Methodology document for the WHO e-atlas of disaster risk.
Volume 1. Exposure to natural hazards
Version 2.0

Flood hazard modelling

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Contents

Preface

Being able to conduct geographically based risk assessment at the sub national level requires being in a position to spatially distribute all the elements reported in following conceptual formula[1]:

$$\text{Risk} \propto \frac{\text{Hazard x Vulnerability}}{\text{Capacity}}$$

This process being very much driven by the type of hazard faced by the population and/or the key infrastructures in a given country the World Health Organization has been working, since 2006 on the development and improvement of an electronic atlas which could stimulate ministries of health and other health stakeholders to improve their disaster management capacity as well as serve as the entry point for conducting sub national geographically based risk assessments.

The WHO e-atlas of disaster risk models the distribution of natural hazards and population's exposure and provides baseline data and maps needed to advocate for resources to improve disaster preparedness; aid emergency response measures; and assist in identifying, planning and prioritizing areas for mitigation activities.

The first version of the e-atlas published in 2008 covered the WHO Eastern Mediterranean Region (22 countries) and five natural hazards (flood, seismic [earthquake], landslide, heat and wind speed) and was distributed to more than 500 users.

Encouraged by this success, working in close collaboration with the WHO Regions and taking advantage of the establishment of the Vulnerability and Risk Analysis and Mapping programme (VRAM), it was decided to publish a second version of the e-atlas that would, this time, also the 46 countries forming the WHO African Region as well as 32 countries of the WHO European Region (due to limited resources, this version of the e-atlas focuses on Central Europe only).

Building on the successful collaboration established between the Taroudant polydisciplinary faculty of Ibn Zohr University, Agadir, Morocco and the VRAM, most of the models used in the first version of the e-atlas have been improved and heat replaced by heat wave, a current preoccupation of many ministries of health.

In order to allow for any other region or country to also apply the models on their own it has been decided to document not only the research behind the models but also provide users with a protocol that would allow them to generate the final hazard distributions maps. The present series of methodology document is the result of this documentation.

[1] Modified from: Office of the United Nations Disaster Relief Co-ordinator (UNDRO). *Mitigating natural disasters. phenomena, effects and options. A manual for policy makers and planners*. New York, United Nations, 1991.

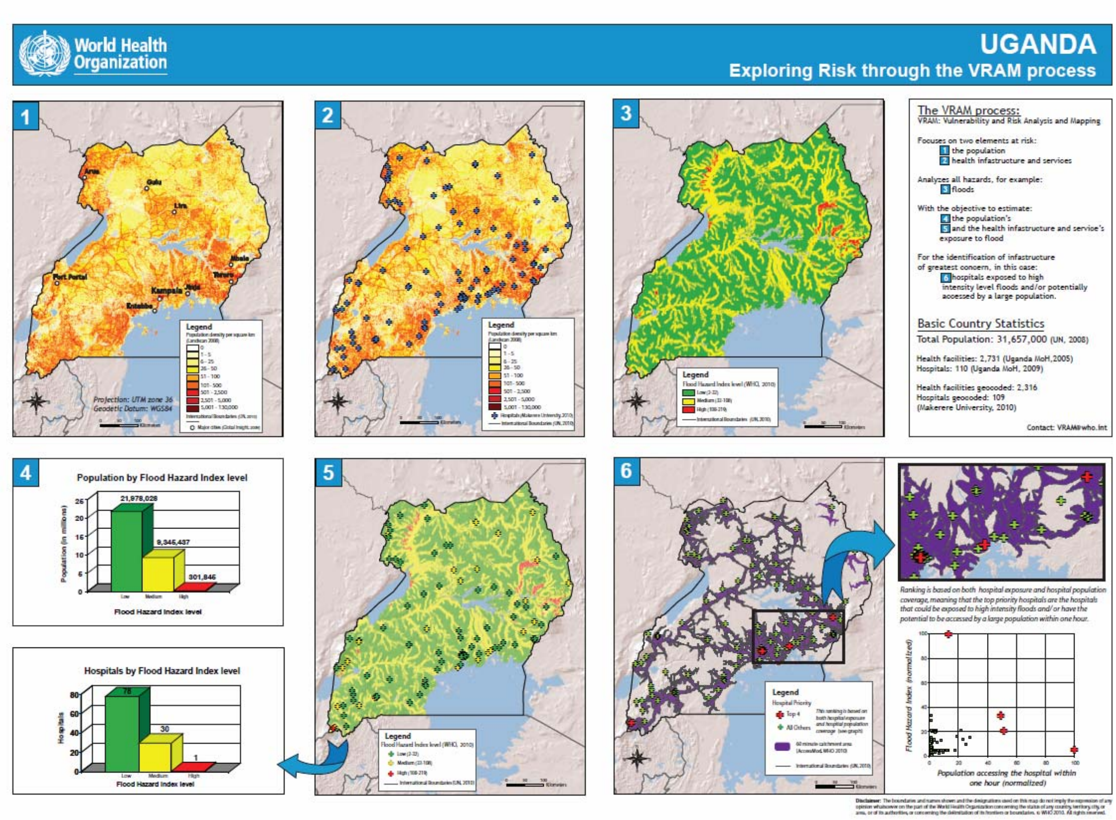
It is important to underline that the hazard distribution maps resulting from the application of these models are nevertheless only the first step of a process allowing countries to assess their risk at the sub national level.

Analysing vulnerability and capacity require a process which is difficult to be applied at the level of a region for the following reasons:

- availability of desegregated data
- incompatibility of indicators from one country to an other
- important differences in terms of health context between one country and another.

WHO has therefore been looking at having the vulnerability, capacity and therefore indirectly risk analysis, conducted on a country by country basis.

In this context, the VRAM is supporting Member States and partners to strengthen their capacity in order to conduct such analysis and have it presented in a manner such as the figure below.



The result of such analysis is then to be integrated in the country Disaster Risk Reduction (DRR) and Health Emergency Preparedness and Response Programmes (HEPRP) and serve, among other things, to build safer hospital, improve mass casualties' management and help specialized units within health Organizations (including MoH) for public health planning.

At the same time, the baseline data, information and maps collected or produced through the process can be used by health authorities and partners to take informed decisions in times of crises.

