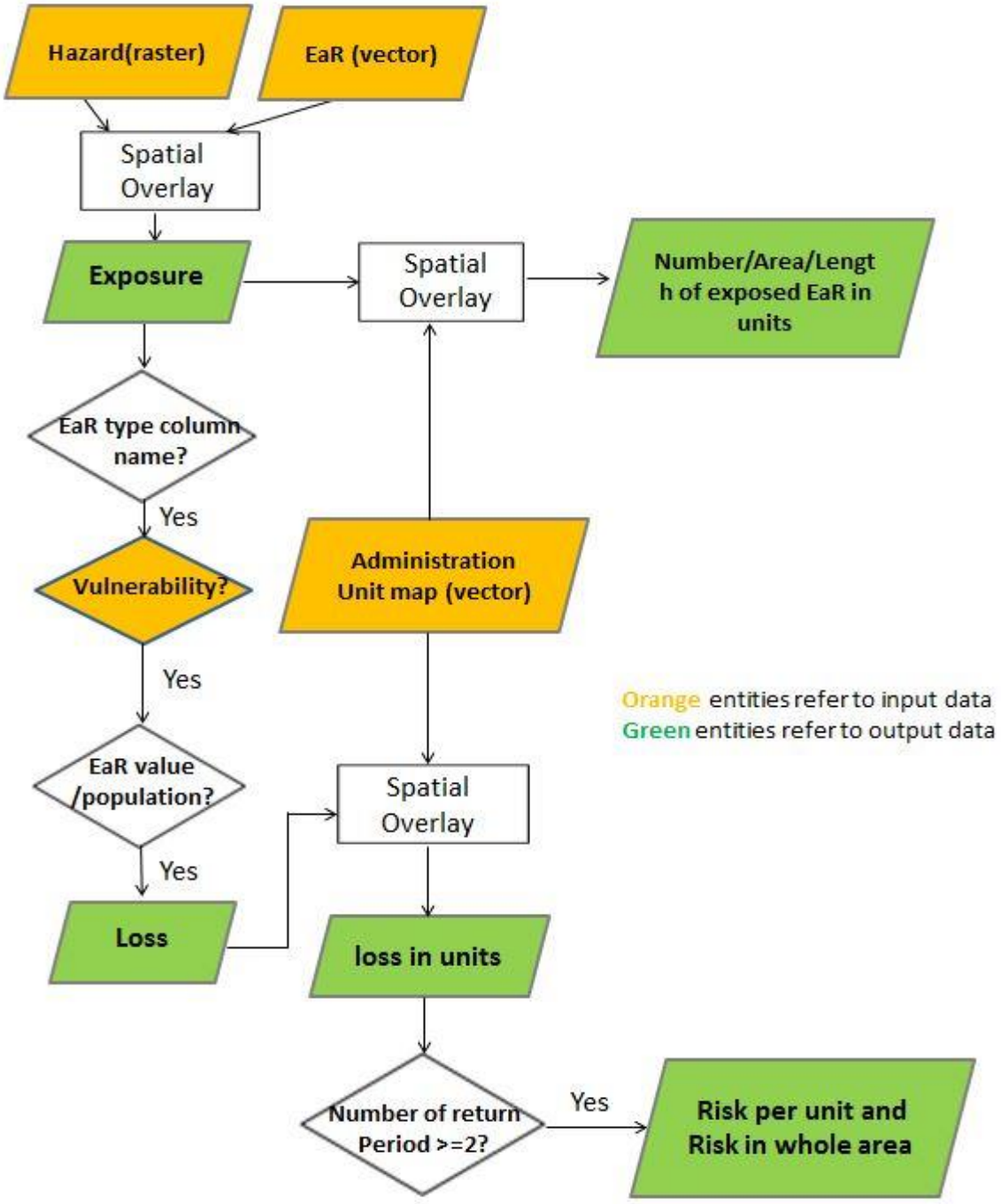


Figure 5.1: Work Flow of Risk Analysis in the RiskChanges System

5.1. Loss calculation process

For each Element at Risk (EaR), its loss under a hazard is calculated based on Eq. 1.

$$\text{Loss}=\text{Spatial Probability}* \text{Vulnerability}*\text{Value (or Population No.)} \quad (1)$$

To perform this equation, spatial probability, vulnerability and value (or population number) of the considered EaR should be available. Spatial probability is either map or value depends on users' input. Vulnerability value is determined by vulnerability table and intensity value that the EaR is exposed in. The value or population number is stored in the attributes of EaR map, which can be obtained directly if users provide attribute column name. The loss calculation consist of 3 steps, namely,

Step 1: Clip

To obtain intensity values or spatial probability values each EaR was exposed in, the postGIS spatial function 'ST_Clip' was used to perform the spatial overlay and clip between hazard maps (raster) and EaR maps (vector). Below is an example:

```
--extract the intensity pixels located in the zone of land parcel id=41
SELECT ST_Clip (rast, geom)
from flood_depth, land_parcels
where ST_Intersects(geom, ST_ConvexHull(rast)) and gid=41;
```

Step 2: Intensity to Vulnerability

If the EaR Type is building or point, find the maximum intensity value within the intensity pixels clipped by each EaR boundary. The vulnerability of each EaR is based on the maximum intensity it is exposed in and the vulnerability table.

If the EaR Type is land parcel, the values of the intensity pixels clipped by each EaR boundary can be reclassified by the vulnerability values according to vulnerability tables. PostgreSQL/PostGIS provides the function 'ST_Reclass' to fulfill this purposes**.**

Step 3: Final Multiplication

If the EaR Type is building or point, the loss is calculated based on Eq. 1, in which the vulnerability value is the one obtained in Step 2, and the spatial probability is the maximum pixel value within the intensity pixels clipped by each EaR boundary (obtained in Step 1)

If the EaR Type is land parcel, calculation follows the Fig. 5.2, in which the vulnerability is the pixels obtained in Step 2 and the spatial probability is the one obtained in Step 1

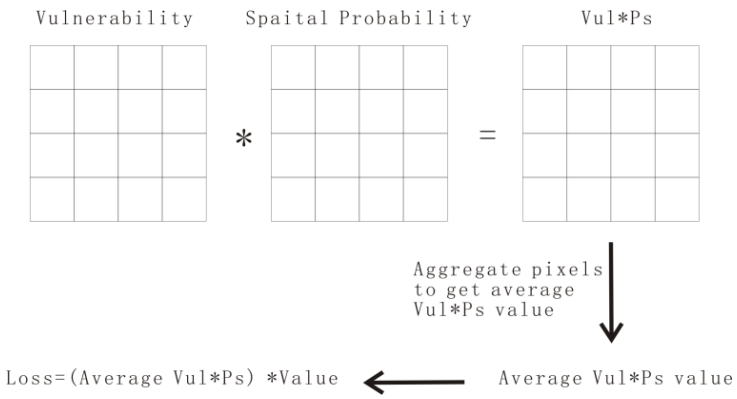


Figure 5.2: Work Flow of Loss Calculation for Land parcel type

5.2. Risk calculation process

To calculate the risk, an administration unit map is required. The risk calculation includes two steps;

Step 1: Aggregation

Since the risk value is unit based, the administration unit map within the study area is used to aggregate the loss values of all the EaR within each unit. The function 'ST_summarystats' available in PostGIS can achieve this purpose.

