Italian Ministry for the Environment and Territory

Asian Disaster Preparedness Center

RISK ASSESSMENT AND EVALUATION ArcGIS® toolbox

USER'S MANUAL

CRATER

COASTAL RISK ANALYSIS OF TSUNAMIS AND ENVIRONMENTAL REMEDIATION

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***C**OASTAL **R**ISK **A**NALYSIS OF **T**SUNAMIS AND **E**NVIRONMENTAL **R**EMEDIATION*

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1. TSUNAMI VULNERABILITY AND RISK ANALYSIS

1.1 Introduction

The tsunami event occurred on 26th December 2004 in South Eastern Asia caused more than 200.000 casualties along the coasts of Indonesia, Thailand, Malaysia, India, Sri Lanka and other countries facing the Indian Ocean.

Tsunami was initiated by an extremely high magnitude earthquake (9.3 on the Richter scale) localized a few kilometers eastward of the Sumatra coasts, along the subductive system characterized by the Sunda Arc.

Because of the presence of this active tectonic margin a new Tsunami event can not be excluded in the future.

In order to better face any future occurrence of Tsunamis, the SAVE module of the CRATER project focuses on the risk analysis method.

In the last years a number of International and National associations, such as UNDP (United Nations Development Program), NOAA (National Oceanic and Atmospheric Administration, U.S.) and FEMA (Federal Emergency Management Agency, U.S.) suggested guidelines for extreme natural events risk analysis. CRATER project started from these guidelines and from data gathered after the Tsunami of 26th December 2004. One of the main aims of the CRATER project was to create a complete tool for Tsunami risk analysis in coastal areas.

A risk to a natural event is defined as the mathematical product between vulnerability and hazard; it refers to the expected loss from a given hazard to a given element at risk.

Vulnerability is defined as the potential for damage while hazard, for a Tsunami event, is defined as the wave height.

Risk management is a two parts process involving risk assessment and risk evaluation.

Risk assessment is mainly a scientific and quantitative exercise out coming from analysis of field and-or experimental data (e.g. modeled tsunami wave height) and from an overall understanding of the nature of the hazard and of vulnerable parameters (UNDP, 1994).

Risk evaluation joins perceived risk to a more enlarged qualitative analysis including, for example, cost benefit trade off and socio economic impact.

Main vulnerable parameters -in the case of a Tsunami event- are: population, built environment, infrastructures, ecosystem and environment.

Understanding vulnerability and hazard level, identification of possible mitigation measures, of the socio-economic impact caused by the event and the cost-benefit trade off they all give information needed to evaluate the level of risk. Decision makers and end users such as local authorities, NGO, disaster and prevention officers will be able to decide the level of risk and plan which protection level is needed to put in place proposed mitigation measures.

2. VULNERABILITY LEVEL

Vulnerability parameters identifies for the study are:

- **population**
- **built environment**
- **socio-economic aspects**
- **environment**

For each of these parameters a list of *impact elements* have been made. Impact elements are those characteristics of the parameter considered that could be mostly affected by the tsunami wave. Summation of the impact elements defines the vulnerability of a chosen parameter.

For example, in the case of built environment the impacts elements are:

- building material “m”
- description of ground floor “g”
- number of stories “s”
- design “d”
- foundations “f”

For every building we assigned a numeric value to each impact elements.

These values are integer numbers ranging between 1 and 5, where 5 stands for the maximum contribution given by the impact element to the total building vulnerability. A building made of concrete will have a low value of “m”, for example m=1, because it is supposed to be more resistant to the Tsunami wave. If the building material is wood the value of “m” will be higher, for example m=5. As for the impacts elements, a level of vulnerability ranging between 1 and 5 has been chosen for each vulnerable parameter.

Vulnerability level is given by:

$$V(a, A) = S_i (w_i \cdot e_i) \qquad \text{for } i = 1, n \qquad (1)$$

Where:

V (a, A) = vulnerability level of the element *a* (e.g. a given building), belonging to the vulnerability parameter A (e.g. the built environment).

$\mathbf{w}_i$ = weighting coefficient

$\mathbf{e}_i$ = vectorial value estimated for the impact element

n= total number of impact elements related to the parameter A.

2.1 Multi-criteria analysis

Multi-criteria analysis is a decision making process. CRATER team experts have optimized this technique and applied it for the first time to a vulnerability problem.

Outcome of the multi-criteria analysis are the weighting coefficients w_i of the relation (1).

The practical example given below, in which multi-criteria analysis is applied to the “built environment” vulnerable parameter, would help the understanding of this process.

First step: to identify the impact elements that need to be weighted:

Impact elements:

- Building material (m)
- Description of ground floor (g)
- Number of stories (s)

- Design (d)
- Foundations (f)

Second step: identify the weighting criteria:

Weighting Criteria:

- Structural damage
- Damage given to flooding

Weighting criteria are identifying the type of damage the parameter would be subject to.

Third step is a pair wise comparison between weighting criteria.

	Structural damage	Damage given to flooding	Fictitious factor	Total	**Weight (= Total/3)**
Structural damage	\	1	1	2	**0.667**
Damage given to flooding	0	\	1	1	**0.333**
Fictitious factor	0	0	\	0	**0**

In the matrix above the weighting criteria have been compared with pair wise matches. Introduction of a so called *fictitious factor* is needed for obvious calculation reasons.

From the above table is clear that in this case a structural damage has more weight than the damage given to flooding.

Impact elements are valued among themselves in respect to a single weighting criterion. This should give a ranking level of impact element in respect to a given weighting criterion.

First table below is relative to the structural damage criterion, second one to the damage given to flooding.

Structural damage	m	G	s	f	D	Fictitious factor	Total	Relative weight = Total/ 15
m	\	0	1	1	1	1	4	**0.267**
G	1	\	1	1	1	1	5	**0.333**
S	0	0	\	0	0	1	1	**0.067**
F	0	0	1	\	1	1	3	**0.2**
D	0	0	1	0	\	1	2	**0.133**
Fictitious factor	0	0	0	0	0	\	0	**0**

Damage given to flooding	M	G	s	Fictitious factor	Total	Relative weight = Total/ 6
M	\	0	0	1	1	**0.167**
G	1	\	0	1	2	**0.333**
S	1	1	\	1	3	**0.5**
Fictitious factor	0	0	0	\	0	**0**

Elements d and t have not been inserted being these elements not related to flooding.

Summarizing the above results, we obtain:

	Weight of criterion	Relative weight m	Relative weight g	Relative weight s	Relative weight d	Relative weight f
Structural damage	**0.667**	0.267	0.333	0.067	0.133	0.2
Damage given to flooding	**0.333**	0.167	0.333	0.5	0	0

Total weight calculation:

		Total weight m	**Total weight g**	**Total weight s**	**Total weight d**	**Total weight f**
Structural damage		0.178	0.222	0.045	0.089	0.133
Damage given to flooding		0.056	0.111	0.166	0	0
TOTAL		**0.234**	**0.333**	**0.211**	**0.089**	**0.133**

NB. Total weight of each impact element, in respect to both criteria, is calculated as product between the criterion weight and the relative weight of the impact element considered.

Final calculation of building vulnerability will be then given by:

V(a, built environment) = 0.234 m + 0.333 g +0.211 s + 0.089 d + 0.133 f

Single values of impact elements m, g, s, d, f are ranging between 1 and 5 as previously stated.

This method could be applied to any of the other vulnerability parameters.

Once vulnerability level is calculated it will be possible to insert these values in a vulnerability map.

Next paragraph describes how to create a built environment vulnerability map using GIS software. The method shown can be applied also to all others vulnerable parameters.

2.2 TUTORIAL: Creating a “built environment” vulnerability map

In this paragraph we present a list of all the steps required to create a built environment vulnerability map of the study area using the ArcGis ArcMap 9.0 software by ESRI. The aim is to assign to each building in the pilot area a vulnerability level value, as an integer number between 1 and 5.

The CD-Rom included with the manual contains all the files needed to perform the case study simulation.

Starting Data:

1. A **geo-referenced** shape file representing all the buildings of the study area as polygons. We will call it “buildings”. This shape file for the pilot area is located in “Buildings_Vulnerability_tutorial/Shapefile”.

2. The attribute table of the “buildings” shape file must contain one field for each impact element related to the built environment. These impact elements are:

a) **Building material** -------- field name: “Build_mat”

b) **Description of ground floor** -------- field name: “g_floor”

c) **Foundations** -------- field name: “foundat”

d) **Design** -------- field name: “design”

e) **Number of stories** -------- field name: “BL_NSTOREY”

You should have data for any impact element for each building.

The five fields containing the impact elements must be filled with all these data. For example, if a building is made of concrete, the user will have to write “concrete” in the field “Build_mat”, at the line related to that building.

In the case that you miss information about any of the impact elements of a particular building you just have to write "unknown" in the relative field, at the line related to that building.

Steps required:

1. Open ArcGis ArcMap 9.0. Import all shape files in the "Building_vulnerability_tutorial/Shapefile" folder and the aerial photo located in the "Aerial_Photo" folder.