1. Introduction

This document describes the methodology and protocol developed by the Taroudant polydisciplinary faculty of Ibn Zohr University in close collaboration with the VRAM and then used to generate and document maps presenting the spatial distribution of flood hazard for the *WHO e-atlas of disaster risk, volume 1: exposure to natural hazards, Version 2.0.*

The methodology used to spatially distribute flood hazard combines the extent of past flood events with the spatial distribution of causal factors. This combination enables the calculation of a weighted score for each individual causal factor. The spatial distribution of the weighted scores are then aggregated to derive the distribution of the flood hazard index (FHI) before being reclassified to obtain the spatial distribution of the intensity level of flood hazard for the region covered by the e-atlas.

The methods and process presented in this document could be applied to other geographic areas provided that the analyses use geospatial data of similar or better quality and resolution.

2. Methodology

Over the past 25 years, a large amount of research has been conducted in order to identify techniques for the generation of flood hazard maps. These techniques, presented in this section, include hydrological frequency analysis, hydraulic modelling, hydrological modelling and statistical methods.

Hydrologic frequency analysis uses historical flood data to calculate the probability and extent of future flood events for different intervals (10, 50, 100, and 500 years) [McKerchar and Pearson, 1990; Gabriele and Arnell, 1991; Pearson, 1991; Sarma, 1999; Kjeldsen et al., 2002; Kroll and Vogel, 2002]. This procedure requires adequate historical meteorological and stream flow data to allow statistical analysis to an accepted confidence level. Additionally, changes in stream and flood flows, caused by reservoir regulation, channel improvements (levees) or land use changes, limit the usefulness of historical data because the physical parameters that existed when the floods occurred no longer exist. Due to these two disadvantages, flood frequency analysis is not used in this protocol.

Hydraulic models convert discharge flow values into stream or flood depths. The Hydrologic Engineering Center's river analysis system (HEC-RAS) model developed by the Hydrologic Engineering Center (HEC) of the US Army Corps of Engineers (USACE) calculates and estimates the duration and extent of inundation, changes in water depth and velocity through time at any location based on measurements of unsteady flows through a river network [USACE, 2001a; USACE, 2001b]. The following data are needed to calculate viable inundation estimates using the HEC-RAS model: a high-resolution digital elevation model (DEM), a stream network model, detailed cross-sectional geometries of channels and adjacent flood plains, and flow length parameters. Although this model yields accurate and actionable results for small catchment areas, it is very difficult to apply this model to a large geographic area such as a country because of the robust input data requirements.

Hydrological models use mathematical calculations with known or assumed values for various components of the hydrologic cycle to analyse the behaviour of stream-flows and floods in a specific watershed. Hydrological models can be divided into deterministic models that are based on specific physical parameters and processes and stochastic models that allow for probabilistic variability in both parameters and processes [Storm, 1989; Meijerink et al., 1994; Mannaerts, 1996; Viessman and Lewis, 1996; Venkatesh and Jain, 1997; Seth, 1999; Al-Rawas et al., 2001; Nyarko, 2002]. These models require careful and accurate calibration to yield accurate estimates of flood prone areas. Calibration of a hydrological model for the region covered in this version of the e-atlas would for example have been enormously time-consuming.

Statistical methods combine historical flood frequency and distribution of flood causal factors in order to predict areas with a probability of floods across a geographic area. This method allows for the calculation of a flood hazard index (FHI) based on the weighted scores of the causal factors and the historical flood distributions [Islam and Sado, 2000].

The first three methods described here require resources and data far beyond the frame of the present project; therefore it has been decided to use a statistical method for spatializing the distribution of the intensity level of flood hazard over the region covered in this version of the e-atlas.

Among the statistical methods already developed, the one used by Islam and Sado [2000] in Bangladesh has several advantages:

- it yields realistic estimates without using an empirical model
- it requires historical flood distributions and causal factor data, which are readily available for the region covered in this version of the e-atlas
- it can be readily applied with the GIS technologies used throughout the development of the atlas
- it considers both the susceptibility of each area to inundation and the factors related to flood emergency management.

The implementation of this method goes through the application of the following steps (Figure 1):

1. identification of the causal factors
2. classification of the number of past flood events distribution map
3. estimation of the weighted score for each causal factor by crossing them with the reclassified flood frequency layer
4. standardization of the weighted scores
5. aggregation and classification of the resulting map to obtain the spatial distribution of the intensity level of flood hazard.