Step 2: Calculate annualized risk

If the number of return period involved is larger than 2, the annualized risk, either per unit or in the whole study area, is computed based on the equation below.

$$\text{Risk}=\frac{1}{T1}*S1+\left(\frac{1}{T2}-\frac{1}{T1}\right)*\frac{S1+S2}{2}+\left(\frac{1}{T3}-\frac{1}{T2}\right)*\frac{S2+S3}{2}+\left(\frac{1}{T4}-\frac{1}{T3}\right)*\frac{S3+S4}{2}+\left(\frac{1}{T5}-\frac{1}{T4}\right)*\frac{S4+S5}{2}$$

Where T1, T2 etc. are the return periods used, and S1 , S2 etc. are the losses in a unit. For example, taking the data listed in table 5.1 below as loss values, the annualized risk value is 18.9 euro.

Table 5.1: dummy for risk calculation demonstration

Return Period (yr)	Loss (€)
250	1000
100	500
50	200
25	100
10	10
5	2

$$\text{Risk}=\frac{1}{250}*1000+\left(\frac{1}{100}-\frac{1}{250}\right)*\frac{1000+500}{2}+\left(\frac{1}{50}-\frac{1}{100}\right)*\frac{500+200}{2}+\left(\frac{1}{25}-\frac{1}{50}\right)*\frac{200+100}{2}+\left(\frac{1}{5}-\frac{1}{10}\right)*\frac{10+2}{2}=18.9€\text{ per year}$$

5.3. Data Model

The Entity Relationship diagram (**Fig 5.3**) illustrates the physical data model of the risk analysis module within the system, followed by a list of table schema where more detailed description is provided.

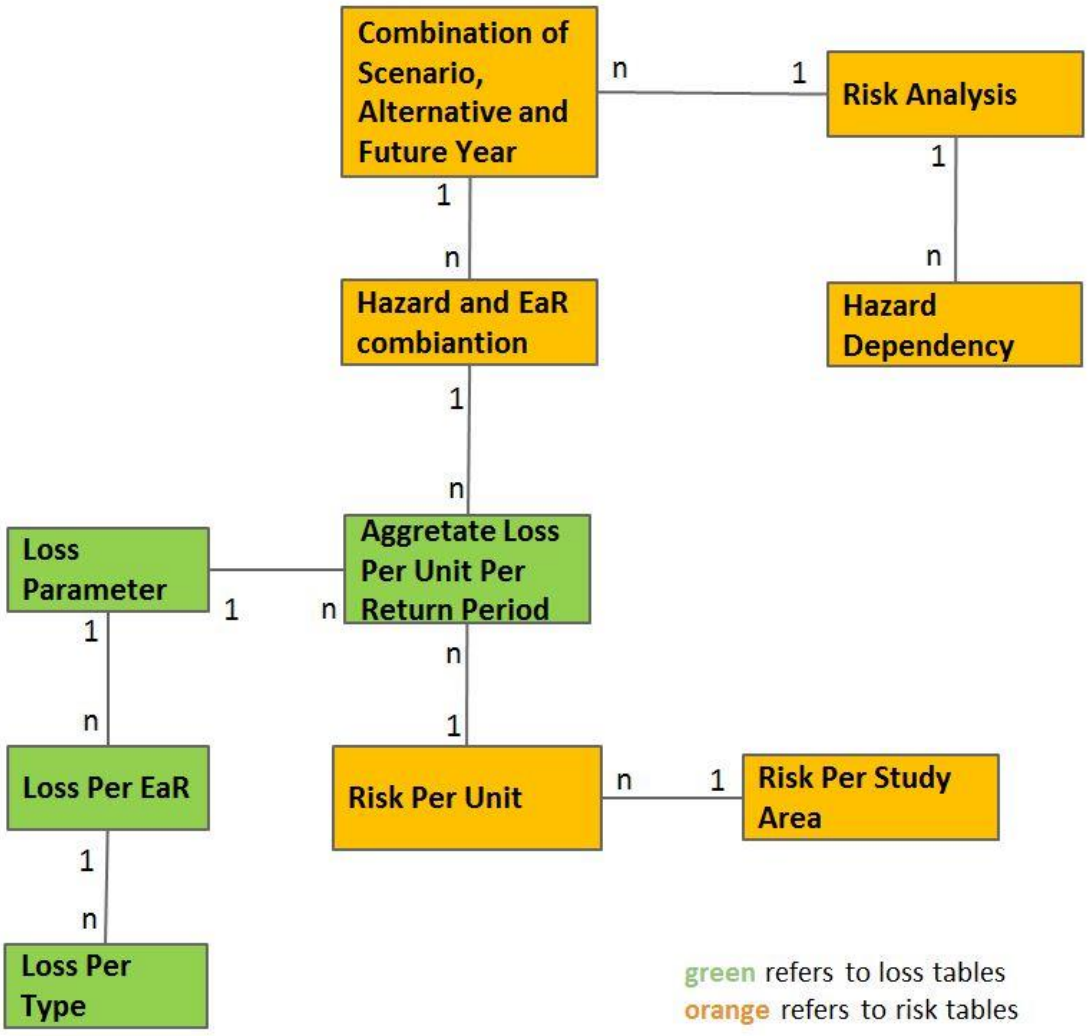


Figure 5.3: Entity Relationship graph of Risk Analysis Module

- **LossPerEAR table in study area schema**

LossPerEAR			
Description	Loss per EAR related information is stored in this table. It's actually a description table for the loss or exposure values per EAR, which are stored in the LossType table.		
Attribute	**Description**	**Type**	***Examples of values***
lossPerEARID	ID of lossPerEaR	serial	1,2,3…

earID_fk	ID of the EAR	Integer	1,2,5,6,…
lossMapParamsID_fk	ID of the loss map parameters	Integer	1,3,4,6,…
exposedPercentage	Percentage of the EAR under exposure	Double	0.50, 0.60, …
maxHazardIntensity	Maximal intensity of the hazard per EAR	Double	10.5, 9.8,…
Primary Key	**lossPerEARID**		
Foreign Keys	**lossMapParamsID_fk** reference the table 'lossMapParameters'.		