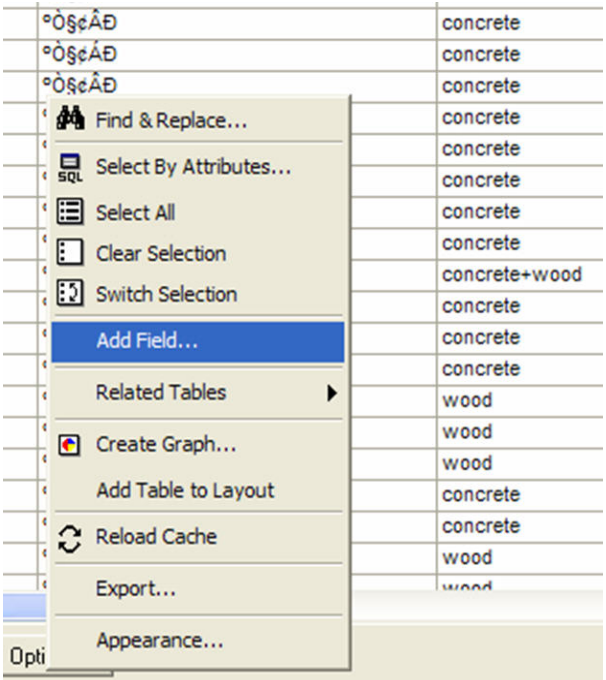
2. Create 5 new fields (short integer) in the attribute table of "buildings" shape file, one for each impact element, and call them:

- "m" for the building material
- "g" for description of ground floor
- "s" for the number of stories

- “d” for the design
- “f” for the foundations

Each of these fields must be filled with the impact elements value that will be introduced at step 3. To create a new field:

a) Open the “buildings” attribute table and click on “Options”, then choose “Add field” (**Figure 1**).



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ºÒ§¢ÂĐ
Find & Replace...
Select By Attributes...
Select All
Clear Selection
Switch Selection
Add Field...
Related Tables
Create Graph...
Add Table to Layout
Reload Cache
Export...
Appearance...
Opti
concrete
concrete
concrete
concrete
concrete
concrete
concrete
concrete
concrete+wood
concrete
concrete
concrete
wood
wood
wood
concrete
concrete
wood

Figure 1

b) In the window that appeared type “m” in the “Name” box and select “Short Integer” in the “Type” box, then click “Ok” (**Figure 2**).

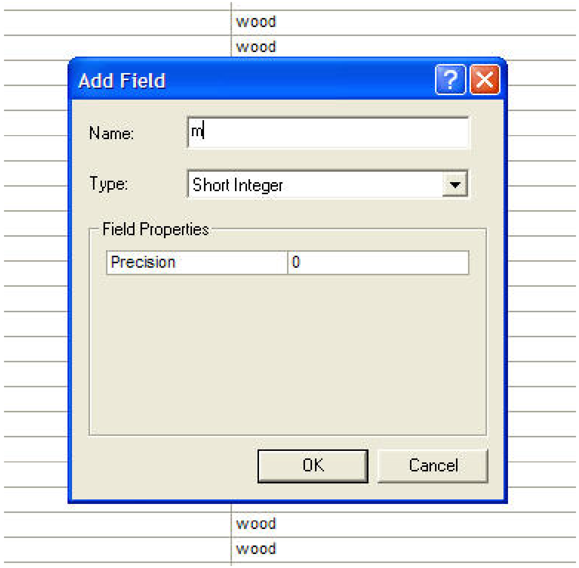


Figure 2

c) Do the same for “g”, “s”, “d”, “f”, obtaining (**Figure 3**):

Attributes of Buildings

m	s	g	f	d	design
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown
0	0	0	0	0	unknown

Figure 3

3. Choose an integer numeric value between 1 and 5 for each impact element, where 5 stands for maximum vulnerability and 1 for minimum vulnerability. For example, the impact element value for building material (that is “m”) will be 5 if the structure is made of wood (high vulnerability), 3 if it is made of bricks (mean vulnerability) and 1 if it is made of reinforced concrete (low vulnerability). Suggested impact element’s values are listed in Table 1.

IMPACT ELEMENT	Suggested impact element's value:				
	=1	**=2**	**=3**	**=4**	**=5**
m	Reinforced concrete		Bricks or wood + concrete		Wood
g	Open plan without movable objects		Open plan with movable objects		No open plan
s	5 stories	4 stories	3 stories	2 stories	1 story
f	deep pile foundations		mean foundations		surface spread foundations
d	long building side perpendicular to the coast line		long building side oblique to the coast line		long building side parallel to le coast line

Table 1

4. Put the numeric value chosen for each impact element in the relative field (“m”, “g”, “s”, “d”, “f”) following these instructions:

a) Open the attribute table of the “buildings” layer

b) Click on “Options” and then on “Select by attributes”

c) Double click on the field “build_mat”

d) Click on the symbol “=”

e) Click on the button “Get Unique Values”. A list of all the buildings materials will appear in the box on the right.

f) Double click on the first material of the list, for example “concrete” (**Figure 4**)

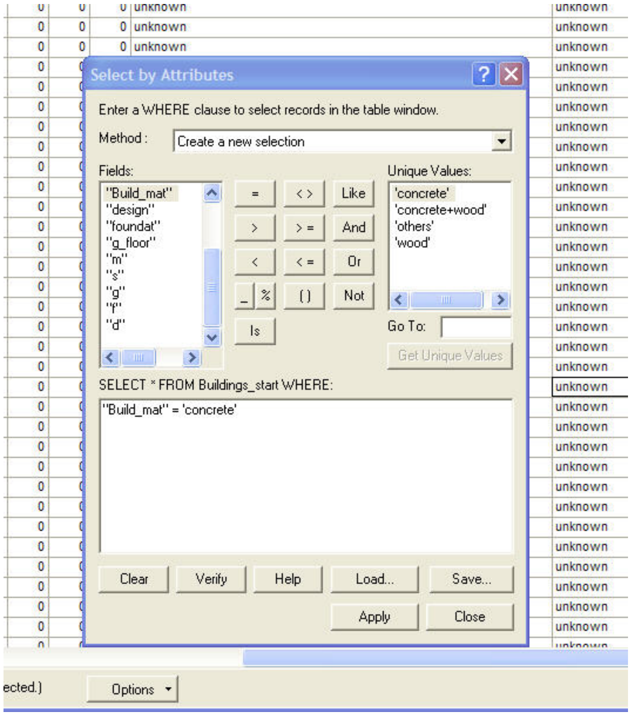


Figure 4

g) Click on “Apply”. All buildings made of concrete are now selected.

h) Close the attribute table

i) Click on the “editor” button and choose “start editing”

j) Select the “buildings” layer in the “Target” box

k) Click on the attribute button, on the left of the “Target” box (**Figure 5**). A new window called “attributes” will appear (**Figure 6**)

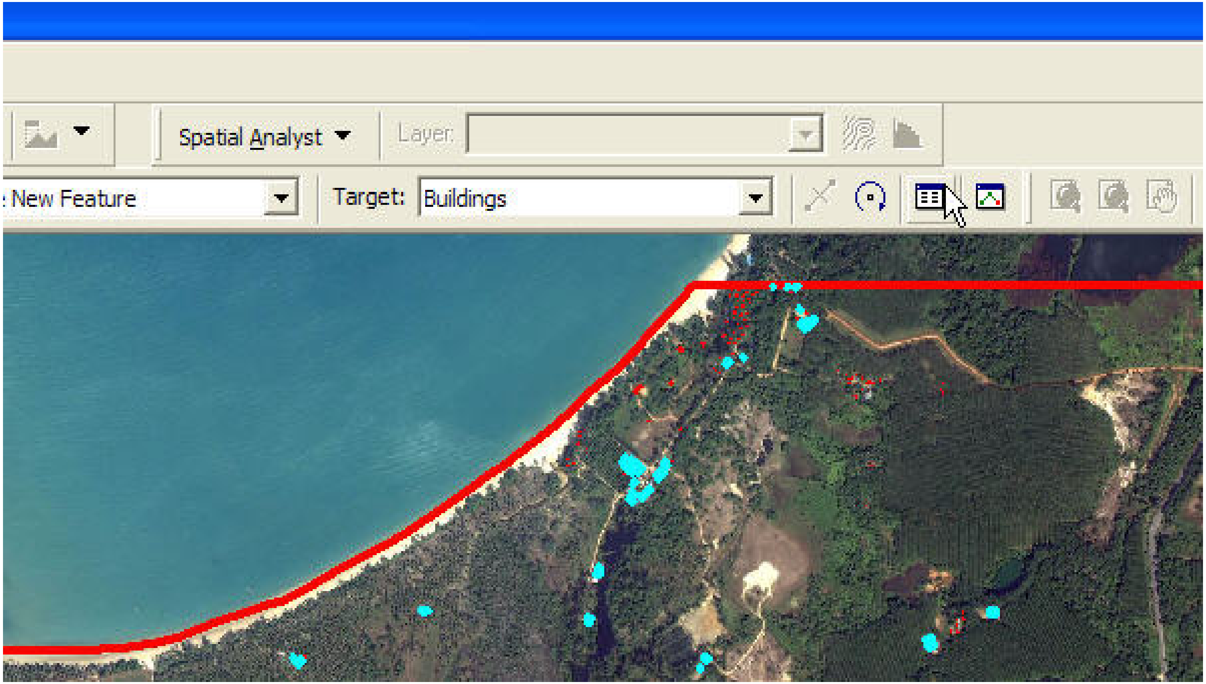
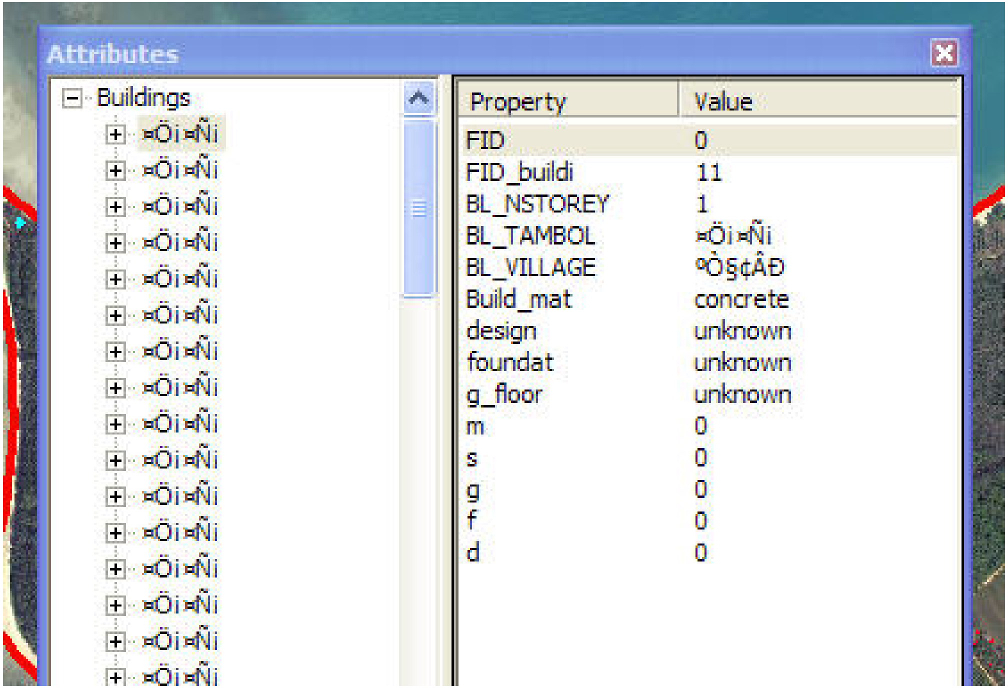


