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B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

The contribution of remote sensing in hydraulics and hydrology, analysis and evaluation of digital terrain model for flood risk mapping

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Abstract

The study of flood risk involves the knowledge of the spatial variability in the characteristics of the vegetation cover, terrain, climate and changes induced by the intervention of humans in watersheds. The increased needs of the actors in land management mean that static maps no longer meet the requirements of scientists and decision-makers. Access is needed to the data, methods and tools to produce complex maps in response to the different stages of risk evaluation and response. The availability of very high spatial resolution remote sensing data (VHSR) and digital terrain model (DTM) make it possible to detect objects close to human size and, therefore, is of interest for studying anthropogenic activities. The development of new methods and knowledge using detailed spatial data, coupled with the use of GIS, naturally becomes beneficial to the risks analysis. Indeed, the extraction of information from specific processes, such as vegetation indices, can be used as variables such as water heights, flow velocities, flow rates and submersion to predict the potential consequences of a flood. The functionalities of GIS for cartographic overlay and multi-criteria spatial analysis make it possible to identify the flood zones according to the level of risk from the flood, thus making it a useful decision-making tool.

This study was carried out on the territory of watersheds in the Annaba region, East of Algeria. The choice was guided by the availability of data (satellites images, maps, hydrology, etc.) and hydrological specificities (proximity to an urban area). The adopted model is divided into two parts. The first part is to establish a methodology for the preservation of wetland biodiversity and the protection of urban areas against floods. Thanks to the multi-criteria spatial analysis and the functionalities of the GIS, we established a flood risk map for the watershed defined above. The result was satisfactory compared with the field reality. The second part of the model consisted of the integration of cadastral information with the flood risk map obtained in the first part of our research.

The primary objective of this mapping is to contribute to the development of flood risk management plans (in the sense of risk reduction). The mapping stage also provides quantitative elements to more accurately assess the vulnerability of a territory.

Key words: *Annaba, cadastral information, digital terrain model (DTM), flood risk, GIS, multi-criteria spatial analysis, remote sensing, VHSR*

INTRODUCTION

Risk research is not purely theoretical: the aim is often to improve decisions involving human lives and land uses through decision making which is better and thus permits guidance regarding the economic and social development of the sectors concerned [RENAUD 2006].

Many methods for acquiring geographic information are available. This study of natural hazards is based on the technological development of satellite imagery, including remote sensing from airborne or spaceborne platforms. These techniques and methods can be used at different stages in the risk management process: in anticipation of a hazardous event, in crisis management, and then for feedback and mitigation [CHARLEUX-DEMARGNE 2001].

Risk mapping requires a multidisciplinary approach (e.g. involving meteorology, hydrology, statistics, hydraulics, topography, geology, civil engineering, economy and environment). Once these data are collected, analysis makes it possible to control the use and the development of land. Any analysis of natural hazards must be carried out based on the understanding that risk mapping will allow planners to reduce hazards not eliminate them, because zero risk does not exist and knowledge is uncertain [PUECH, BAILLY 2003].

In this context, our study of flood risk aims to study the practical application of spatial information in the management process and more precisely its integration in the process of multi-criteria analysis allowing the reduction of relative uncertainties in our understanding of the risk.

STUDY AREA

The city of Annaba is located in the extreme North-East of Algeria next to the city of El-Taref, on the Mediterranean Sea (Fig. 1). It has an area of 1429 km^2, with an 80 km stretch of the coastline. It is bordered by the Mediterranean Sea to the North, the city of Guelma to the South, the city of El-Taref to the East and the city of Skikda to the West.

With its strategic geographic position the city of Annaba can play a relevant role in the development of the economic activity of Algeria. It is administratively organized in 6 districts and 12 municipalities, which are: Annaba, Seraïdi, El Bouni, El Hadjar, Sidi Amar, Ain Berda, Cheurfa, El Eulma, Berrahal, Oued El Aneb, Tréat, Chétaïbi. Its population is nearly 585,000 inhabitants, with a density of 415 inhabitants per km^2 [PDAU 2004].

What is the problem in the study area and how you want to solve or give solutions?

The city of Annaba and its region are on a flat plate; almost at sea level, limited to the west by the Edough mountain range. This mountainous slope pours all its rainwater towards the sea while crossing the city, which generates during the rainy period, often floods. The importance of quantifying this stormwater and the vulnerability of sites is necessary to make any flood control solution more rigorous.

The objective of our study is to establish a flood risk map, for which we have the topographic data, satellite imagery and other exogenous data.