- **LossType table in study area schema**

LossType			
Description	Loss or exposure values per EAR are stored in this table.		
Attribute	**Description**	**Type**	***Examples of values***
lossTypeID	ID of the Loss Type	serial	1,2,5,8,…
exposureOrLoss	whether it is loss value per EAR or exposure value	Boolean	True, false
lossType	Type of the loss/exposure depending on which earAmountAttributeName used	Character varying	physical, population etc…
avgSTD	Discriminating if its average or std value	Character varying	AVG or STD
value	The value of the loss/exposure per EAR	Double	1002.64
lossPerEARID_fk	ID of the loss per EaR table	Integer	1, 4, 7, …
Primary Key	**lossTypeID**		
Foreign Keys	**lossPerEARID_fk** reference the table 'lossPerEAR'.		

- **Aggregated Loss Per Unit Per Return Period table in study area schema**

aggregateLossPerUnitPerRetPeriod			
Description	This table contains the loss or exposure values aggregated per (admin) unit and per Return Period		
Attribute	**Description**	**Type**	***Examples of values***
aggrLoss_u_rp_ID	ID of the record in aggregated loss per unit per return period	serial	1, 2, 3, …
unitgid_fk	ID of the unit	integer	1, 2, 3, …
lossMapParamsID_fk	ID of the Loss Map parameters	Integer	1, 2, 3, …
exposureOrLoss	Discriminating between exposure or loss value	Boolean	Exposure or Loss
lossType	Type of the loss/exposure	Character varying	physical, population etc…
hazEaRCombID_fk	ID of the combination of hazard and EaR combination	Integer	1, 2, 3, …
riskPerUnitID_fk	ID of the risk per Unit	Integer	1, 2, 3, …
avgValue	Average loss/exposure value per unit	Double	32600.32
stdValue	Standard deviation loss/exposure value	Double	500.35

	per unit		
Primary Key	**aggrLoss_u_rp_ID**		
Foreign Keys	**lossMapParamsID_fk** references the table 'lossMapParameters'. **hazEaRCombID_fk** references the table 'selectedHazEARComb. **riskPerUnitID_fk** references the table 'riskPerUnit.		

- **Risk Analysis table in study area schema**

riskAnalysis			
Description	Hazard dependency for multiple hazard risk analysis		
Attribute	**Description**	**Type**	*Examples of values*
riskAnalysisID	ID of the hazard dependency	serial	1,2,5,8,…
riskDisplayName	Risk analysis name defined by users	Character varying	Risk computation
objective	Objective of the risk analysis	Character varying	Analyze
unitID_fk	ID of the unit layer name	integer	1,2,3…
projectID_fk	ID of the project	integer	1,2,3…
Primary Key	riskAnalysisID		
Foreign Keys	**unitID_fk** reference the table 'unitMap'. **projectID_fk** reference the table 'project'.		

- **Hazard Dependency table in study area schema**

hazardDependency			
Description	Hazard dependency for multiple hazard risk analysis		
Attribute	**Description**	**Type**	*Examples of values*

hazDepID	ID of the hazard dependency	serial	1,2,5,8,…
riskAnalysisID_fk	ID of the risk analysis	integer	1,2,3…
hazType_fk	ID of hazard type	integer	1,2,3…
groupNumber	Group Identifier	integer	1,2,3…
Primary Key	hazDepID		
Foreign Keys	**riskAnalysisID_fk** reference the table 'riskAnalysis'. **hazType_fk** reference the table 'hazardType'.		

- **Selected Node table in study area schema**

selectedNode			
Description	The table contains the selected combination of scenario, future year and alternative		
Attribute	**Description**	**Type**	***Examples of values***
nodeID	ID of the selected combination of scenario, future year and alternative	serial	1,2,3, …
scenarioID_fk	ID of the scenario	integer	1,2,3…
futYear_fk	ID of future year	integer	1,2,3…
altID_fk	ID of alternative	integer	1,2,3…
riskAnalysisID_fk	Id of risk analysis	integer	1,2,3…
Primary Key	**nodeID**		
Foreign Keys	**riskAnalysisID_fk** reference the table 'riskAnalysisID'. **scenarioID_fk** reference the table 'scenario'. **altID_fk** reference the table 'alternative'. **futYearID_fk** reference the table 'futureYear'.		

- **Selected Hazard and EaR table in study area schema**

selectedHazEARComb			
Description	The table contains the selected combination of hazard and EaR in risk analysis		
Attribute	**Description**	**Type**	***Examples of values***
hazEARCombID	ID of the selected hazard and EaR	serial	1,2,3, …
nodeID_fk	ID of the selected combination of scenario, future year and alternative	integer	1,2,3…
hazType_fk	ID of hazard type	integer	1,2,3…
earType_fk	ID of ear type	integer	1,2,3…
isTotal	If it is to compute risk considering total hazard and total EaR	integer	1
Primary Key	**hazEARCombID**		
Foreign Keys	**nodeID_fk** reference the table 'selectedNode'. **hazType_fk** reference the table 'hazardType'. **earType_fk** reference the table 'earType.		

- **Risk Per Unit table in study area schema**

riskPerUnit			
Description	The table contains the risk value in units		
Attribute	**Description**	**Type**	***Examples of values***
riskPerUnitID	ID of the risk per unit	serial	1,2,3, …
riskAAL	Annualized risk value	double	235.22
riskPerStudyAreaID_fk	ID of risk in the whole study area	double	356.12

Primary Key	**riskPerUnitID**
Foreign Keys	**riskPerStudyAreaID_fk** reference the table 'riskPerStudyArea'.

- **Risk Per Study Area table in study area schema**

riskPerStudyArea			
Description	The table contains the risk value in the whole study area		
Attribute	**Description**	**Type**	*Examples of values*
riskPerStudyAreaID	ID of the risk in the whole study area	serial	1,2,3, …
riskAAL	Annualized risk value in the whole study area	double	235.22
Primary Key	**riskPerStudyAreaID**		

5.4. Codes

The table below shows the name of the file or folder which contains the codes of the functions in risk analysis module.