Figure 5



Attributes
Buildings
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
¤Öi¤Ñi
Property
Value
FID
0
FID_buildi
11
BL_NSTOREY
1
BL_TAMBOL
¤Öi¤Ñi
BL_VILLAGE
ºÒ§¢ÅÐ
Build_mat
concrete
design
unknown
foundat
unknown
g_floor
unknown
m
0
s
0
g
0
f
0
d
0

Figure 6

l) Double click on “buildings” group in the box on the left

m) In the box on the right, click on the “m” field in the “Property” column. The line of the “m” field will be selected.

n) Click in the “m” line you have selected, under the “Value” column

o) Type the numeric value you want to assign to the impact element “m”, for all buildings made of concrete (for example if m=1 type 1)(**Figure 7**).

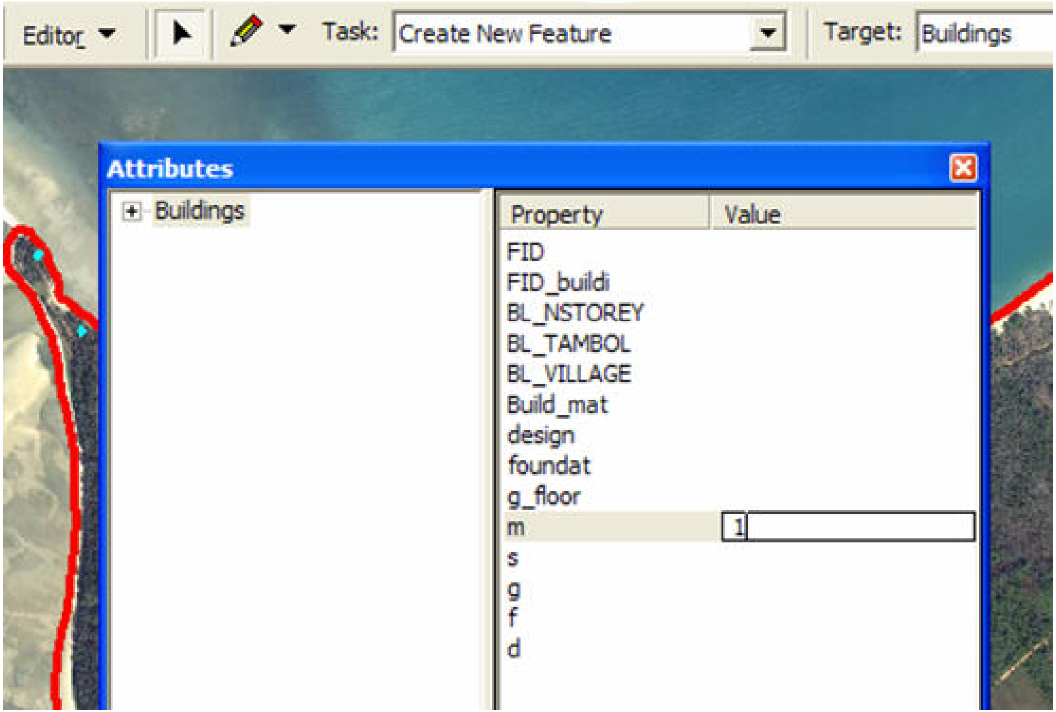

Editor
Task:
Create New Feature
Target:
Buildings
Attributes
Buildings
Property
Value
FID
FID_buildi
BL_NSTOREY
BL_TAMBOL
BL_VILLAGE
Build_mat
design
foundat
g_floor
m
1
s
g
f
d

Figure 7

p) Press enter. Now all buildings made of concrete have an impact element value equivalent to 1 (m=1).

q) Save your edits (Click on “editor” button and choose “Save Edits”)

r) Repeat all from line a), choosing the subsequent building material at line f). When all building materials have been considered it could remain only some buildings with “unkown” material: assign them the maximum impact element’s value, that is 5.

s) Repeat all changing impact element at line c). Finally you will obtain an attribute table looking like the one in **Figure 8**.

BL_NSTOREY	Build_mat	m	s	g	d	f
1	concrete	1	5	5	5	5
1	concrete	1	5	5	5	5
1	concrete	1	5	5	5	5
1	concrete	1	5	5	5	5
1	concrete+wood	3	5	5	5	5
1	concrete	1	5	5	5	5
1	concrete	1	5	5	5	5
1	concrete	1	5	5	5	5
1	concrete	1	5	5	5	5
1	concrete	1	5	5	5	5
1	concrete	1	5	5	5	5
1	concrete	1	5	5	5	5
1	concrete	1	5	5	5	5
1	concrete+wood	3	5	5	5	5
1	concrete	1	5	5	5	5
1	concrete	1	5	5	5	5
1	wood	5	5	5	5	5

Figure 8

5. Calculate the vulnerability level of every building.

a) Stop editing clicking on “Editor” and select “Stop editing”.

b) Open the “buildings” attribute table and click on “Options”, then choose “Add field”

c) In the window that appears type “BV1” in the “Name” box and select “Float” in the “Type” box. Then put both “precision” and “scale” equal to 2 (**Figure 9**). Click “Ok”.

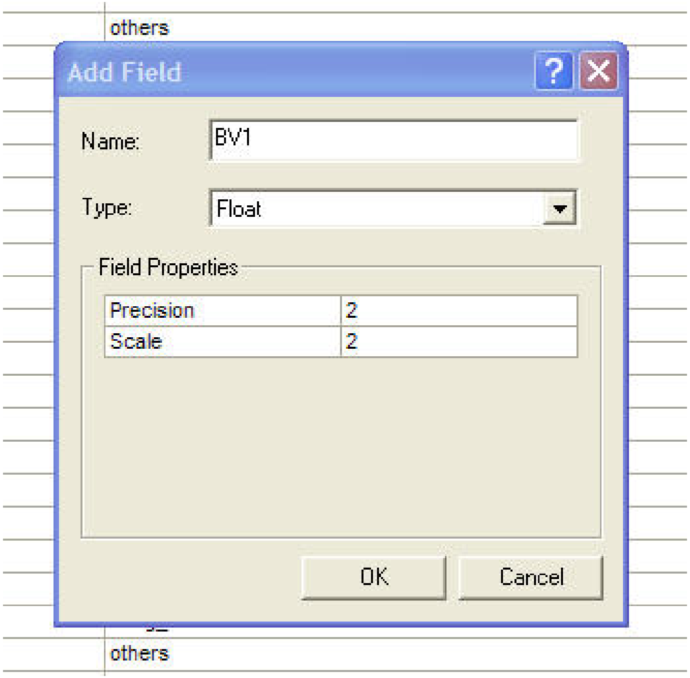

others
Add Field
Name:
BV1
Type:
Float
Field Properties
Precision
2
Scale
2
OK
Cancel
others

Figure 9

d) Restart editing

e) In the attribute table select the BV1 field clicking on the name of the field.

f) Right click on the field name BV1 in the attribute table and select “Calculate values…” (**Figure 10**)