DATA TYPOLOGY AND SOURCE OF ACQUISITION

The multi-source data used in the framework of this research were:

- **topographic maps**: our study area was covered by maps at a scale of 1:25,000;
- **the ESRI ArcGIS10.4**: tool was calibrated in UTM 32 Datum WGS 84 projection, which was the projection system of the ALSAT-2 image using easily identifiable points distributed homogeneously over the whole topographic map; this process was used to digitize the maps or to register the maps to the image;
- **the ESRI ArcGIS10.4** software is a geographic information system (GIS) tool used to create, process the geographic information map; it compiles, assembles; combines data; and creates thematic maps with generic vector or raster data;
- **ENVI software**: version 4.7 was used to carry out several processing on the image; numerous image analysis and processing tools (standard and new) are included in the software, such as classification, geometric corrections, spectral analysis tools, radar tools, X, Y, Z profile [GENDREAU 1999];

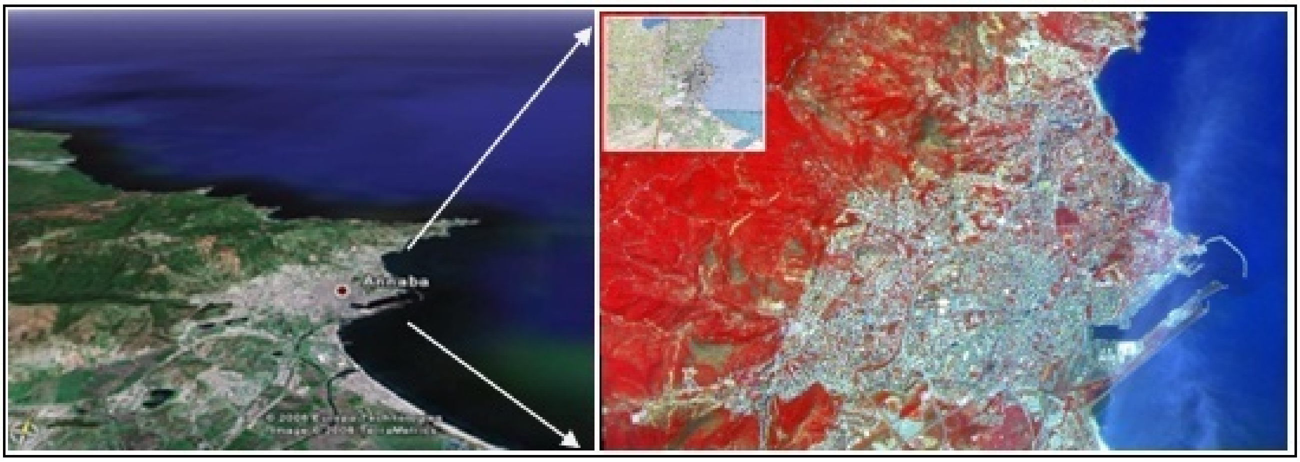

Fig. 1. Location of the city of Annaba; source: own elaboration

- **Image Alsat-2**: main characteristics of the image are:
  - date of the image: 30.09.2016,
  - the image spatial resolution is: 2.5 m (panchromatic), 10 m (multispectral, 4 bands), Swath: 17.5 km,
  - size of image: 17.5 km×17.5 km.

COLLECTED DATA PREPROCESSING SCENARIO

A flood risk mapping project requires the joint work of a multidisciplinary team and the use of as much data as possible to define the zones according to the degree of hazard and damage.

The following pre-processing was applied to the data to facilitate their subsequent integration in the GIS process [RADECKI-PAWLIK *et al.* 2014] to produce thematic maps necessary for the risk determination. From a technical point of view, they allow information to be extracted from the maps relating to the main parameters characterizing the watershed.

- **Topography**: a very influential parameter in hydrology, in particular in relation to the time that takes for water to flow from the top of the catchment to the watershed outlet (concentration time). When the concentration time is reached it means that all the regions of the watershed have participated in the flow. Steeper topography equates to a shorter concentration time.
- **Slope**: an important characteristic which illustrates the topography of the watershed. Moreover, slope influences the peak flow during a downpour.
- **The vegetation cover** and the type of soil are intimately linked, and together they influence surface flow. The vegetation cover retains a variable proportion of atmospheric moisture according to its density, its nature and the amount of precipitation.
- **The nature of the soil** intervenes in the rapidity of floods and in their volumes. The infiltration rate, retention capacity, initial losses and runoff coefficients are functions of soil type and thickness [KEBLOUTI *et al.* 2015].
- **Geology**: knowledge of the geology of a catchment is essential for the proper management of the physiographic characteristics. The geology of the substratum directly affects surface runoff and regional groundwater flow and the mechanics of fluids combined with the hydrochemistry and the permeability of the lands subsurface [RADECKI-PAWLIK *et al.* 2014].