	View (UI design)	**Controller (action)**	**Python(server)**
Loss computation	**/app/view/loss**	**/app/controller/loss**	**/python/loss**
Load loss combination	/lossUI.js	/lossCal.js	/load_loss_combination.py
Compute loss	/lossUI.js	/lossCal.js	/compute_loss.py, loss_building.txt,loss_landparcel.txt,loss_line.txt
Delete loss data	/lossUI.js	/lossCal.js	/deleteLossMap.py
Risk computation	**/app/view/risk**	**/app/controller/risk**	**/python/risk**
Create Risk Analysis	/RiskAnalysisManager.js, RiskUI.js	/RiskCal.js	/CreateRiskAnalysis.py
Delete Risk Analysis	/RiskAnalysisManager.js	/RiskCal.js	/DeleteRiskAnalysis.py

Edit Risk Analysis	/EditRiskUI.js	/RiskCal.js	/EditRiskAnalysis.py
Compute Risk	/GroupHazdUI.js, RiskUI_Dash.js, RiskUI_Matrix.js,	/RiskCal.js	/compute_risk.py, aggregate_loss.txt
Visualize Risk curve and AAL value	/RiskVisualUInew.js, RiskVisualCurve.js	/RiskCal.js	/loadRiskCurve.py, load_riskAALForWholeArea.py

6. Cost Benefit Analysis Module

The Cost & benefit analysis (CBA) is a popular tool to conduct assessment of investments in the public and private sector with the objective to compare the incurred costs and resulting benefits by using a defined metric and taking into account the value from now and the future. Most popular metrics are the Net Present Value(NPV), Benefit-Cost Ratio(BCR) and the Internal Rate of Return(IRR).

6.1. CBA calculation methods

The used method in question is a financial quantitatively Cost & Benefit Analysis. Only monetary losses are taken into account, the main benefits are the avoided losses by the implementation of a risk reduction alternative. To estimate the benefits, the annualized average losses (AAL) for both are required, namely, the current situation without risk mitigation and the AAL for the situation in which we have risk mitigation in place for all reference years defined for each scenario of change. For example:

$$\textbf{Benefits}_{2015-2024} = R_{current}(SC_0)_{2015} - R_{Alternative}(SC_0)_{2015}$$

$$\textbf{Benefits}_{2025-2039} = R_{current}(SC_0)_{2025} - R_{Alternative}(SC_0)_{2025}$$

$$\textbf{Benefits}_{2040-2049} = R_{current}(SC_0)_{2040} - R_{Alternative}(SC_0)_{2040}$$

Where:

$R_{current}(SC_i)_t$ = Annualized risk without mitigation in scenario i for reference year t.

$R_{Alternative}(SC_i)_t$ = Annualized risk with mitigation alternative in scenario i for reference year t.

Start year of the analysis: 2015

Reference years: 2015, 2025, 2040 and 2050

Three cost benefit metrics are involved in the RiskChanges system: NPV, BCR and IRR.

- **Net Present Value (NPV)** takes the net benefit (benefit minus costs) each year and discounts these to their present day value. If the result is greater than zero, this indicates that the benefits outweigh the costs. The higher the value, the greater the financial argument for initiating the project.

$$NPV = \sum_{i=1}^{i=n} \frac{B_i - C_i}{(1+r)^i}$$

Where:

Bi is the benefit in ith reference year

Ci =Cost value in ith reference year

n=the number of reference years

r=the interest rate user input

- **Benefit-Cost Ratio (BCR)** indicates how much benefit will accrue for every $1 of cost. A BCR greater than 1 indicates that the project is worth investing in from a financial perspective

$$BCR = \frac{\sum_{i=1}^{i=n} \frac{B_i}{(1+r)^i}}{\sum_{i=1}^{i=n} \frac{C_i}{(1+r)^i}}$$

Where:

Bi is the benefit in ith reference year

Ci =Cost value in ith reference year

n=the number of reference years

r=the interest rate user input

- **Internal Rate of Return (IRR)** is often used when determining economic efficiency, and is expressed as a percentage. If the IRR is bigger than the interest rate user defined, then is good to go ahead with the project

$$\sum_{i=1}^{i=n} \frac{B_i - C_i}{(1+r)^i} = 0$$

Where:

Bi is the benefit in ith reference year

Ci =Cost value in ith reference year

n=the number of reference years

r=IRR

6.2. Data model

The Entity Relationship diagram (Fig 6.1) illustrates the physical data model of the cost benefit analysis module within the system, followed by a list of table schema where more detailed description is provided.