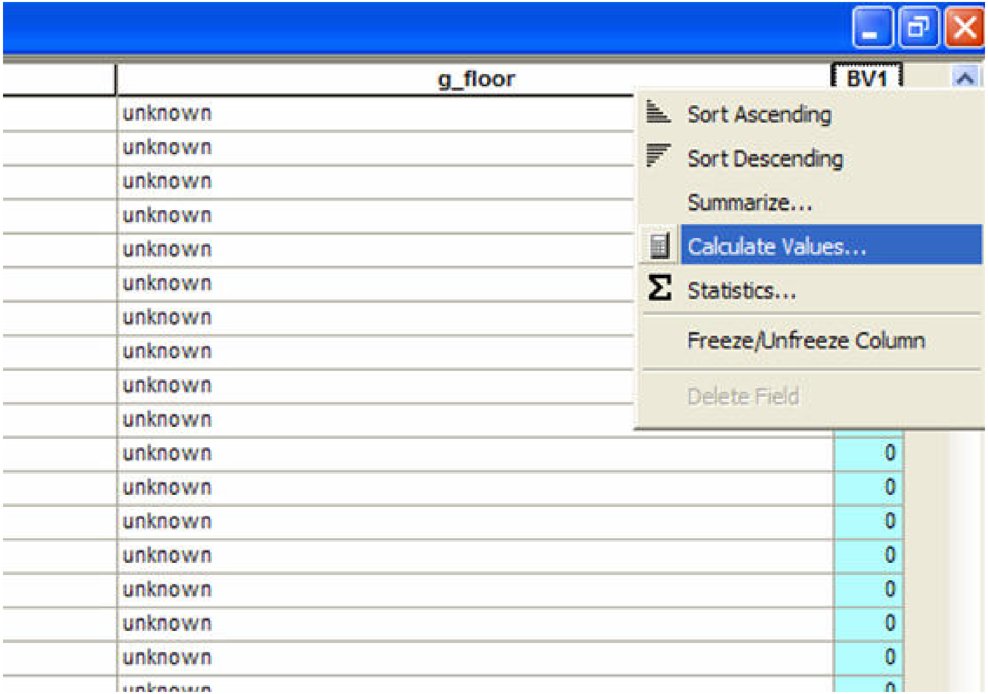

g_floor
BV1
unknown
Sort Ascending
Sort Descending
Summarize...
Calculate Values...
Statistics...
Freeze/Unfreeze Column
Delete Field
0

Figure 10

g) Insert the relation for the computation of the building vulnerability level in the box under “BV1=”. The relation is:

BV1= 0.234 m + 0.333 g +0.211 s + 0.089 d + 0.133 f

Click on m,g,s,d,f in the “Fields” box and on the mathematical operators buttons to insert them in the relation above (**Figure 11**).

This relation comes from the general vulnerability level relation, in which weighting factors have been calculated using multi-criteria analysis.

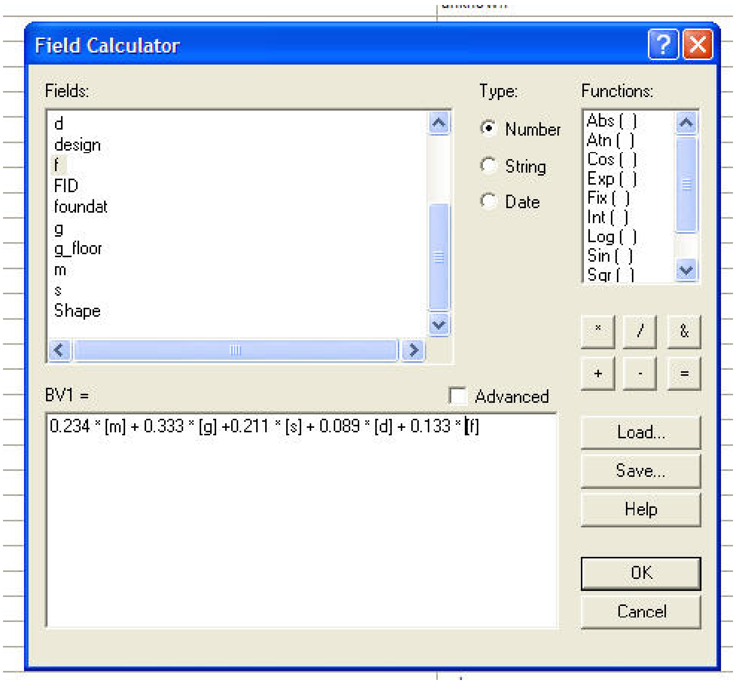

Field Calculator
Fields:
d
design
f
FID
foundat
g
g_floor
m
s
Shape
Type:
Number
String
Date
Functions:
Abs ( )
Atn ( )
Cos ( )
Exp ( )
Fix ( )
Int ( )
Log ( )
Sin ( )
Sqr ( )
BV1 =
Advanced
0.234 * [m] + 0.333 * [g] +0.211 * [s] + 0.089 * [d] + 0.133 * [f]
Load...
Save...
Help
OK
Cancel

Figure 11

f) Click “Ok”. In the field “BV1” you have calculated the vulnerability level of each building as a floating number (**Figure 12**). In order to obtain integer numbers you must approximate them all.

g_floor	BV1
unknown	4.1
unknown	4.1
unknown	4.1
unknown	4.1
unknown	4.5
unknown	4.1
unknown	4.1
unknown	4.1
unknown	4.1
unknown	4.1
unknown	4.1
unknown	4.1
unknown	4.1
unknown	4.5
unknown	4.1
unknown	4.1
unknown	5
unknown	5
unknown	5
unknown	5
unknown	4.1
unknown	5

Figure 12

g) Close the attribute table. Save your edits and stop editing

h) Open the attribute table. Add a new field called BV_MAX (short integer).

i) Select by attributes (“Options”- “Select by Attributes”) all buildings with a “BV1” value included in the [0;1] interval (BV1>0 and BV1<=1). You can do this by typing:

"BV1" >0 AND "BV1" <=1 (**Figure 13**)

Click “Apply”.

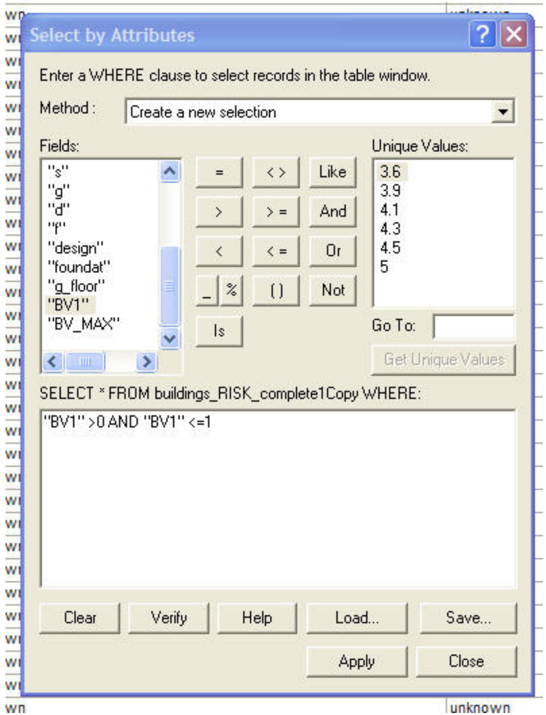

Select by Attributes
Enter a WHERE clause to select records in the table window.
Method :
Create a new selection
Fields:
"s"
"g"
"d"
"f"
"design"
"foundat"
"g_floor"
"BV1"
"BV_MAX"
=
<>
Like
>
>=
And
<
<=
Or
_
%
()
Not
Is
Unique Values:
3.6
3.9
4.1
4.3
4.5
5
Go To:
Get Unique Values
SELECT * FROM buildings_RISK_complete1Copy WHERE:
"BV1" >0 AND "BV1" <=1
Clear
Verify
Help
Load...
Save...
Apply
Close
unknown

Figure 13

j) Close the attribute table and Restart editing

k) Click on the attribute button, on the left of the "Target" box. A new window called "attributes" will appear

h) Double click on "buildings" group in the box on the left

i) In the box on the right, click on the "BV1" field in the "Property" column. The line of the "BV1" field will be selected.

l) Click in the "BV1" line you have selected, under the "Value" column

m) Type the integer value of 1 and press Enter. In this way you have assigned to all buildings with a BV1 included between 0 and 1 a BV_MAX value of 1, converting all floating numbers into integer, and approximating them to 1.

n) Repeat steps i) to m) assigning BV_MAX = 2, 3, 4, 5 to buildings having BV1 respectively included in [1;2] (BV1>1 and BV1<=2); [2;3] (BV1>2 and BV1<=3); [3;4] (BV1>3 and BV1<=4); and [4;5] (BV1>4 and BV1<=5), interval.

o) Save your edits. Now every building in your study area has a Vulnerability level (BV_MAX) in the attribute table of “buildings” layer. This value is an integer number between 1 and 5 (**Figure 14**).

	m	s	g	d	f	BV1	BV_MAX
	1	5	5	5	5	4.064	5
	1	5	5	5	5	4.064	5
	5	5	5	5	5	5	5
	5	5	5	5	5	5	5
	5	5	5	5	5	5	5
	5	5	5	5	5	5	5
	1	5	5	5	5	4.064	5
	5	5	5	5	5	5	5
	1	5	5	5	5	4.064	5
	1	4	5	5	5	3.853	4
	1	4	5	5	5	3.853	4
	1	4	5	5	5	3.853	4
	1	4	5	5	5	3.853	4
	1	5	5	5	5	4.064	5
	1	4	5	5	5	3.853	4
	1	5	5	5	5	4.064	5

Figure 14

6. Plot the 5 vulnerability levels on the map assigning different colors to buildings having different vulnerability levels (BV_MAX).

a) Right click on the “buildings” layer in the layer box.

b) Select “Properties”, then “Symbology”. In the “Show” Box select “Categories” and then “Unique values” (**Figure 15**).

c) In the “value field” box select “BV_MAX” and click “Add all values”. All the BV_MAX values appear with different colors. Click “Apply” and then “Ok”. Your vulnerability map is finished (**Figure 16**).

d) Save your project.