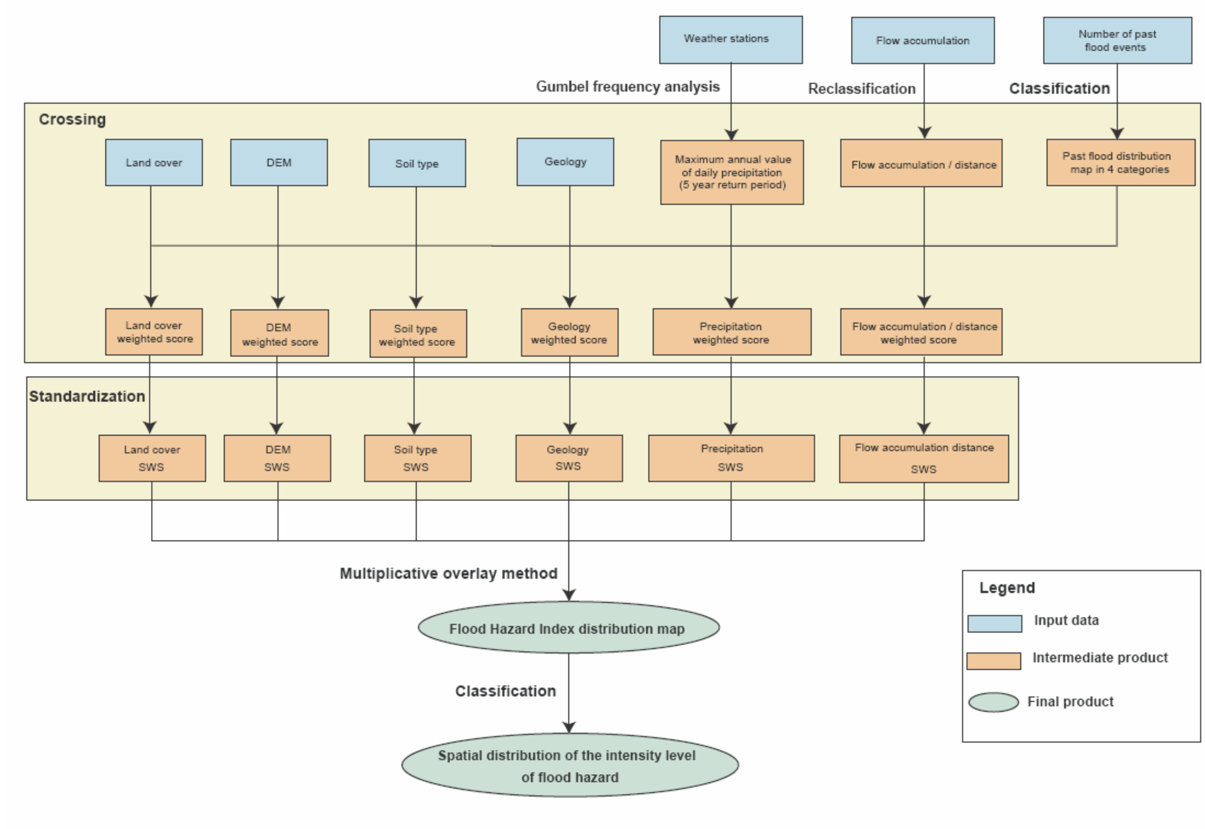


Figure 1. Methodology for generating the spatial distribution of the intensity levels of flood hazard

2.1 Identification of the causal factors

The methodology described in this document uses a composite flood hazard index based on six causal factors. These factors, which are listed here, have been selected based on different case studies of relevance to the region covered in this version of the e-atlas.

- *Land cover*. This describes the appearance of the landscape and is generally classified by the amount and type of vegetation, which is a reflection of its use, environment, cultivation and seasonal phenology. Land cover has a direct influence on a number of parameters in the hydrologic cycle including interception, infiltration, concentration and runoff behaviour, and therefore indirectly on flooding. Together these characteristics yield information about the hydrological response and the degree of flood hazard [Sarma, 1999; Islam and Sado, 2000; Nyarko, 2002; Todini et al., 2004; Bapalu and Sinha, 2005]

- *Elevation*. The likelihood of a flood increases as the elevation of a location decreases, making it a reliable indicator for flood susceptibility [Islam and Sado, 2000; Al-Rawas at al. 2001; Nyarko, 2002; Sanyal and Xi Lu, 2003; Shrestha, 2004; Todini et al. 2004; UNDP, 2004; Bapalu and Sinha, 2005; Peduzzi et al. 2005].

- *Soil type and soil texture*. Nyarko [2002] and Todini et al. [2004] report that the soil type and texture play a role in determining the water holding and infiltration characteristics of an area and consequently affect flood susceptibility.

- *Lithology*. The macroscopic nature of an area can influence its susceptibility to floods. Areas that consist of largely impermeable surface geology are more susceptible to flooding [Islam and Sado, 2000]. However, since lithology data were not available for the region covered in this version of the e-atlas, surface geology was used instead.

- *Flow accumulation volume and distance from the flow accumulation path*. Areas located close to the flow accumulation path and in particular when a large volume has accumulated upstream are more likely to get flooded [Islam and Sado, 2000; Al-Rawas at al., 2001; Nyarko, 2002; Todini et al., 2004; Bapalu and Sinha, 2005]. These two factors have been combined into one in the context of the present work.

  Flow accumulation is calculated for each cell by determining the number of upstream cells that drain into it. Grid cells with high flow accumulation values are areas of concentrated flow and are identified as stream channels according to the specified flow accumulation threshold. Grid cells with flow accumulation values of zero are topographic highs or ridges.

  In order to estimate a stream network from a flow accumulation layer a flow accumulation threshold must be chosen. The threshold is the minimum number of cells that must drain into a cell for it to be determined to be part of a stream network. The use a of lower flow accumulation threshold results in a more detailed (and computationally intensive) stream network.

  In the literature there is no agreement on the ideal threshold value for reproducing actual stream networks. In practice the determination of the threshold is an interactive process in which several values are used until the desired resolution of the stream network is achieved. In this protocol, after testing numerous thresholds, a threshold value of 100 cells (equating to a drainage area of 100 km^2) was used.

  Once the threshold is set, cells with flow accumulations greater than the threshold are designated as "stream channel" cells and will comprise the estimated stream network. Ultimately, the stream network is buffered to determine the distance of a location from the nearest stream channel.

- *Precipitation*. The likelihood of a flood increases as the amount of rain and snow at a location increases [Nyarko, 2002; Todini et al. 2004]. In this study, the annual daily maximum precipitation has been used with a return period of 5 years calculated using the Gumbel frequency analysis method[2].

[2] Please refer to the *Methodology and implementation for generating the dataset* document available in the e-atlas DVD for more information regarding the implementation of this method.

2.2 Classification of the number of past flood events and causal factors distribution maps

The spatial distribution of the number of previous flood events observed between 1985 and 2009, which can be considered as a measure of the flood frequency, was classified into four specific levels of historical hazard (Table 1)[3].

Table 1. Correspondence between the number of past floods events and the historical flood hazard level

Number of past flood events 1985–2009	Historical flood hazard
0	Non hazardous
1–4	Low
5–9	Medium
>9	High

Similarly, the other causal factors were reclassified into ordinal classes following the process reported in the *Methodology and procedures for modelling the spatial distribution of flood hazard* document available in the e-atlas.

2.3 Estimation of the weighted scores

The causal factors are weighted based on their spatial correlation with the distribution of the historical flood hazards.

By crossing the reclassified flood frequency distribution map with each causal factor distribution grid the area percentage distribution of each class/category is obtained according to the historical flood hazard classification.

The weighted score for each category was then calculated as the sum of the products between the area percentage of the category for each historical flood hazard level and the associated damage coefficient using the following equation [Islam, 2000]:

$$\text{weighted score} = (0 \times a) + (1 \times b) + (3 \times c) + (5 \times d) \qquad \text{Equation 1}$$

with: a = area percentage of the category in areas with no historical flood hazard
b = area percentage of the category in areas with low historical flood hazard
c = area percentage of the category in areas with medium historical flood hazard
d = area percentage of the category in areas with high historical flood hazard
0, 1, 3, 5 = corresponding damage coefficients attached to each specific historical flood hazard class to express the severity of each level of historical flood hazard.

[3] Please refer to the *Methodology and implementation for generating the dataset* document available in the e-atlas for more information regarding the creation of the past flood events distribution map.

2.4 Standardization of the weighted scores

Once the weighted scores for all of a factor's categories had been calculated they were standardized and rescaled into ordinal classes according to a scale from 1 to 3—1 indicating categories with the lowest likelihood for a flood to occur in a given area and 3 the categories with the highest.