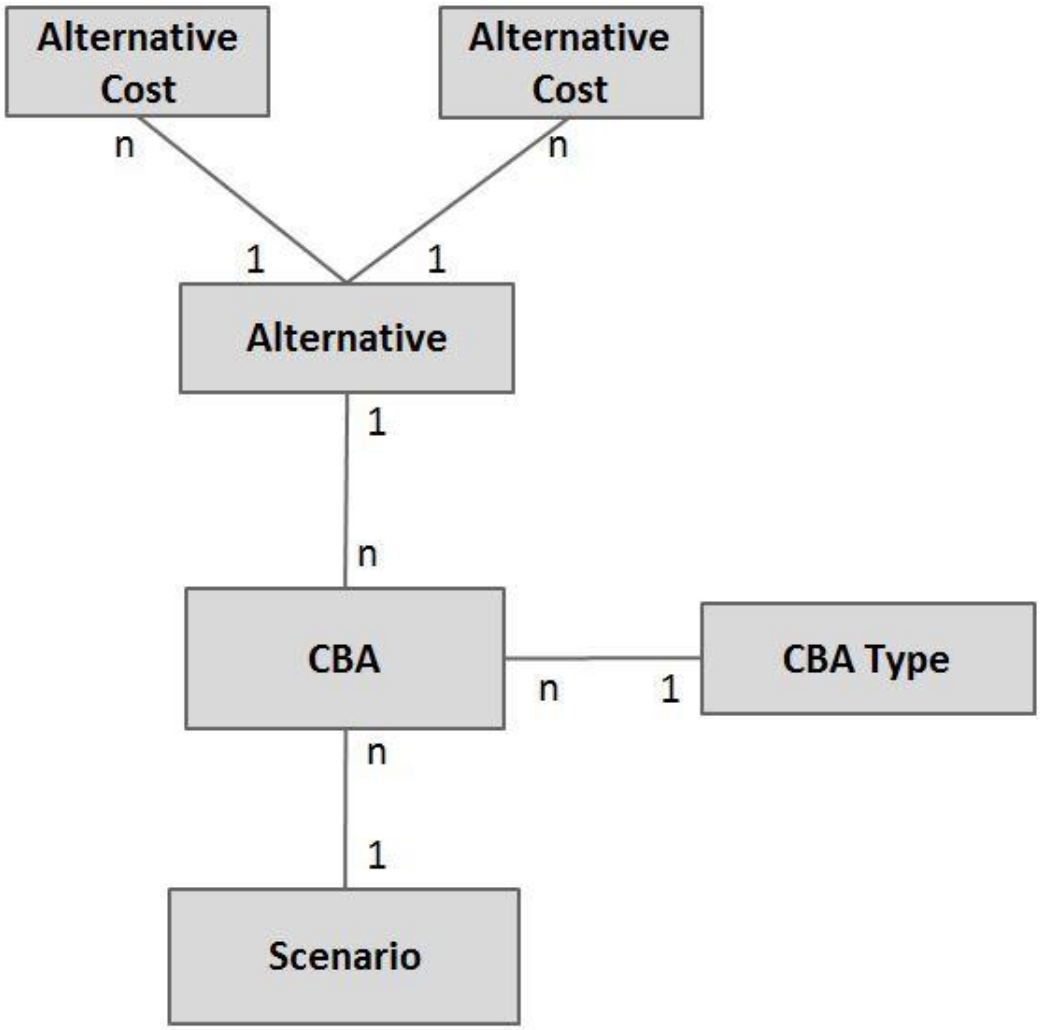


Figure 6.1: Entity Relationship graph of Cost-Benefit Analysis Module

- **CBA table in study area schema**

cba			
Description	CBA analysis		
Attribute	**Description**	**Type**	***Examples of values***
cbaID	ID of the CBA	Integer	1,2,3,..
discountRate	Interest/Discounting Rate	Real	0.10, 0.05,…

projectID_fk	Project ID	Integer	1,2,3,..
name	Cost benefit analysis name defined by users	Character varying	CBA01
PeriodAnalysisStart	Start Year of the Investment	Integer	2014
periodNumberYears	Lifetime of the measurement	Integer	3
Purpose	Purpose of the CBA	Character varying	This benefit cost analysis is for management…
Perspective	The perspective of CBA	Character varying	The perspective of this benefit cost analysis is for….
goal	The goal of CBA	Character varying	The goal of this benefit cost analysis is ….
cbaType_fk	Type of the CBA	Integer	1,2,3, …
RiskAnalysisID	The ID of risk analysis user created	integer	1,2,3, …
SelectedAlternativeID	The ID of the alternative for CBA	Integer	1,2,3, …
SelectedScenarioID	The ID of the scenario for CBA	integer	1,2,3, …

Primary Key	**cbaID**
Foreign Keys	**cbaType_fk** references the table 'cbaType'. **RiskAnalysisID** references the table 'riskAnalysis'. **SelectedAlternativeID** references the table 'alternative'. **SelectedScenarioID** references the table 'scenario'.

- **CBA Type table in study area schema**

cbaType			
Description	Contains the types of the CBA, such as backward-looking or forward-looking.		
Attribute	**Description**	**Type**	*Examples of values*
cbaTypeID	ID of cbaType	Integer	1,2,4,..
cbaType	Defines the type of the CBA	Integer	backward-looking, forward-looking
description	Additional description about each CBA type	Character varying	Forward-looking is a CBA procedure that…
Primary Key	**cbaTypeID**		

- **Alternative Cost table in study area schema**

AlternativeCost			
Description	Contains the costs related to the Risk Reduction Alternative.		
Attribute	**Description**	**Type**	*Examples of values*

altCostID	ID of the alternative cost	serial	1,2,3, …
AltID_fk	ID of alternative	integer	1,2,3, …
CostStubType	Cost type	Character varying	maintance
Recurrent	Whether it is recurrent	Character Varying	R, F
CostDescription	Description for the cost	Character Varying	Cost for maintenance, labour etc…
StartYear	The start year of the alternative	Integer	2015
EndYear	The end year of the alternative	Integer	2025
Qty	quantity	integer	1,2,3, …
UnitCost	The cost value	Double	2003.23…
Primary Key	**altCostID**		
Foreign Keys	**AltID_fk** references the table 'alternative'.		

- **Alternative Benefit table in study area schema**

AlternativeBenefit			
Description	Contains the benefits related to the Risk Reduction Alternative.		
Attribute	**Description**	**Type**	***Examples of values***
altBenID	ID of the alternative benefit	Integer	1,2,3,…

AltID_fk	ID of alternative	integer	1,2,3, …
StartYear	The start year of the alternative	Integer	2015
EndYear	The end year of the alternative	Integer	2025
YearlyAmount	The benefit amount per year	double	10032.33,…..
Description	Alternative benefit description	Character Varying	This alternative start to benefit from….
Recurrent	Whether it is recurrent	Character Varying	R, F
Primary Key	**altBenID**		
Foreign Keys	**AltID_fk** references the table 'alternative'.		

6.3. Codes

The table below shows the name of the file or folder which contains the codes of the functions in cost benefit analysis module.

	View (UI design) **(/app/view/cba)**	**Controller (action)** **(/app/controller/cba)**	**Python(server)** **(/python/cba)**
Create Cost Benefit Analysis	/AddCbaItemVIew.js	/CBAManagerCtrl.js,CBA AddItemCtrl.js, CBACtrl.js	/insertCBA.py
Delete Cost Benefit Analysis	/CbaManagerView.js	/CBAManagerCtrl.js	/delCBA.py
Edit Cost Benefit Analysis	/CostBenefitMatrixV iew.js	/CBAManagerCtrl.js, CBACtrl.js	/getCBAItems.py, updateCBA.py
Save Cost Benefit	/CbaSaveView.js	/CBAMatrix.js,	/insertCBA.py

metrics result		CbaSaveViewCtrl.js	
Visualize Cost-Benefit Result	/CostBenefitMatrixVisualizationView.js	/CBAVisualizationCtrl.js	/getDataVisualization.py

7. Multiple Criteria Decision Making Module

Multiple Criteria Decision Making (MCDM) in the 'RiskChanges' system is to priority alternatives for risk reduction planning based on risk reduction, criteria and weights. It starts with an intelligence phase for recognition of the decision problems and identifying the objectives. Development of the alternatives and assigning the variable by decision makers to each alternative are employed to the design phase. Final phase evaluates the optimal choice by comparing the alternatives, defining indicators, assigning a weight to each and ranking them. Fig. 7.1 shows the flowchart of MCDM module and the input and the output in the system. The results of Cost Benefit Analysis and Risk Analysis under different scenarios for different future years will be automatically added to the indicator matrix for Multi-Criteria evaluation and comparison.