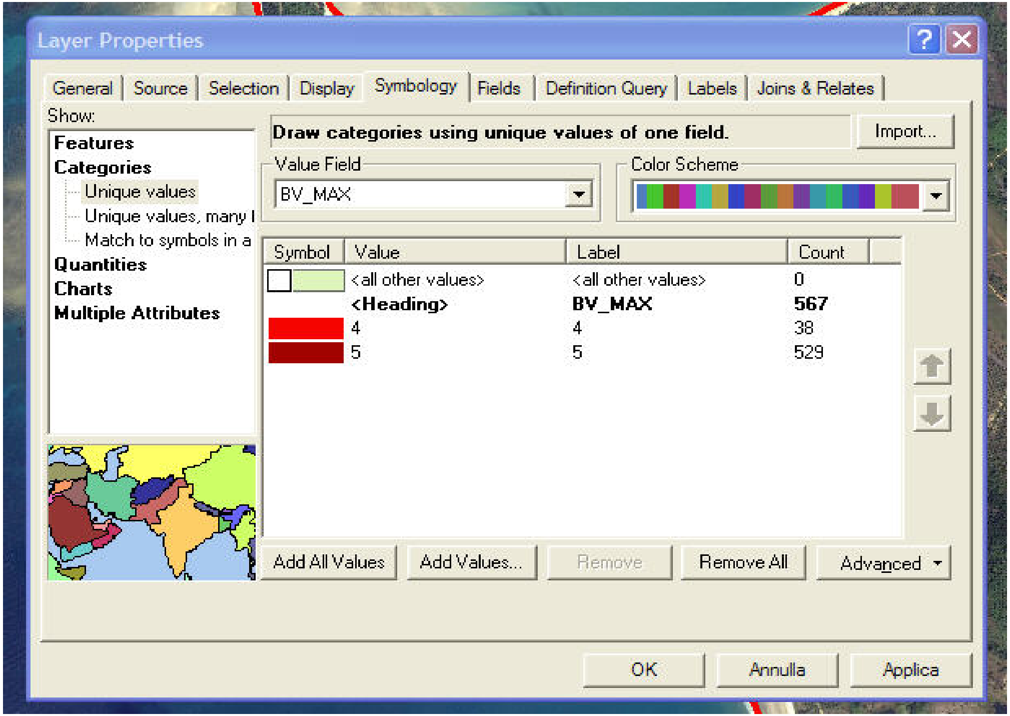

Layer Properties
General
Source
Selection
Display
Symbology
Fields
Definition Query
Labels
Joins & Relates
Show:
Features
Categories
Unique values
Unique values, many f
Match to symbols in a
Quantities
Charts
Multiple Attributes
Draw categories using unique values of one field.
Import...
Value Field
BV_MAX
Color Scheme
Symbol
Value
Label
Count
<all other values>
<all other values>
0
<Heading>
BV_MAX
567
4
4
38
5
5
529
Add All Values
Add Values...
Remove
Remove All
Advanced
OK
Annulla
Applica

Figure 15

Figure 16

2.3 Creating a "Population*" vulnerability map*

The method for creating risk and vulnerability maps for population using ArcGis ArcMap 9.0 is the same we presented in the paragraph above.

Impact elements for population are:

1. Density (total number of people)

2. Number of children, senior citizens and invalids.

3. Gender (number of women)

4. Mean income

All data about these impact elements must refer to a particular **reference unit.** Population risk and vulnerability will be calculated for this reference unit. The smallest reference unit for population is a building, but if you don't have population data so detailed you should choose a bigger reference unit (for example a neighborhood, or a village, or even a district) according to the resolution of data you have available.

For every reference unit you must also know:

- High season and low season density
- Mean time for evacuation

Reference unit must be imported in the GIS project as a geo-referenced polygons shape file.

The relation for calculating population vulnerability of a chosen reference unit is:

$$PV\ (\textit{Population Vulnerability}) = K_E \{S_{DN}\ S_H\ [PV_H] + S_{DN}\ S_L\ [PV_L]\ \}$$

Where:

- K_E is a factor that takes into account the mean time for evacuation of the reference unit you chose, under the assumption that the launch of the Tsunami alarm would happen 15 minutes before the wave arrival. Suggested values of K_E are listed in the following table. If the early warning system would be faster or slower you should consequently modify the suggested K_E values.

Suggested K_E values (with a Tsunami alarm 15 minutes before the wave arrival)	Mean time for evacuation (minutes)	**K_E**
AREA 1	< 5	**0.4**
AREA 2	between 5 and 10	**0.6**
AREA 3	between 10 and 15	**0.8**
AREA 4	> 15	**1**

- S_{DN} depends on the time arrival of the tsunami wave (day or night), and:

  $S_{DN} = BV/5$ if the Tsunami happens during the night (all the people are inside buildings)

  $S_{DN} = (1/2 + BV/10)$ if the Tsunami happens during the day (people are for a half inside buildings and for a half outside)

  If the chosen reference area is bigger than a building (for example a village) the BV value is the mean of all buildings inside the reference unit.

- S_H is a switch taking into account the high tourist season, and:

  $S_H = 1$ if the Tsunami occurs in high tourist season

  $S_H = 0$ if the Tsunami occurs in low tourist season

- S_L is a switch taking into account the low tourist season, and:

  $S_L = 1$ if the Tsunami occurs in low tourist season

  $S_L = 0$ if the Tsunami occurs in high tourist season

- PV_H (*population vulnerability in High season*) is the population vulnerability level in the reference unit, calculated for high season using relation (1) and the population impact elements listed above.

$$PV_H = [w_1 \text{ (density)}_H + w_2 \text{ (gender)}_H + w_3 \text{ (children/seniors/Invalids)}_H + w_4 \text{ (mean income)}_H]$$

Weights must be calculated with multi-criteria analysis. To calculate weights, chose as first the population weighting criteria and follow the example given for buildings vulnerability.

- PV_L (*population vulnerability in Low season*) is the population vulnerability level in the reference unit, calculated for low season.

$$PV_H = [w_1\ (\text{density})_L + w_2\ (\text{gender})_L + w_3\ (\text{children/seniors/Invalids})_L + w_4\ (\text{mean income})_L]$$

2.4 Creating a "Socio-Economic Aspects" vulnerability map

Expressed in the simplest terms, a disaster affects assets (direct damages) and the flow for the production of goods and services (indirect losses) (ECLAC, 2003). In this way socio-economic aspects can suffer both direct and indirect damages.

Only vulnerability to direct damages can be plotted on maps, because indirect damages are not linked to any particular location on the territory. Indirect damages must be considered from a qualitative-descriptive point of view.

A direct damages vulnerability map can be created following the method presented above.

For buildings the only socio-economic impact element is the “buildings use”. The relation (1) is reduced to:

$$SEV \text{ (Socio-Economic Vulnerability)} = (e_1 \times BV)/5$$

where e_1 is the value given to the impact element “building use”. Suggested values for e_1 are shown in the following table:

Socio-economic vulnerability of buildings	
Building use	e_1
PUBLIC HEALTH	5
EDUCATION	3
DRINKING WATER AND SANITATION	4
TRANSPORTS	3
ENERGY	3
INDUSTRY AND COMMERCIAL	2
AGRICOLTURE AND LIVESTOCK	3
TOURISM	4
AUTHORITIES	5
RELIGIOUS/HISTORICAL	2
LIVING HOUSE	1

For land use the relation (1) becomes:

$$SEV = (e_1)$$

Suggested e_1 values for land use are shown in the following table:

Socio-economic vulnerability of land use	
Building use	e_1
TRANSPORTS	3
RIVER AND CHANNELS	1
LAKES AND WET LANDS	2
NOT CULTIVATED LANDS	1
AGRICOLTURE: ANNUAL CROPS	2
AGRICOLTURE: PERMANENT PLANTATIONS	3
BEACH	2
FISHING POOLS	3

2.5 Creating an “Environment” vulnerability map

For a more specific analysis we have divided the “Environment” into four sub-parameters:

1. Surface water
2. Ground water
3. Coastal zone
4. Internal areas

Impacts elements are:

1. Surface water

   a) the river capacity

   b) rainfall/evaporation

2. Ground water

   a) presence of low lying areas, eroded pockets, restricted drainage canals

   b) number of wells

   c) tide effect on rivers mouths

d) rainfall/evaporation

e) soil permeability

f) depth of the aquifer

g) the hydraulic conductivity of the aquifer

3. Coastal zone

a) Coastal features (sandy beach, sandy beach with dunes, coast with rocks)

b) Artificial coastal defenses (walls behind the beach)

c) Topography (flat area= high vulnerability)

d) Wetlands extent, protected wetlands

e) Submerged and intertidal zones features (coral reef extent and depth, mangroves forests extent, Posydonia praires extent)

4. Internal areas

a) protected areas extent (high vulnerability)

b) extent of zones of ecological interest (mean vulnerability)

c) extent of agricultural areas (low vulnerability)

Every sub-parameter must be divided into a number of reference units, for example following the administrative boundaries. Reference unit must be imported in the GIS project as a geo-referenced polygons shape file. For each reference unit you have to calculate the vulnerability level, using relation (1).

3. HAZARD MAPPING

In the case of a Tsunami risk, hazard has been defined as the maximum height of the water column reached in each point of the study area during the flooding of the 26 December 2004. To obtain these values, CRATER experts simulated the inundation and the consequential flooding using two different numerical models. The first, starting from the record of the tide level gauges, transferred the waves from offshore to the coast line. The second one, starting from the waves heights on the coast line, simulated the flooding of the study area, giving as output the maximum water height reached in each point inland. In order to give a prompt vision of how many floors of each building got inundated, assuming the height of each floor equal to 3 meters, the water height values have been divided in 4 intervals:

- From zero to 3 meters **H=1**
- From 3 to 6 meters **H=2**

- From 6 to 9 meters **H=3**
- More than 9 meters **H=4**

Where "H" stands for the **hazard level**. H will be used in the computation of the risk level. Using a GIS software, these four intervals have been plotted on an hazard map, identifying 4 different areas (**Figure 17**).