2.5 Creation of the intensity level of flood hazard distribution map

Each causal factor distribution map was reclassified to contain the distribution of the corresponding standardized weighted score before being combined using the multiplicative overlay method. For each cell, this method multiplies the score of all the causal factors together to produce the distribution of the flood hazard index.

Finally, the flood hazard index distribution map was reclassified into five intensity levels (very low, low, medium, high and very high) using a natural breaks scheme. The natural breaks scheme determines the break points between classes by analysing how the data are clustered. Class boundaries are set where there are relatively large jumps in data values.

3. Implementation of the methodology

This chapter describes how the methodology presented in chapter 2 of this document is implemented using the software listed in section 3.1.

The names of the files are reported in bold in the text; when a "*" follows the file name this indicates an input datum that is described in the *Methodology and implementation process for generating the dataset* document that can also be found in the first volume of the e-atlas.

3.1 Required software

The implementation of the methodology and processes presented in this document requires the following software:

- ArcView 3.*x* with the Spatial Analyst 1.1 extension, both developed by the Environmental Systems Research Institute (ESRI) Inc., for the geospatial operations
- Microsoft Office Excel 2003 to standardize and rank the weighted scores.

The following publicly available scripts and extensions which are accessible directly in the e-atlas DVD (in the tools section) have also been used:

- Grid Analyst (GridAnalyst.avx)
- XTools (Xtoolsmh.avx)
- Grid and Theme Projector v.2 (grid_theme_prj.avx)
- Grid Transformation Tool (sptrnsfrm.avx).

These scripts have to be uploaded in ArcView before applying any of the process described in the following sections.

3.2 Preparation of the causal factors

This section describes the process applied on the different input data layers to obtain the spatial distribution of the causal factors.

3.2.1 Conversion of the vector data into grid

The following steps are applied in order to convert the geology vector layer into grid

1. Upload the geology vector layer (**st_ar_geology.shp*)** as well as the international boundary layer (**st_ar_int_bord.shp*)** in a view in ArcView.

2. Make the geology shapefile the active theme.

3. Use the Theme>Convert to Grid function.

4. In the first window, assign a directory and save the resulting grid as **st_ar_geology**; click OK.

5. Choose **st_ar_int_bord.shp*** as the reference for the output Grid Extent shapefile. This will keep the grid theme extent the same as the original polygon theme extent.

6. For the Output Grid cell size, choose 0.008333°, which corresponds to 1 km at the equator, the resolution selected for the e-atlas.

7. Use the default number of rows and number of column values.

8. For the "field or cell value", choose the field to be converted to a grid; click OK.

9. Click "yes" to join feature attributes to grid and click "yes" to add the theme to the view.

3.2.2 Calculation of the distance from the flow accumulation path

In this section, the distance from the flow accumulation path presenting a minimum volume of flow accumulation is calculated taking into account that the accumulated volume plays a role on the distance that can be covered by a flood; the higher the volume the longer the distance.

3.2.2.1 Elimination of the lowest values of flow accumulation

The following steps are used to keep only cells presenting a flow accumulation value bigger than 100 (km^2):

1. Upload the flow accumulation distribution grid (**st_ar_fa***) in the view and make it the active theme.

2. Use the Analysis>Reclassify function and, in the Reclassify window, specify that you want to convert the values of flow accumulation between 1 and 100 to NoData and all of the rest, except NoData, to 1. The resulting grid is named by default: **reclass of st_ar_fa**.

3. Use the Analysis>Map Calculator function and enter the following formula in the box: ([reclass of st_ar_fa]*[st_ar_fa]). This will keep a grid which contains only the cells that presented a value bigger than 100.

4. Save the output grid under **st_ar_fa_str** using the Theme>Save Data Set function.

3.2.2.2 Calculation of the distance depending on the accumulated volume of water

The classification of the flow accumulation distribution grid into classes and the effective distance from these classes are computed separately as detailed here.

1. Upload the **st_ar_fa_str** grid in the view.

2. Reclassify the **st_ar_fa_str** grid into four ordinal classes corresponding to the surface that each cell is draining using the Analysis>Reclassify function and the information reported in Table 2.

Table 2. Table used for the reclassification of the active flow accumulation path distribution grid

Accumulated volume range	Ordinal classes after reclassification	Corresponding level of accumulation
101–1000	1	Very low
1000–10 000	2	Low
10 000–100 000	3	Medium
>100 000	4	High

3. Save the result of the reclassification as **st_ar_fa_cl**.

4. Project the **st_ar_fa_cl** grid from the Geographic projection to the Equal-Area Cylindrical projection using the process described in Annex 1.

5. Save the resulting grid as **st_ar_fa_cl_m**.

6. Open the attribute table of the **st_ar_fa_cl_m** and select all the records presenting a valued of 1 in the value column.

7. Use the Analysis>Find Distance function to create a grid containing the distances from the selected cells by selecting the following Output Grid specifications in the first window:
    a. set Output Grid Extent = Same as Display
    b. set Output Grid Cell Size = As Specified Below
    c. setCell Size = 1000 m
    d. use the default number of rows and columns.

8. Transform the resulting grid into integers in order to reduce the grid size, by using the Analysis>Map Calculator function and enter the following formula in the box: ([Distance to st_ar_fa_cl_m] + 0.5).Int.

9. Save the resulting grid as **st_ar_dist1**.

10. Project the **st_ar_dist1** grid from the Equal-Area Cylindrical projection to the Geographic one using the steps in Annex 2.

11. Clip the unprojected grid to the international borders (**st_ar_int_bord.shp**) using the following steps:

    a. add the **st_ar_int_bord.shp** shapefile to the view
    b. make the **st_ar_dist1** grid the active theme and use the Grid Analyst>Extract Grid Theme Using Polygon function
    c. select **st_ar_int_bord.shp** from the drop list as the reference on which the grid needs to be clipped
    d. make the resulting grid the active theme and select the Theme>Convert to Grid function to save the output grid as **st_ar_fa_dist1_g**.

12. Repeat steps 6 to 11 for the other classes of flow accumulation (2, 3 and 4), saving the result as **st_ar_fa_dist2_g**, **st_ar_fa_dist3_g** and **st_ar_fa_dist4_g**.

3.3 Classification of the number of past flood events distribution map

Use the following process to reclassify the number of past flood events distribution map according to ordinal classes that can be used in the process.