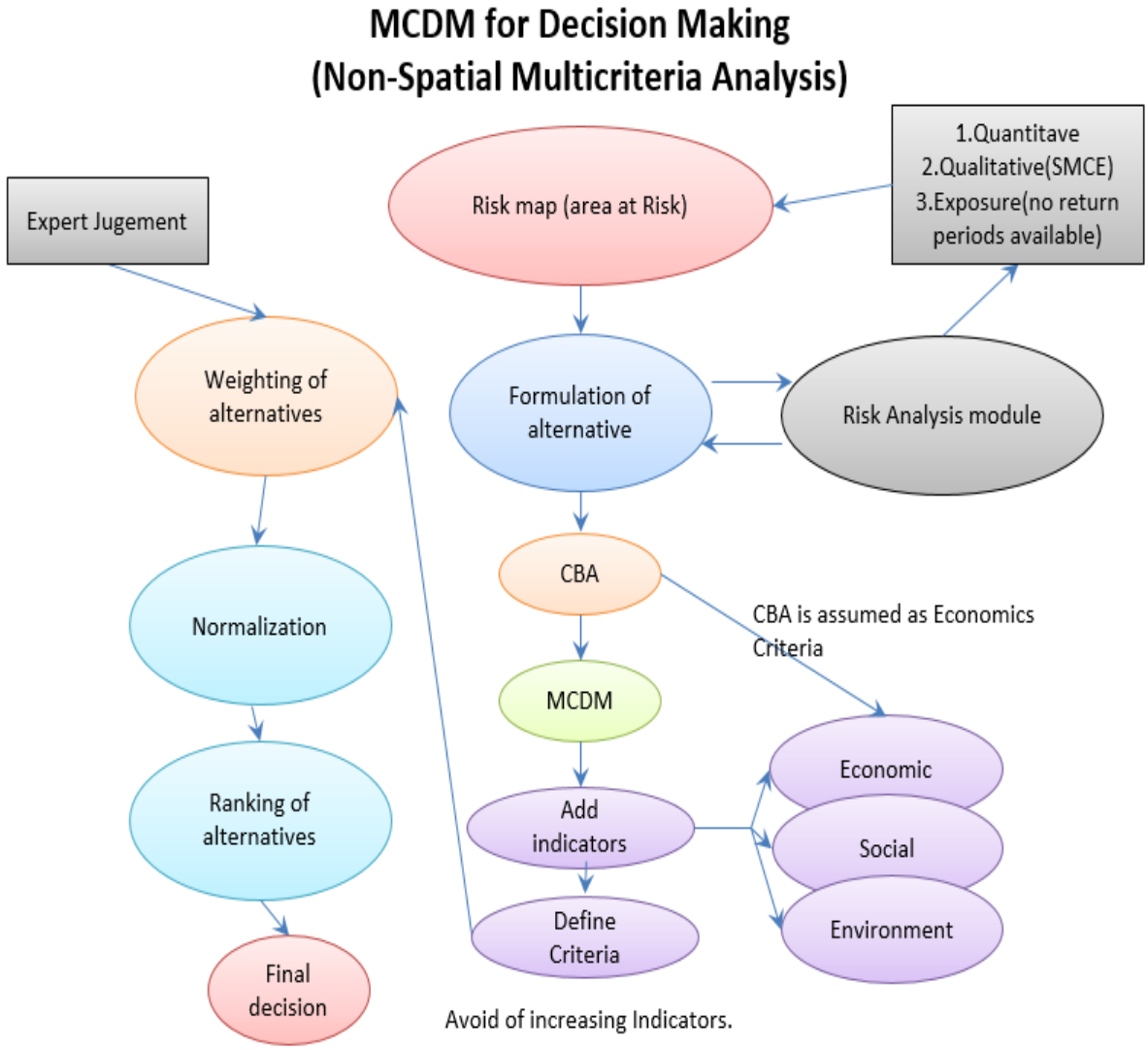


Figure 7.1: Flow chart of MCDM module in the 'RiskChanges' system

7.1. MCDM calculation methods

The multi-criteria evaluation component can only be carried out after the definition of alternatives. The idea is that a decision matrix (shown in table 7.1) is created in which the different alternative appear on the column title. The Indicators (or Criteria) are separated into:

- Cost related indicators: all indicators that make it difficult to implement the risk reduction alternative. These can also be called the disadvantages
- Benefit related indicators: all indicators that make it favourable to implement the risk reduction alternatives.

The stakeholders can prioritize each of the indicators by using ranking or rating method which the users give weights to the indicators here. The system will then show the total score and give a priority on the alternatives.

Table 7.1: Decision Matrix for Multi-Criteria Evaluation included indicators, Weight and Alternatives

		Indicators		**Alternatives**		
		Indicators	**Weight**	**1 (click to view)**	**2(click to view)**	**3(click to view)**
Costs disadvantages	Factual	Construction cost in monetary values		3000000	5000000	10000000
		Maintenance costs, yearly		30000	50000	150000
		Implementation time		5	2	8
	Perception	Resistance by population		low	mod	high
		Political support		high	mod	low
		……				
		……				
		……				
Benefits Advantage	Factual	Risk reduction in monetary value		100000	400000	600000
		Risk reduction : in		150	300	250

		people killed				
		Risk reduction : in people injured		600	800	900
		Internal Rate of Return		+	++	-
		Remaining number of exposed buildings				
		Remaining number of exposed people				
	Perception	Safety		mod	high	high
		Environmental effects		mod	low	high
		Economic opportunities		mod	mod	high
		…….				
Final score						
Priority				3	1	2

7.2. Data Model

The Entity Relationship diagram (**Fig 7.2**) illustrates the physical data model of the multiple criteria decision making module within the system, followed by a list of table schema where more detailed description is provided.