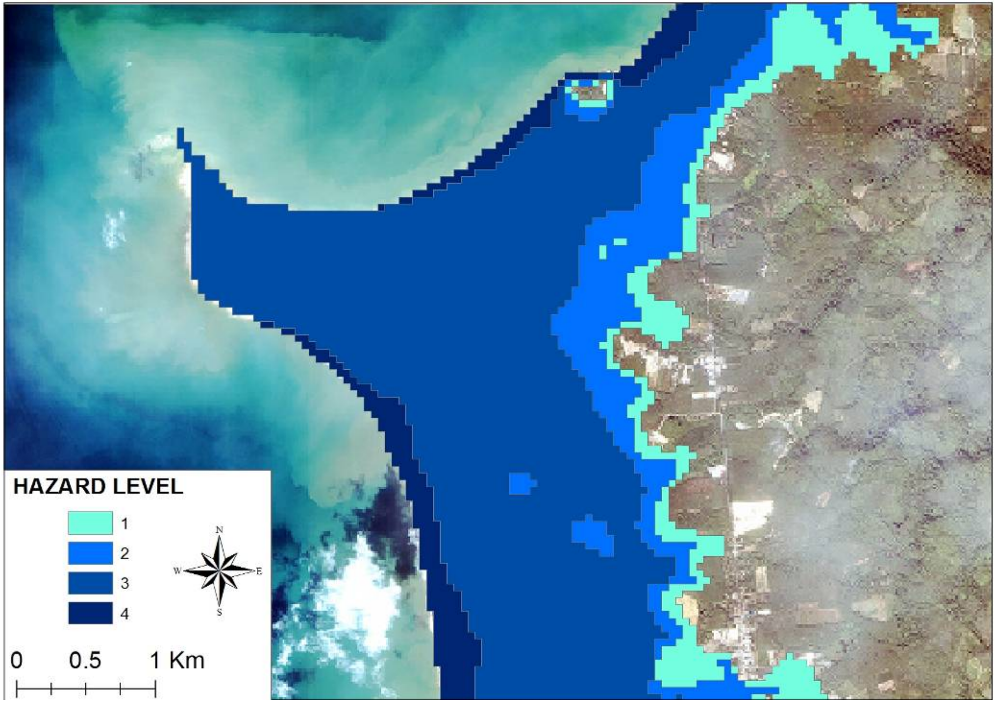


Figure 17. Hazard map of the Khao Lak study area, Thailand.

Users can obtain an approximated evaluation of the hazard map imaging that the study area will be flooded until the topography level curve having the same height of the Tsunami wave on the coast line. In this way users can calculate the maximum water level reached in each position of the study area as the difference between the Tsunami wave height on the coastline and the ground topographic elevation in that point inland.

4. RISK LEVEL

As previously stated, the numeric value of risk can be calculated as the product between vulnerability and hazard level. Since vulnerability level ranges from 1 to 5 and hazard level ranges from 1 to 4, risk level of each vulnerable element will be given by:

$$R=V \times H/4$$

R must be an integer number ranging from 1 to 5, where 5 stands for the maximum risk level. Once risk level has been calculated it will be possible to plot it on a risk map, using a GIS software. The following paragraph shows how to create a risk map for the built environment vulnerable parameter. The same method allows to calculate the risk level for all others vulnerable parameters.

4.1 <u>TUTORIAL</u>: Creating a “built environment” risk map

Now we are going to list all the steps required to create a built environment risk map of the study area, using the ArcGis ArcMap 9.0 software by ESRI. This tutorial starts from the results given above. The main aim is to assign to each building a risk level value as an integer number between 1 (minimum risk) and 5 (maximum risk).

The CD-Rom included with the manual contains all the files needed to perform this tutorial.

Starting data:

The risk level of each building is given by the product between vulnerability level and hazard level, so data required for creating a buildings risk map are:

- The “buildings” shape file obtained resulting from the “building vulnerability tutorial”. In the attribute table of this shape file there is a field called “BV_MAX” reporting the vulnerability level of each building of the pilot area. This shape file is located in the “Building_risk_tutorial /Shapefile” folder, with the name of “buildings”.

- The Hazard map of the pilot area. Hazard map is a polygons shape file called “hazard map” located in the “Building_risk_tutorial /Shapefile” folder. Every polygon represents an area with constant maximum water level reached during the Tsunami of December 26, 2004.The “buildings” attribute table reports in the field “HAZARD” the hazard level value for each polygon.

Steps required:

1. Open ArcGis ArcMap 9.0. Import all shape files present in the “Building_risk_tutorial/Shapefile” folder and the aerial photo located in the “Aerial_Photo” folder of the CD Rom.

2. Open the Arc Toolbox.

3. Double click on “Analysis Tools”

4. Double click on “Overlay”

5. Double click on “Intersect”. The “Intersect” window appears.

6. In the “Input Features“ box select the “buildings” layer and the “hazard_map” layer.

7. In the “Output Feature Class” box select the folder in which you want the output shape file of the intersection to be saved (**Figure 18**)

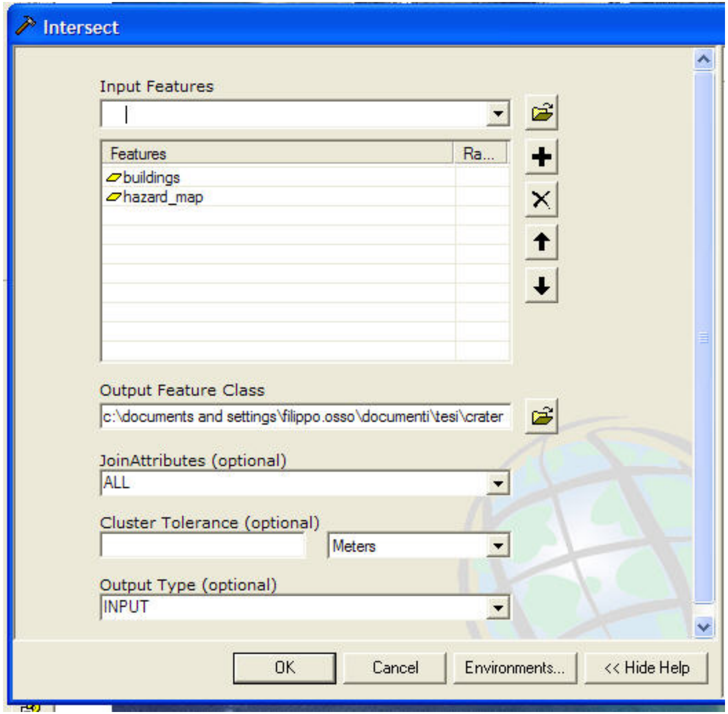

Intersect
Input Features
Features
Ra...
buildings
hazard_map
Output Feature Class
c:\documents and settings\filippo.osso\documenti\tesi\crater
JoinAttributes (optional)
ALL
Cluster Tolerance (optional)
Meters
Output Type (optional)
INPUT
OK
Cancel
Environments...
<< Hide Help

Figure 18

8. Click “OK”. A new polygons shape file called “buildings_Intersect” appears in your layer’s list (**Figure 19**). This shape file is the intersection between “buildings” shape file and “hazard_map” shape file. His attributes table contains both “buildings” fields and “hazard_map” fields (**Figure 20**).

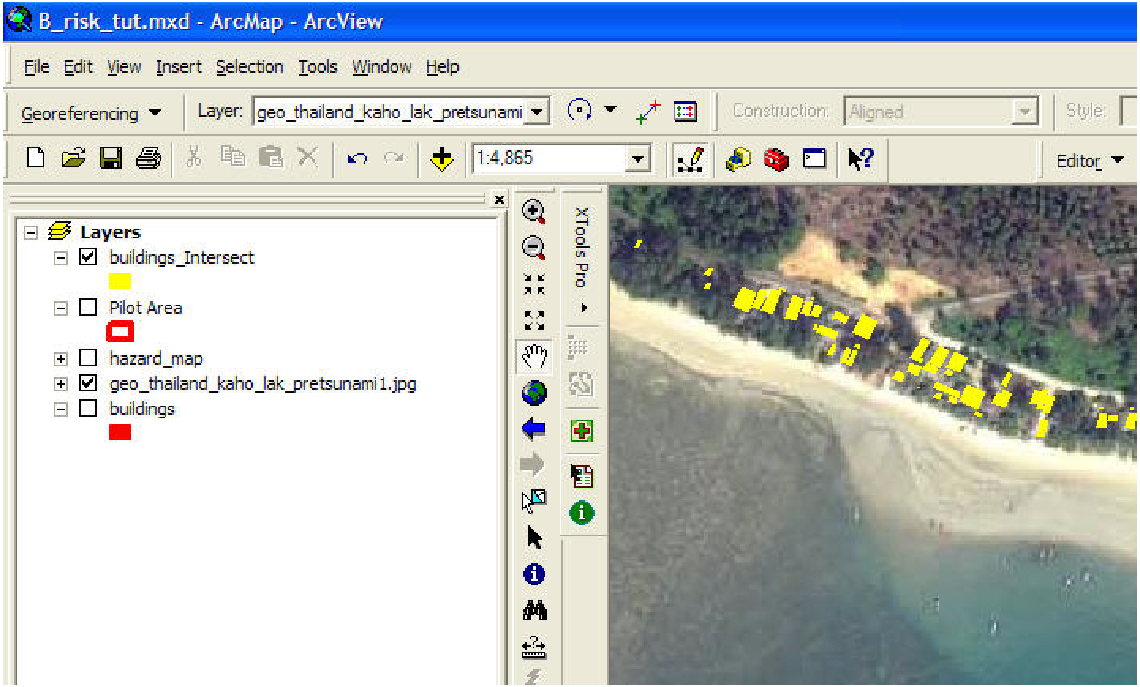

B_risk_tut.mxd - ArcMap - ArcView
File Edit View Insert Selection Tools Window Help
Georeferencing
Layer: geo_thailand_kaho_lak_pretsunami
Construction: Aligned
Style:
1:4,865
Editor
Layers
buildings_Intersect
Pilot Area
hazard_map
geo_thailand_kaho_lak_pretsunami1.jpg
buildings
XTools Pro