1. Make the **st_ar_fl_fr*** grid the active theme in the view.

2. Use the Analysis>Reclassify function to reclassify the grid according to Table 3:

Table 3. Table used for the reclassification of the number of past flood events into ordinal classes

Number of past flood events 1985–2009	Ordinal class
0	1
1–4	2
5–9	3
>9	4

3. Save the output as **st_ar _fl_fr_cl**.

3.4 Estimation of the weighted scores for each causal factor's range or category

This section describes how the weighted scores are calculated for each causal factor.

3.4.1 Weighted scores for the discrete factors

These are the steps to be followed regarding the distribution of the discrete factors (land cover, soil type or geology).

1. In a view, display both the reclassified number of past flood events distribution grid (**st_ar _fl_fr_cl**) and the first causal factor distribution grid (e.g. **st_ar_lc*** for the land cover).

2. Use the Analysis>Tabulate Areas function and in the specify the following in the Tabulate Area window:
   a. select the **st_ar_lc*** grid under Row Theme and specify Value as the Row Field
   b. select the **st_ar _fl_fr_cl** grid under Column Theme and choose Value as the Column Field; click OK.

   The output of step 2 is a table entitled *Areas of st_ar _fl_fr_cl Tabulated for Each Zone in st_ar_lc*, which contains *n* rows and five columns: *Value*, *Value-1, Value-2, Value-3* and *Value-4.* Table 4 shows the area of each type of land cover in each class of historical flood hazard (flood frequency), measured in square degrees.

Table 4. Area distribution for the different historical flood hazard levels for the different land cover categories observed in the study area

Land cover category	Historical flood hazard level				Sum
	Value-1 (no hazard)	Value-2 (low hazard)	Value-3 (medium hazard)	Value-4 (high hazard)	
11	9.597	24.528	5.829	16.480	56.434
14	44.155	142.327	36.103	4.016	226.601
20	53.050	230.309	44.706	5.363	333.428
30	114.568	258.273	67.975	7.197	448.013
40	60.920	101.942	2.968	0.218	166.048
50	85.342	205.154	31.481	1.970	323.947
60	67.052	110.635	18.494	0.577	196.758
70	7.035	20.274	3.653	1.379	32.341
90	32.047	93.203	2.522	0.094	127.866
100	38.338	65.127	5.117	0.348	108.930
110	19.764	108.946	32.903	2.481	164.094
120	12.085	24.508	8.771	2.239	47.603
130	45.591	161.586	47.741	2.257	257.175
140	131.996	181.383	64.055	6.459	383.893
150	131.171	198.687	42.689	5.792	378.339
160	7.229	21.971	0.414	0.005	29.619
170	0.625	0.916	0.026	0.003	1.570
180	10.542	28.434	1.054	0.114	40.144
190	2.180	6.938	1.434	0.428	10.980
200	779.523	733.430	105.797	20.466	1639.216
210	70.924	40.186	2.989	0.411	114.510
220	4.005	10.247	5.839	0.485	20.576
230	0.006	0.007	0.000	0.000	0.013

3. Use the File>Export function to export the resulting cross-tabulation table as a **.dbf** file, and save the new export file as **tabulate_area_fl_fr_cl-st_ar_lc.dbf**.

4. In Microsoft Excel, open the **tabulate_area_fl_fr_cl-st_ar_lc.dbf** file.

5. Name the next adjacent column Sum (shown in Table 4) and calculate the total area occupied by each land cover category over the study area by summing the area of this category observed in each historical flood hazard level.

6. Calculate the corresponding percentage area distribution of each land cover category by historical flood hazard level by dividing the area percentage observed in each level by the summed area observed for the land cover category. For example the percentage area for the land cover category 11 located in the no hazard historical flood level gives: (9.597/56.434) × 100 = 17.01. The results of this operation for the land cover categories reported in Table 4 are shown in Table 5.

Table 5. Calculation of the weighted scores for each land cover category

Land cover category	No hazard (A)	Low hazard (B)	Medium hazard (C)	High hazard (D)	Weighted Score
11	17.01	43.46	10.33	29.20	220.46
14	19.49	62.81	15.93	1.77	119.47
20	15.91	69.07	13.41	1.61	117.34
30	25.57	57.65	15.17	1.61	111.20
40	36.69	61.39	1.79	0.13	67.41
50	26.34	63.33	9.72	0.61	95.52
60	34.08	56.23	9.40	0.29	85.89
70	21.75	62.69	11.30	4.26	117.89
90	25.06	72.89	1.97	0.07	79.18
100	35.20	59.79	4.70	0.32	75.48
110	12.04	66.39	20.05	1.51	134.11
120	25.39	51.48	18.43	4.70	130.28
130	17.73	62.83	18.56	0.88	122.91
140	34.38	47.25	16.69	1.68	105.72
150	34.67	52.52	11.28	1.53	94.02
160	24.41	74.18	1.40	0.02	78.46
170	39.81	58.34	1.66	0.19	64.27
180	26.26	70.83	2.63	0.28	80.13
190	19.85	63.19	13.06	3.90	121.86
200	47.55	44.74	6.45	1.25	70.35
210	61.94	35.09	2.61	0.36	44.72
220	19.46	49.80	28.38	2.36	146.72
230	46.15	53.85	0.00	0.00	53.85

7. Calculate the weighted score using the formula reported in equation 1 (see section 2.3). Results for the land cover categories are reported in Table 5.

8. Save the final table as **st_ar_lc_ws.dbf**, in order to be imported into ArcView.

9. Repeat steps 1 to 8 for the other discrete causal factors distribution maps using appropriate file names for the output files.

3.4.2 Weighted scores for the continuous factors

Although the calculation of the weighted scores for continuous data (elevation, distance from flow accumulation and annual daily maximum precipitation) is similar to the discrete factors, the distribution maps first need to be reclassified into appropriate value ranges before proceeding with the weighting. The process followed for this reclassification is presented in the following sections.

3.4.2.1 Weighted scores for the elevation (DEM) and maximum precipitation distributions layers

The elevation and five year return period maximum precipitation distribution maps are classified into nine categories using the natural breaks method (also referred to as the optimal breaks method and Jenks method). This classification technique identifies break points between classes based on the natural patterns in which the data are clustered. Class boundaries are set where there are relatively big jumps in the data values. This method has been applied as follows:

1. In ArcView, upload the elevation (**st_ar_dem***) and maximum precipitation (**st_ar_prec_5***) distribution grids into a view.

2. Make the elevation grid (**st_ar_dem***) the active theme.

3. Use the Analysis>Reclassify function and specify the following in the Reclassify Value window:
   a. Click on the Classification Field and ensure it reads Values
   b. Click the Classify button and change the setting to read Type = Natural Breaks for and Number of Classes = 9. Click OK.