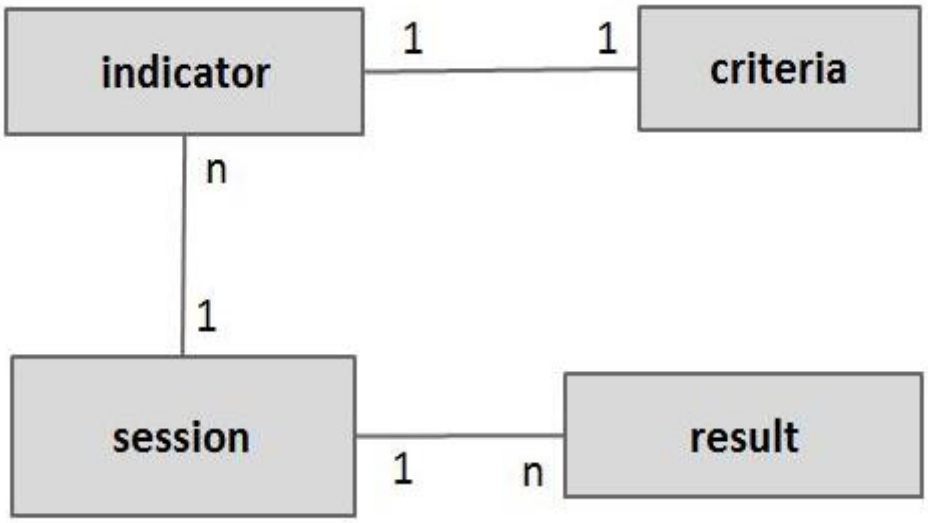


Figure 7.2: Entity Relationship graph of Cost-Benefit Analysis Module

- **Session table in schema 'public' in database 'MCDM'**

session			
Description	Decision session		
Attribute	**Description**	**Type**	*Examples of values*
sessionid	ID of the decision session	serial	1,2,3,..
studyareaid	ID of the study area	Integer	1,2,3,..
projectid	Project ID	Integer	1,2,3,..
sessionname	Decision session name defined by users	Character varying	Decision test
goal	The goal of the decision session	Character varying	The goal of the decision session is to …
authorname	The name of the person who create the session	Character varying	Jhon
Primary Key	**sessionid**		

- **Indicators table in schema 'public' in database 'MCDM'**

indicators			
Description	Indicators in a decision session		
Attribute	**Description**	**Type**	*Examples of values*
indicatorid	ID of the indicator	serial	1,2,3,..
studyareaid	ID of the study area	Integer	1,2,3,..

projectid	Project ID	Integer	1,2,3,..
riskid	The ID of the risk analysis used for this decision making	Integer	1,2,3,..
typeindicator	The type of the indicator, benefit or cost	Character varying	Benefit, cost
scaleindicator	The scale of the indicator	Character varying	Ratio, qualification…
groupindicator	The indicator group, system produced or user defined	Character varying	System, user
subgroup	the sub group	Character varying	Risk, cost, public, social,…
source	The source of the indicator	Character varying	ITC institute
indicatorname	The name of the indicator	Character varying	Economic_risk
sessionid	The ID of the session	Integer	1,2,3,..
Primary Key	**indicatorid**		
Foreign Keys	**sessionid** references the table 'session'.		

- **Indicator value table in schema 'public' in database 'MCDM'**

sesindalt			
Description	Indicator values		
Attribute	**Description**	**Type**	*Examples of values*
sesindalt	ID of the indicator value	serial	1,2,3,..
altid	ID of the alternative	Integer	1,2,3,..
senarioid	The ID of the scenario	Integer	1,2,3,..
futureyearid	The ID of future year	Integer	1,2,3,..
indicatorid	The ID of the indicator	Integer	1,2,3,..
value	The indicator value	numeric	36.34,…
valuestd	The indicator standard deviation value	numeric	0.02,…
Primary Key	**sesindalt**		
Foreign Keys	**indicatorid** references the table 'indicators'.		

- **criteria table in schema 'public' in database 'MCDM'**

criteria			
Description	criteria		
Attribute	**Description**	**Type**	*Examples of values*

criteriaid	ID of the criteria	serial	1,2,3,..
indicatorid	ID of the decision session	Integer	1,2,3,..
sessionid	ID of the session	Integer	1,2,3,..
minimum	The minimum value of the same indicators among all the alternatives	Double	13.56,…
maximum	The maximum value of the same indicators among all the alternatives	Double	35.23,…
valuefunction	The function used to standardize indicator values	Character varying	Maximum Standardization
weight	The indicator standard deviation value	numeric	0.02,…
weight	The weight value defined by users	numeric	0.3,…
rankweight	The rank of criteria defined by users	numeric	1,2,3,…
weightnor	The normalized weight value based users'input	numeric	0.1,0.3,…

Primary Key	**criteriaid**
Foreign Keys	**sessionid** references the table 'session'. **indicatorid** references the table 'indicators'.

- **result table in schema 'public' in database 'MCDM'**

result			
Description	Containing the results of decision making		
Attribute	**Description**	**Type**	*Examples of values*
resultid	ID of the result	serial	1,2,3,..
altid	ID of the alternative	Integer	1,2,3,..
sessionid	ID of the session	Integer	1,2,3,..
results	The result value	double	0.53,..
Primary Key	**sesindalt**		
Foreign Keys	**sessionid** references the table 'session'.		

7.3. Codes

The table below shows the name of the file or folder which contains the codes of the functions in multiple criteria decision making module.

	View (UI design) **(/app/view/decision)**	**Controller (action)** **(/app/controller/decision)**	**Python(server)** **(/php/decision)**
Create/Delete decision Session	/AddSession.js, NewSession.js	/NewSession.js	/addSession.php, delSession.php
Add / Remove /Edit Indicator	/ AddCritera.js, DefineCriteria.js	/DefineCriterias.js	/addCriteria.php, defineCriteria.php,

			delCriteria.php, editCriteria.php
Criteria Definition (Standardization)	/StandardCriteria.js	/MCDMDashBoard.js	/standardView.php, addStandard.php
Weight Indicator	/PrioritizeCriteria.js	/ PrioritizeCriteria.js	/editWeight.php
Compare and Visualize	/ViewRank.js, CompResult.js	/ViewRank.js	/addResults.php,

8. Visualization Module

"RiskChanges" Visualization Module is a combination of methods and techniques, which enables the end-users querying, visualizing and comparing the risk-related data within the SDSS. The visualization techniques implemented so far offer data filtering, interactive map navigation, querying and comparison tools. The map comparison tools are of great importance within the SDSS and include the following: swiping tool for comparison of different data of the same location, linked views for comparison of data from different locations and a time slider tool for monitoring changes in spatio-temporal data. All these techniques are part of the interactive interface of the system and make use of spatial and spatio-temporal data.

8.1. Publishing layers to Geoserver

- **create workspace and store**

When a new study area is created by the user, a workspace and a store with the same name of the study area will be automatically created in Geoserver using the pycurl libraries. A piece of the codes are pasted below.