Figure 19

g_floor	m	s	g	d	f	BV1	BV_MAX	FID_hazard	HAZARD
	1	5	5	5	5	4.064	5	1	4
	1	5	5	5	5	4.064	5	3	1
	1	5	5	5	5	4.064	5	2	2
	1	5	5	5	5	4.064	5	3	1
	3	5	5	5	5	4.532	5	0	3
	1	5	5	5	5	4.064	5	0	3
	1	5	5	5	5	4.064	5	0	3
	1	5	5	5	5	4.064	5	0	3
	1	5	5	5	5	4.064	5	0	3
	1	5	5	5	5	4.064	5	0	3
	1	5	5	5	5	4.064	5	0	3
	1	5	5	5	5	4.064	5	2	2
	1	5	5	5	5	4.064	5	0	3
	3	5	5	5	5	4.532	5	0	3
	1	5	5	5	5	4.064	5	0	3
	1	5	5	5	5	4.064	5	0	3
	5	5	5	5	5	5	5	2	2
	5	5	5	5	5	5	5	3	1
	5	5	5	5	5	5	5	2	2
	5	5	5	5	5	5	5	3	1

Figure 20. The “buildings_Intersect” attribute table contains both “buildings” fields and “hazard_map” fields

9. Open the “buildings_Intersect” attribute table. Add a new field and call it R1 (Type: Float, Field properties: Precision =2, Scale=2) (**Figure 21**). Click “OK”

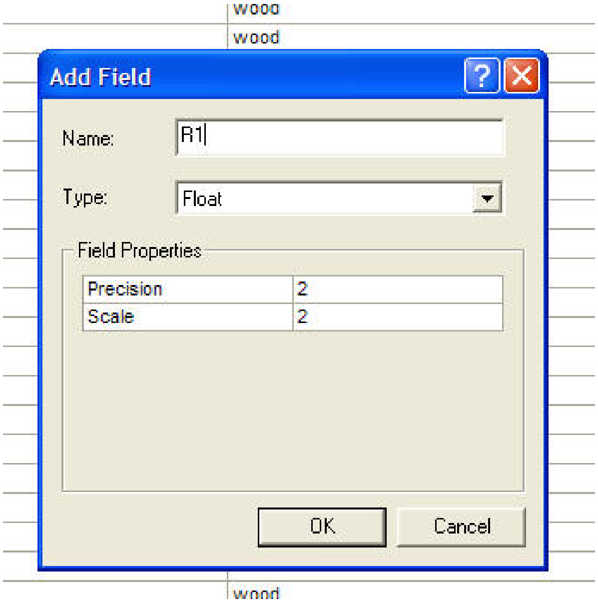


Figure 21

10. Start editing

11. In the "buildings_Intersect" attribute table select the R1 field clicking on the name of the field.

12. Right click on the field name R1 in the attribute table and select "Calculate values…" (**Figure 22**)

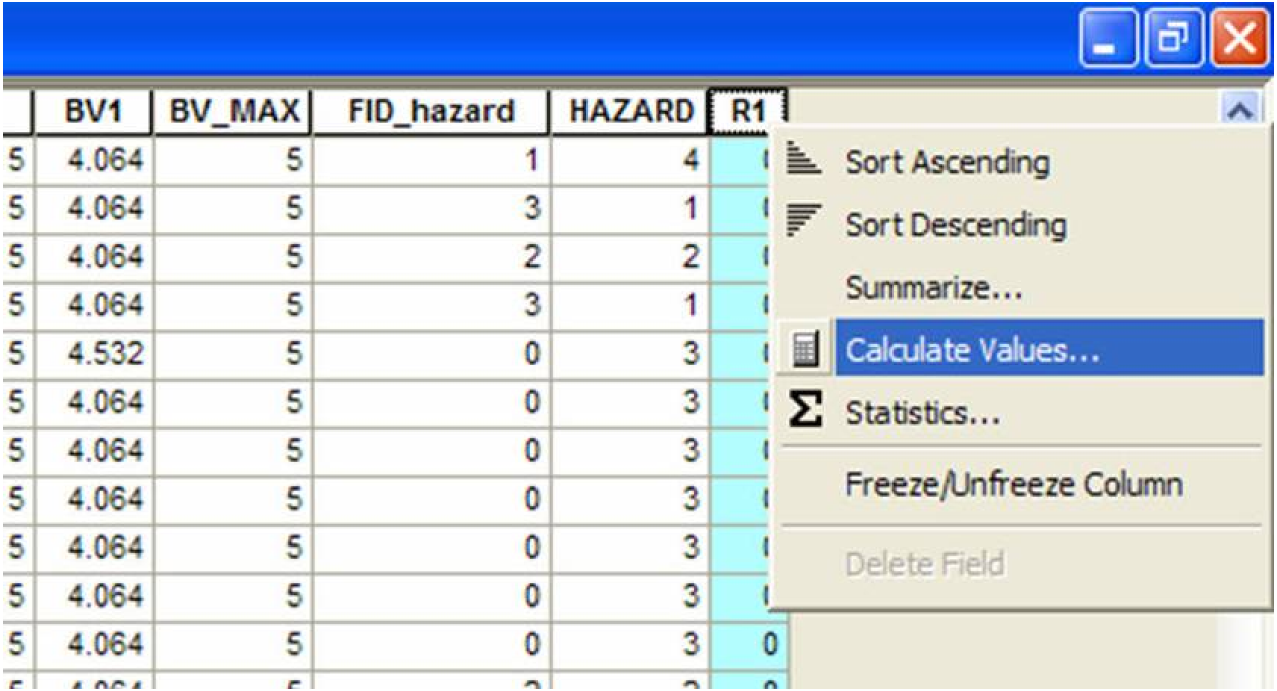

BV1
BV_MAX
FID_hazard
HAZARD
R1
Sort Ascending
Sort Descending
Summarize...
Calculate Values...
Statistics...
Freeze/Unfreeze Column
Delete Field

Figure 22

13. Insert the relation for the computation of the building risk level in the box under “R1=”. The relation is:

R1 = BV_MAX * HAZARD / 4

Click on “BV_MAX” and on “HAZARD” in the “Fields” box and on the mathematical operators buttons to insert them in the relation above (**Figure 23**).

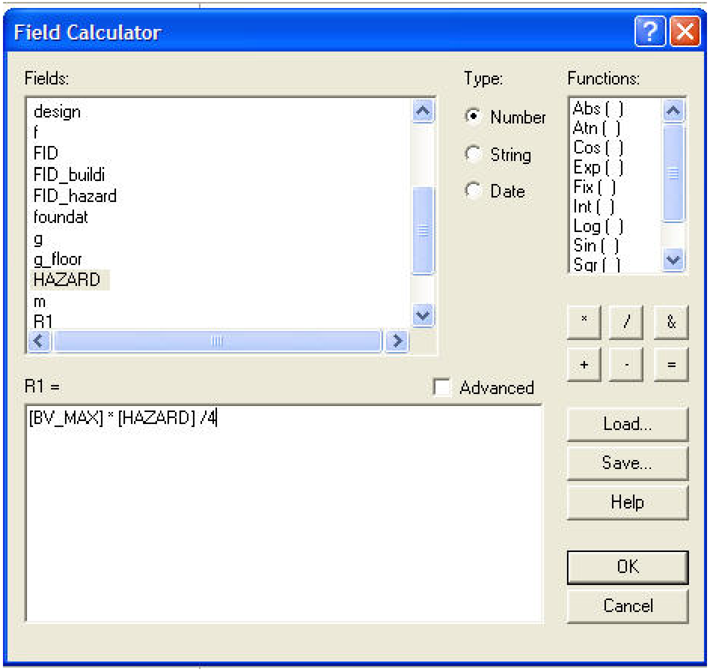

Field Calculator
Fields:
design
f
FID
FID_buildi
FID_hazard
foundat
g
g_floor
HAZARD
m
R1
Type:
Number
String
Date
Functions:
Abs ( )
Atn ( )
Cos ( )
Exp ( )
Fix ( )
Int ( )
Log ( )
Sin ( )
Sqr ( )
*
/
&
+
-
=
R1 =
Advanced
[BV_MAX] * [HAZARD] /4
Load...
Save...
Help
OK
Cancel

Figure 23

14. Click “Ok”. In the field “R1” you have just calculated the risk level of each building, but not as integer numbers (**Figure 24**). In order to obtain integer numbers you must approximate them all.

g	d	f	BV1	BV_MAX	FID_hazard	HAZARD	R1
5	5	5	4.064	5	1	4	5
5	5	5	4.064	5	3	1	1.3
5	5	5	4.064	5	2	2	2.5
5	5	5	4.064	5	3	1	1.3
5	5	5	4.532	5	0	3	3.8
5	5	5	4.064	5	0	3	3.8
5	5	5	4.064	5	0	3	3.8
5	5	5	4.064	5	0	3	3.8
5	5	5	4.064	5	0	3	3.8
5	5	5	4.064	5	0	3	3.8
5	5	5	4.064	5	0	3	3.8
5	5	5	4.064	5	2	2	2.5
5	5	5	4.064	5	0	3	3.8
5	5	5	4.532	5	0	3	3.8