4. Use the Theme>Save Data Set function to save the resulting grid under **st_ar_dem_cl**.

5. Use the same process as the one described in section 3.4.1 to estimate the weighted score.

6. Repeat steps 1 to 5 for the maximum precipitation distribution grid.

3.4.2.2 Weighted scores for the distance from flow accumulation distribution layer

Each of the grids created in section 3.2.2.2 is reclassified according to three flood likelihood classes as reported in Table 6 in order to account at the same time for the distance to the flow accumulation path and the accumulated volume of water along it. In this regards, a high level of flow accumulation will potentially have an impact further away from the flow accumulation path than a low flow accumulation.

The literature does not provide indications about the optimum ranges to be used; the values reported in Table 6 therefore reflect choices that yield rationalized behaviour in the modelling process.

Table 6. Table used for the reclassification of the grids containing the distance to the flow accumulation path for the four classes of flow accumulation

Flow accumulation class	Proximity to flow accumulation (km)	Flood likelihood class
4: High	Intervals 0 – 5	3
	Intervals 5 –10	2
	Intervals 10 –15	1
	Intervals >15	0
3: Medium	Intervals 0 – 3	3
	Intervals 3 – 6	2
	Intervals 6 – 9	1
	Intervals >9	0
2: Low	Intervals 0 – 2	3
	Intervals 2 – 3	2
	Intervals 3 – 4	1
	Intervals >4	0
1: Very low	Intervals 0 – 1	3
	Intervals 1 – 2	2
	Intervals 2 – 3	1
	Intervals >3	0

The following process is used for the reclassification.

1. Upload the **st_ar_dist1**, **st_ar_dist_2**, **st_ar_dist3** and **st_ar_dist4** grids in a view (see section 3.2.2.2).

2. Make the **st_ar_dist1_g** grid the active theme.

3. Use the Analysis>Reclassify function to reclassify the grid according to the classes reported in Table 6 for the very low level of flow accumulation.

4. Save the output as **st_ar_R1**.

5. Repeat steps 1 to 4 on the other grids and save the result as **st_ar_R2**, **st_ar_R3** and **st_ar_R4**.

6. Derive the maximum likelihood class between the four reclassified grids (**st_ar_R1, st_ar_R2, st_ar_R3,** and **st_ar_R4)** using the following process:
   a. make sure that the Grid Transformation Tool extension is uploaded in ArcView
   b. use the Transform Grid>Combine function to combine the **st_ar_R1, st_ar_R2, st_ar_R3,** and **st_ar_R4**
   c. name the output grid **combin_y**. The resulting grid will contains the values of the susceptibility classes for each grid in separated columns R1, R2, R3 and R4
   d. make the **combin_y** the active grid and open its attribute table
   e. add a field called Max in this attribute table
   f. select the header of the Max column and click on the Calculate button
   g. type the following formula in the calculator window: [R1] Max [R2] Max [R3] Max [R4]
   h. use the Analysis>Map Calculator function and type the following formula in the window: [combin_y.max] to create a grid where each cell contains the maximum susceptibility class observed among the grids containing the distance from the flow accumulation path
   i. save the resulting grid as **st_ar_fa_cl**
   j. use the same process as the one described in section 3.4.1 to estimate the weighted score.

3.5 Standardization of the weighted scores for each causal factor

The next step is using the linear interpolation technique to standardize the weighted scores of each causal factor to allow their combination. In this process all the causal factors are standardized according to a scale going from 1 to 3, where 1 represent the lowest likelihood for a flood to occur in a particular area and 3 the highest. The process is as follows (Table 7).

1. In Microsoft Excel, open the **st_ar_ lc_ws.dbf** file.

2. Calculate the minimal and maximal values of the weighted score column using the min and max function and put the results at the bottom of this column. Referring to Table 7 as an example, *xmin* = 44.72 and *xmax* = 220.46.

3. Add a new column on the right and call it SWS to contain the results of the calculation for the standardized weighted scores.

4. Specify that *ymin* = 1 and *ymax* = 3 at the bottom of this new column.

5. Below the weighted score column use the slope and intercept function to calculate these two parameters for the weighted score value.

6. Choose the cells where the *ymin* and *ymax* are inserted as “y_knowns” and select the cells containing the *xmin* and *xmax* as “x_knowns” and click OK.

7. Apply the slope and intercept value to each of the weighted scores using this formula:

   $$\text{integer}([\text{slope} \times \text{weighted score}] + \text{intercept} + 0.5)$$

   to obtain the standardized weighted score for each land cover category. As an example the application of this formula for the second land cover category gives:

   $$\text{integer}([0.01138033 \times 119.47] + 0.49108032 + 0.5) = 2$$

8. Save the final table as **st_ar_lc_SWS.dbf**, in order to be imported into ArcView

9. Repeat steps 1 to 8 on the other causal factors distribution maps and save the resulting files under a name that corresponds to the name of each layer.

Table 7. Example of calculation of the standardized weighted scores (SWS) for the land cover categories

Land cover category	A	B	C	D	Weighted score	SWS
11	17.01	43.46	10.33	29.20	220.46	3
14	19.49	62.81	15.93	1.77	119.47	2
20	15.91	69.07	13.41	1.61	117.34	2
30	25.57	57.65	15.17	1.61	111.20	2
40	36.69	61.39	1.79	0.13	67.41	1
50	26.34	63.33	9.72	0.61	95.52	2
60	34.08	56.23	9.40	0.29	85.89	1
70	21.75	62.69	11.30	4.26	117.89	2
90	25.06	72.89	1.97	0.07	79.18	1
100	35.20	59.79	4.70	0.32	75.48	1
110	12.04	66.39	20.05	1.51	134.11	2
120	25.39	51.48	18.43	4.70	130.28	2
130	17.73	62.83	18.56	0.88	122.91	2
140	34.38	47.25	16.69	1.68	105.72	2
150	34.67	52.52	11.28	1.53	94.02	2
160	24.41	74.18	1.40	0.02	78.46	1
170	39.81	58.34	1.66	0.19	64.27	1
180	26.26	70.83	2.63	0.28	80.13	1
190	19.85	63.19	13.06	3.90	121.86	2
200	47.55	44.74	6.45	1.25	70.35	1
210	61.94	35.09	2.61	0.36	44.72	1
220	19.46	49.80	28.38	2.36	146.72	2
230	46.15	53.85	0.00	0.00	53.85	1
				min	44.72	1
				max	220.46	3
				slope	0.01138033	
				intercept	0.49108032	

3.6 Creation of the intensity level of flood hazard distribution layer

The creation of the intensity level of flood hazard distribution layer goes through three steps based on the layers and tables prepared in the previous sections.