Table 8.1: Python codes to create a workspace in Geoserver

```
        """
    create a workspace in geoserver
    Input parameters: specify the workspace name you want to be created, geoserver connection parameters: Geoserver user name, password and URL, workspace name
    """
        c=pycurl.Curl();
       //workspace xml
        workspace_xml="<workspace><name>{0}</name></workspace>".format(workspace_name)
        //connect with the geoserver using the user name and password
       c.setopt(pycurl.USERPWD, geoserver_user + ':' + geoserver_password)
        c.setopt(c.URL, '{0}/rest/workspaces'.format(geoserver_url))
        c.setopt(pycurl.HTTPHEADER, ["Content-type: text/xml"])
        c.setopt(pycurl.POSTFIELDSIZE, len(workspace_xml))
        c.setopt(pycurl.READFUNCTION,DataProvider(workspace_xml).read_cb)
        c.setopt(pycurl.POST, 1)
        c.perform()
```

Table 8.2: Python codes to create a postGIS store in Geoserver

```
    """
    create a postgis store in geoserver
    Input parameters: specify the store name you want to be created, the postgis database parameters including host, port, database name, schema, user and password,
    geoserver connection parameters: Geoserver user name, password and URL, workspace name
    """
        c = pycurl.Curl()
      #connect with geoserver
      c.setopt(pycurl.USERPWD, geoserver_user + ':' + geoserver_password)
      c.setopt(c.URL, '{0}/rest/workspaces/{1}/datastores'.format(geoserver_url, workspace_name))
      c.setopt(pycurl.HTTPHEADER, ["Content-type: text/xml"])

      #make the connection with postgis database
      database_connection='<dataStore>'\
      '<name>{0}</name>'\
      '<connectionParameters>'\
      '<host>{1}</host>'\
      '<port>{2}</port>'\
      '<database>{3}</database>'\
      '<schema>{4}</schema>'\
      '<user>{5}</user>'\
      '<passwd>{6}</passwd>'\
      '<dbtype>postgis</dbtype>'\
      '</connectionParameters>'\
      '</dataStore>'.format(store_name,host,port,database_name,schema,postgis_user,postgis_pass);
      c.setopt(pycurl.POSTFIELDSIZE, len(database_connection))
      c.setopt(pycurl.READFUNCTION,DataProvider(database_connection).read_cb)
      c.setopt(pycurl.POST, 1)
      c.perform()
```

- **publishing postGIS table to Geoserver**

When an EaR layer is uploaded in the database, or a loss / risk map is computed and generated as a view in the database, these layers will be automatically published to the store with the same name of the study area. Codes are listed in Table 8.3.

Table 8.3: Python codes to publish a postGIS table in Geoserver

```
"""
   publish a table (not used for raster table) in postgis to geoserver
   input parameters: specify the name of the table in the postgis database to be published, specify the store,workspace name, and  the Geoserver user name, password and URL
   """
      c = pycurl.Curl()
      layer_xml="<featureType><name>{0}</name></featureType>".format(table_name)
      c.setopt(pycurl.USERPWD, geoserver_user + ':' + geoserver_password)
      #connecting with the specified store in geoserver
      c.setopt(c.URL,       '{0}/rest/workspaces/{1}/datastores/{2}/featuretypes'.format(geoserver_url, workspace, store_name))
      c.setopt(pycurl.HTTPHEADER, ["Content-type: text/xml"])
      c.setopt(pycurl.POSTFIELDSIZE, len(layer_xml))
      c.setopt(pycurl.READFUNCTION,DataProvider(layer_xml).read_cb)
      c.setopt(pycurl.POST, 1)
      c.perform()
```

- **publishing raster layers to Geoserver**

When a hazard raster layer is uploaded in the database, the raster layers will be automatically published to the workspace with the same name of the study area. Table 8.4 illustrates the codes for this purpose using pycurl.

Table 8.4: Python codes to publish a raster file in Geoserver

```
"""
   publishing a raster file to geoserver
   the coverage store will be created automatically as the same name as the raster layer name.
   input parameters: the parameters connecting geoserver (user,password, url and workspace name),the path to the file and file_type indicating it is a geotiff, arcgrid or other raster type
   """
      c=pycurl.Curl()
```

```
        filesize =os.path.getsize(path_to_file)
        #get the file name, to be used as the same as the layer name in Geoserver
        file_name=os.path.basename(path_to_file)
        f=file_name.split(".")
        if len(f)>0:
           file_name=f[0]
        c.setopt(pycurl.USERPWD, geoserver_user + ':' + geoserver_password)
        #transform type into lowercase,like 'ARCGRID' into 'arcgrid'
        #uppercase is not workable
        file_type=file_type.lower()
        c.setopt(c.URL,
'{0}/rest/workspaces/{1}/coveragestores/{2}/file.{3}'.format(geoserver_url,workspace,file_name,file
_type))
        c.setopt(pycurl.HTTPHEADER, ["Content-type:image/tiff" ])
        c.setopt(pycurl.READFUNCTION,FileReader(open(path_to_file, 'rb')).read_callback)
        c.setopt(pycurl.INFILESIZE,filesize)
        c.setopt(pycurl.POST, 1)
        c.setopt(pycurl.UPLOAD, 1)
        c.perform()
```

8.2. Single Map Visualization

In the visualization module, there are three kinds of single map visualization, namely, input data (Hazard and EaR), loss data and risk data. To easily find the layer users would like to visualize, a filtering/searching tool is required. The first action in the input data filtering and visualization is to select the study area, the available project, the available scenarios, future years and alternatives one by one. Afterwards, all the available hazards and EaR layer names will appear. User could choose the layer name for visualization. Similarly to the input data query and visualization, the loss data query and risk data query require the specification of several items by users. Once the layer name to be visualized is determined by users, the WMS is used to load the layer from Geoserver. The javascript codes are shown in table 8.5.

Table 8.5: Python codes to visualize a single map

```
var layerUrl = 'http://changes.itc.utwente.nl:8080/geoserver/'+work_space_name+'/wms/';
var layerConfig = {format: 'image/png'};
```

```
var layerUrlParams = {layers: name, visibility: true, isBaseLayer: false, transparent: 'true'};
//finally, create the layer
var layer = new OpenLayers.Layer.WMS(layer_name, layerUrl, layerUrlParams, switchDisplay, layerConfig);
```

8.3. Map comparison

Map comparison is composed by three different web-GIS applications: layers comparison, two maps comparison and time series animation

- **Layers comparison**

This application is composed by two map objects, each of them created by the layers selected by users. The layers selected in the left field-set correspond to the left map and the ones selected in the right field-set to the right map. The center of the second map is located at ½ window distance from the first map, giving thus the impression of overlay. By making resizable the two windows, which hold the maps, the interface can be used as a swiping tool. The codes to fulfill these purposes are in the files 'app/view/mapview/CompareMaps.js', 'app/view/mapview/CompareLossMaps.js' and 'app/view/mapview/CompareRiskMaps.js'.

- **Time series animation**

The differences in data can be detected through time animation by selecting layers in the Querying and visualization interface. The implementation is based on the generation of an animated gif image from the multiple layers in the WMS request. The codes are in the files 'app/view/mapview/Animation.js', 'app/view/mapview/LossAnimation.js' and 'app/view/mapview/RiskAnimation.js'.