Figure 24

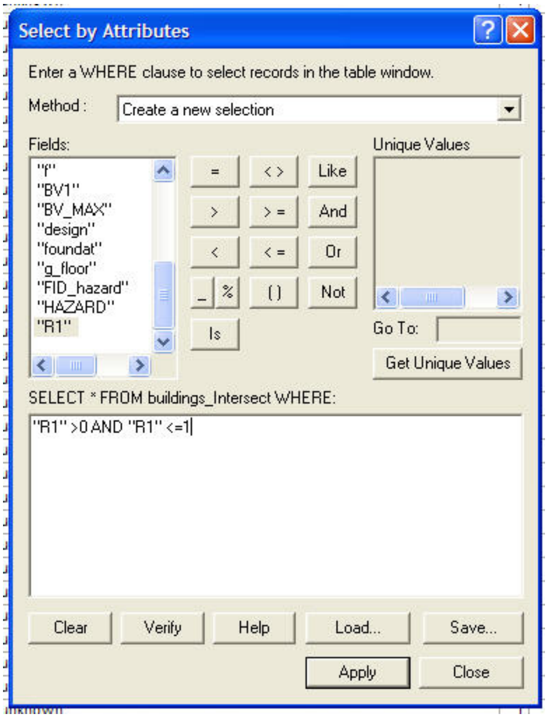
15. Close the attribute table. Save your edits and stop editing

16. Open the “buildings_Intersect” attribute table. Add a new field and call it RISK_MAX (short integer).

17. Select by attributes (“Options”- “Select by Attributes”) all buildings with a “R1” value included in the]0;1] interval (R1>0 and R1<=1). You can do this by typing:

"R1" >0 AND "R1" <=1

Click “Apply” (**Figure 25**).



Select by Attributes
Enter a WHERE clause to select records in the table window.
Method :
Create a new selection
Fields:
"f"
"BV1"
"BV_MAX"
"design"
"foundat"
"g_floor"
"FID_hazard"
"HAZARD"
"R1"
=
<>
Like
>
>=
And
<
<=
Or
_
%
()
Not
Is
Unique Values
Go To:
Get Unique Values
SELECT * FROM buildings_Intersect WHERE:
"R1" >0 AND "R1" <=1
Clear
Verify
Help
Load...
Save...
Apply
Close

Figure 25

18. Close the “buildings_Intersect” attribute table and Restart editing

19. Click on the attribute button, on the left of the “Target” box. A new window called “attributes” will appear.

20. Double click on “buildings_Intersect” group in the box on the left

21. In the box on the right, click on the “R1” field in the “Property” column. The line of the “R1” field will be selected.

22. Click in the “R1” line you have selected, under the “Value” column

23. Type the integer value of 1 and press Enter (**Figure 26**). In this way you have assigned to all buildings with a R1 included in the interval [0;1] a RISK_MAX value equivalent to 1, converting all floating numbers in integer, and approximating them to 1.

24.

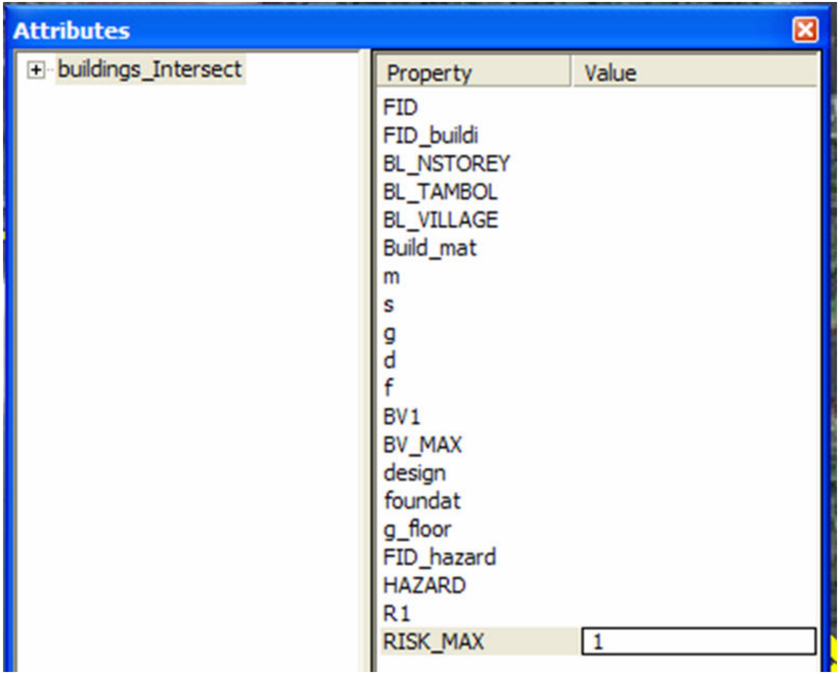

Attributes
buildings_Intersect
Property
Value
FID
FID_buildi
BL_NSTOREY
BL_TAMBOL
BL_VILLAGE
Build_mat
m
s
g
d
f
BV1
BV_MAX
design
foundat
g_floor
FID_hazard
HAZARD
R1
RISK_MAX
1

Figure 26

25. Repeat steps 17) to 23) assigning RISK_MAX = 2, 3, 4, 5 to buildings having R1 respectively included in [1;2] (BV1>1 and BV1<=2), [2;3] (BV1>2 and BV1<=3), [3;4] (BV1>3 and BV1<=4), and [4;5] (BV1>4 and BV1<=5)intervals.

26. Save your edits. Now every building in your study area has a Risk level (RISK_MAX) in the attribute table of “buildings_Intersect” layer. This value is an integer number between 1 and 5 (**Figure 27**).

m	s	g	d	f	BV1	BV_MAX	HAZARD	R1	RISK_MAX
1	5	5	5	5	4.064	5	4	5	5
1	5	5	5	5	4.064	5	1	1.3	2
1	5	5	5	5	4.064	5	2	2.5	3
1	5	5	5	5	4.064	5	1	1.3	2
3	5	5	5	5	4.532	5	3	3.8	4
1	5	5	5	5	4.064	5	3	3.8	4
1	5	5	5	5	4.064	5	3	3.8	4
1	5	5	5	5	4.064	5	3	3.8	4
1	5	5	5	5	4.064	5	3	3.8	4
1	5	5	5	5	4.064	5	3	3.8	4
1	5	5	5	5	4.064	5	3	3.8	4
1	5	5	5	5	4.064	5	2	2.5	3
1	5	5	5	5	4.064	5	3	3.8	4
3	5	5	5	5	4.532	5	3	3.8	4
1	5	5	5	5	4.064	5	3	3.8	4

Figure 27

27. Plot the five risk levels on the map assigning different colors to buildings having different risk levels (RISK_MAX), as you did in the case of vulnerability level.

28. Your risk map is finished (**Figure 28**). Save your edits.

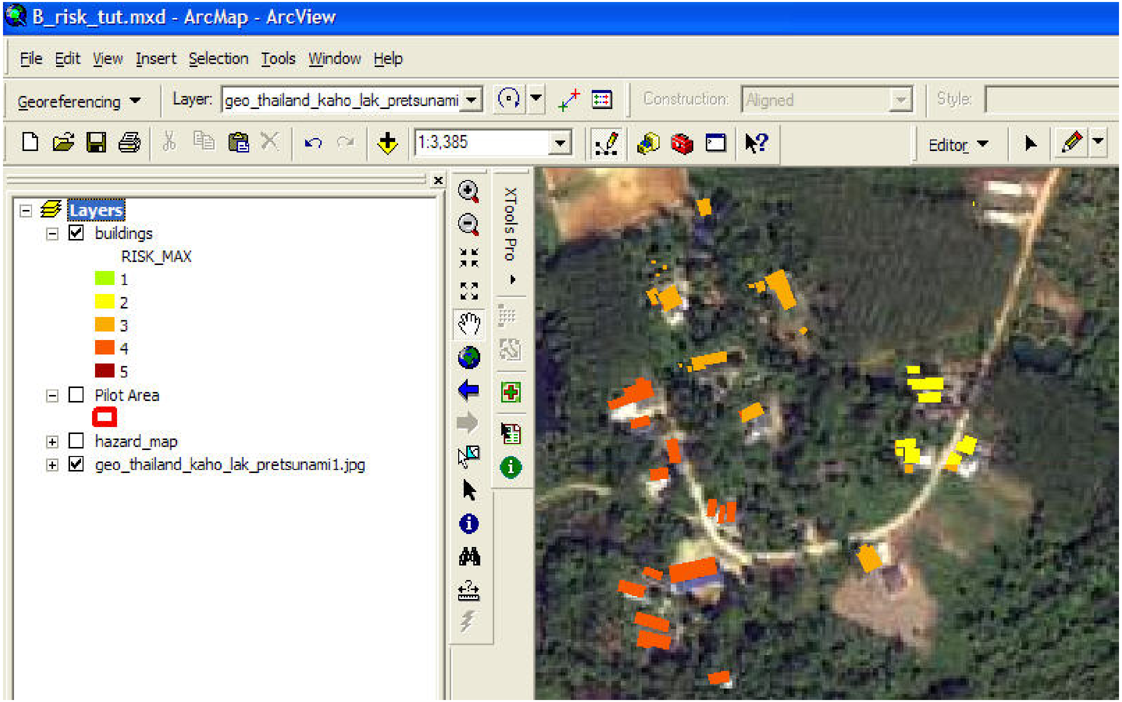


Figure 28. A detail of the buildings risk map of the pilot area