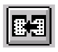
In the first stage the causal factor distribution maps are reclassified to obtain the distribution of the standardized weighted scores for each of them as follows.

1. In ArcView, open the attribute table of the **st_ar_lc** distribution grid.

2. In the legend of the ArcView project, select Table and add the **st_ar_lc_SWS.dbf** table.

3. Find the column in common between the attribute table of the **st_ar_lc** grid and the **st_ar_lc_SWS.dbf** table.

4. Highlight the header of the column in question in the **st_ar_lc_SWS.dbf** file and then do the same in the attributes table of the **st_ar_lc** grid.

5. Join the two tables by clicking on the join button  on the toolbar.

6. Use the Analysis>Map Calculator function, double-click on the [st_ar_lc.SWS] option in the list and click the evaluate button to create a grid containing the spatial distribution of the standardized weighted score.

7. Save the resulting grid as **st_ar_lc_SWS**.

8. Repeat steps 1 to 7 on the other causal factor distribution grids remembering that for the continuous factors (altitude and distance to flow accumulation path) the grids created in section 3.4.2 have to be used. Save the resulting grids using, the following file names: **st_ar_soil_SWS**, **st_ar_geology_SWS**, **st_ar_dem_SWS**, **st_ar_fa_SWS** and **st_ar_prec_SWS**.

In the second stage the flood hazard index (FHI) is calculated by combining the standardized weighted scores distribution maps for each causal factor as follows:

1. Upload all the standardized weighted scores distribution grids (**st_ar_lc_SWS**, **st_ar_soil_SWS**, **st_ar_geology_SWS**, **st_ar_dem_SWS**, **st_ar_fa_SWS** and **st_ar_prec_SWS**) into a view.

2. Use the Analysis>Map Calculator function and enter the following formula in the window: ([st_ar_lc_SWS]*[st_ar_soil_SWS]*[st_ar_geology_SWS]*[st_ar_dem_SWS]*[st_ar_fa_SWS]*[st_ar_prec_SWS]).

3. Save the resulting grid as **st_ar_FHI**; this is the flood hazard index distribution layer for the selected zone. The metadata for this layer are presented in Annex 3.

4. If **st_ar_FHI** presents a large amount of neighbourhood variation ("noise"), you can use the Generalize Grid>Smooth Surface function and save the output grid under **st_ar_fl_ucl**.

In the final stage, the flood hazard index distribution map is reclassified according to the five selected intensity levels using method as follows:

1. Upload the **st_ar_FHI** or **st_ar_fl_ucl** grid in a view and make this the active grid.

2. Use the Analysis>Reclassify function and specify the following in the Reclassify Value window that appears:
   a. click on the Classification Field and ensure it reads Values
   b. click the Classify button, and change the setting to read for Type = Natural Breaks and Number of Classes = 5; click OK.

   The five classes that are obtained correspond to the following intensity levels:
   1: very low
   2: low hazard
   3: medium
   4: high
   5: very high.

3. Use the Theme>Save Data Set function and save the resulting grid as **st_ar_fl_cl**.

The map resulting from the application of this approach for the European Region is reported in Figure 2. Please refer to the e-atlas DVD itself for the maps covering the other two WHO Regions. The associated metadata for these layers can be found in Annex 4.

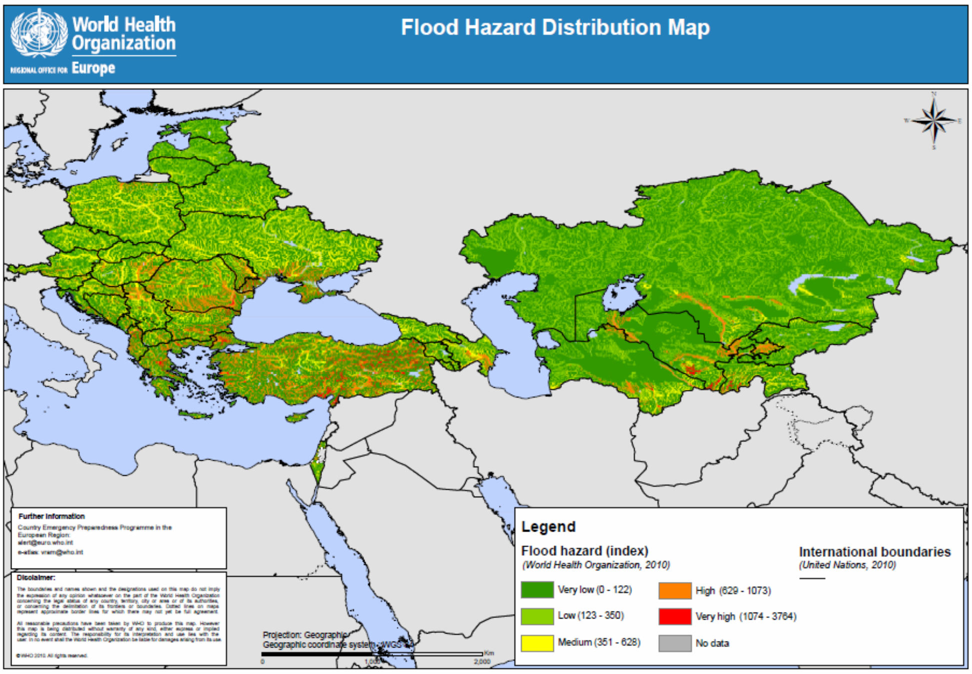


Figure 2. Flood hazard distribution map for the countries of the European Region covered in this version of the *WHO e-atlas of disaster risk*

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Annex 1. Process followed in order to project a layer from the Geographic to the Equal-Area Cylindrical projection

In ArcView

1. Make sure that the Grid and Theme Projector v.2 extensions are uploaded.

Click either on the  button or use the Grid Projector>Grid>Theme Projector function.

2. Select the layer to be projected from the list as the theme to project.

   In the Theme Projector window:

   a. specify the following parameters for the current projection:
      - Category = projection of the world
      - Type = Geographic
      - Current Projection Units = decimal degrees

   b. specify the following parameters for the new projection:
      - Category = projection of the world
      - Type = Equal-Area Cylindrical
      - New Projection Units = meters.

3. Save the output theme under a new name.

Annex 2. Process for unprojecting a layer from the Equal-Area Cylindrical to the Geographic projection

In ArcView

1. Make sure that the Grid and Theme Projector v.2 extensions are uploaded.

2. Click either on the  button or use the Grid Projector>Grid>Theme Projector function.

3. Select the layer to be projected from the list as the theme to project.

   In the Theme Projector window:

   a. specify the following parameters for the current projection:
      - Category = projection of the world
      - Type = Equal-Area Cylindrical
      - New Projection Units = meters

   b. specify the following parameters for the new projection:
      - Category = projection of the world
      - Type = Geographic
      - Current Projection Units = decimal degrees.

4. Save the output theme under a new name.

Annex 3. Metadata for the flood hazard index distribution layer

Dataset title	Spatial distribution of the flood hazard index for the WHO Regions (Africa, Eastern Mediterranean and part of Europe)
Theme keywords	WHO, Africa, Eastern Mediterranean, Europe, natural disaster, Geographic Information System (GIS), natural hazard, flood, inundation
Dataset topic category	Flood
Geographic location	The layer cover a total of 100 countries (22 for the Eastern Mediterranean, 46 for Africa and 32 for Europe)
Publication date	20110301
Data exchange format	ArcView grid
Filename	St_ar_fl_ucl
Dataset edition	Second edition
Abstract	This layer contains the spatial distribution of the flood hazard index for the WHO Regions (Africa, Eastern Mediterranean and part of Europe)
Lineage	The process used to create the flood hazard index distribution layer is described in the *Methodology and implementation process for modelling the spatial distribution of flood hazard* document that can be found in the first volume (2nd edition) of the *WHO e-atlas of disaster risk for the WHO Regions (Africa, Eastern Mediterranean and part of Europe)*
Data quality comments	Please refer to the data-specific metadata for more information regarding the quality of the grids used as input for the creation of the flood hazard grid Because of the methods and resolution used (1 km) special care should be taken when using this dataset for application below the national level The method did not integrate lithology as this layer was not available for the WHO Regions (Africa, Eastern Mediterranean and part of Europe)
Distributor	WHO Mediterranean Centre for Health Risk Reduction

	(WMC)
Spatial representation type	grid
Map projection	Unprojected (Geographic)
Reference system	WGS 84 datum
Geographic box	X min: –25.358747°, X max: 91.8287° Y min: –46.978931°, Y max: 63.459827°
Resolution	30 arc-seconds (0.008333°)
Redistributions constraints	The flood hazard index distribution layer is copyrighted. The owner of the data agrees to the use, reproduction, distribution, display, publication and dissemination at no cost to third parties of the flood hazard index distribution layer, in any manner and in any form whatsoever, subject to the copyright and acknowledgement mentioned in these metadata
Access and use constraints	This layer may not be reproduced, changed, adapted, translated, stored in a retrieval system or transmitted in any form or by any means without prior permission of the copyright holder, except to make a security backup. Requests for permissions, with a statement of purpose and extent, should be address to the VRAM programme at the WHO Mediterranean Centre for Health Risk Reduction (VRAM@who.int)
Acknowledgement	*WHO e-atlas of disaster risk for the WHO Regions (Africa, Eastern Mediterranean and part of Europe)* 2nd edition. Copyright © WHO 2011. All rights reserved
Disclaimer	All reasonable precautions have been taken by WHO to produce this layer. However this layer is being distributed without warranty of any kind, either express or implied regarding its content. The responsibility for its interpretation and use lies with the user. In no event shall the World Health Organization be liable for damages arising from its use
Dataset language	English
Dataset character set	ASCII
Metadata provider	WHO Mediterranean Centre for Health Risk Reduction (WMC).

Metadata contact	El Morjani Zine El Abidine BP 3566 Poste Talborjt 80000 Agadir Morocco Telephone: +212 528 28 55 30 email: elmorjaniz@gmail.com
Metadata date	20110301
Metadata language	English
Metadata character set	ASCII
Metadata standard	ISO 19115

Annex 4. Metadata for the intensity level of flood hazard distribution layer

Dataset title	Spatial distribution of the intensity level of flood hazard for the WHO Regions (Africa, Eastern Mediterranean and part of Europe)
Theme keywords	WHO, Africa, Eastern Mediterranean, Europe, natural disaster, Geographic Information System (GIS), natural hazard, flood, inundation
Dataset topic category	Flood
Geographic location	The layer covers a total of 100 countries (22 for the Eastern Mediterranean, 46 for Africa and 32 for Europe)
Publication date	20110301
Data exchange format	ArcView grid
Filename	st_ar_fl_cl
Dataset edition	Second edition
Abstract	This layer contains the spatial distribution of the intensity level of flood hazard index for the WHO Regions (Africa, Eastern Mediterranean and part of Europe)
Lineage	The process used to create the intensity level of flood hazard index distribution layer is described in the *Methodology and implementation process for modelling the spatial distribution of flood hazard* document that can be found in the first volume (2nd edition) of the *WHO e-atlas of disaster risk for the WHO Regions (Africa, Eastern Mediterranean and part of Europe)*

Data quality comments	Please refer to the data-specific metadata for more information regarding the quality of the grids used as input for the creation of the flood hazard grid Because of the methods and resolution used (1 km) special care should be taken when using this dataset for application below the national level The method did not integrate lithology as this layer was not available for the WHO Regions (Africa, Eastern Mediterranean and part of Europe)
Distributor	WHO Mediterranean Centre for Health Risk Reduction (WMC)
Spatial representation type	grid
Map projection	Unprojected (Geographic)
Reference system	WGS 84 datum
Geographic box	X min: –25.358747°, X max: 91.8287° Y min: –46.978931°, Y max: 63.459827°
Resolution	30 arc-seconds (0.008333°)
Redistributions constraints	The intensity level of flood hazard index distribution layer is copyrighted. The owner of the data agrees to the use, reproduction, distribution, display, publication and dissemination at no cost to third parties of the flood hazard index distribution layer, in any manner and in any form whatsoever, subject to the copyright and acknowledgement mentioned in these metadata
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Dataset language	English
Dataset character set	ASCII
Metadata provider	WHO Mediterranean Centre for Health Risk Reduction (WMC)
Metadata contact	El Morjani Zine El Abidine BP 3566 Poste Talborjt 80000 Agadir Morocco Telephone: +212 528 28 55 30 email: elmorjaniz@gmail.com
Metadata date	20110301
Metadata language	English
Metadata character set	ASCII
Metadata standard	ISO 19115