FLOW CHART OF THE ANALYSIS PROCEDURE

The data analysis chain passed through several processing and control steps, set out in (Fig. 2). The satellite data were geometrically corrected to allow accurate overlay on the cartographic documents on one hand, and to the cadastral data on the other [BOUZAHAR 2010; LEGATES, MCCABE 1999]. Improved processing (e.g. filters and trichromy) was performed subsequently to select the different training zones. The analysis carried out on the samples allowed us to optimize the choice of the classes to be highlighted. Then two methods of automatic classifications (minimum distance and maximum likelihood) were tested. We chose the maximum likelihood criterion [HUET *et al.* 2003], which is based on a probability criterion for the assignment of pixels because it gave us a good result given the location of certain classes in relation to their geographical and topographical situations [ZOPE *et al.* 2015]. The result of the classification allowed us to extract different land use classes over the whole zone.

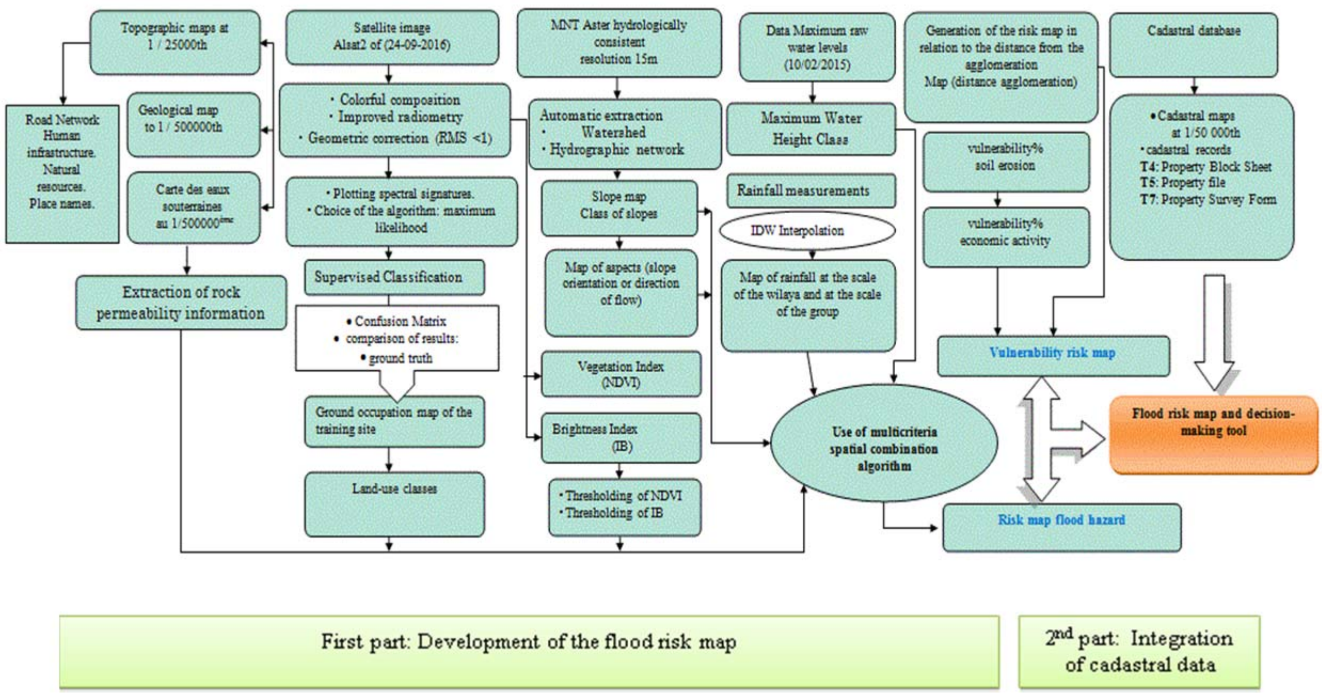

Fig. 2. Model for decision-making; own elaboration

ANALYSIS PERFORMED ON THE ALSAT-2 IMAGE

COLOUR COMPOSITION

Colour composition, as shown in Figure 3, is a useful and widely applied processing. It consists of superimposing images of different wavebands to obtain a coloured output that allows us to extract as much information as possible about the different land use themes. Our choice was based on the RGB tri-chromy [DAOUD 1994]. The red colour is assigned to channel 1; the green colour to channel 3 and the blue colour to 4. This colour combination is rich in information on vegetation themes which stand out in shades of red and the urban fabric which are coloured in cyan.

GEOMETRIC CORRECTION

Satellite images contain spatial distortions due to satellite's movements. Moreover, these data are not represented according to a current cartographic projection [BOUZAHAR 2010; HOSTACHE 2006]. For a very specific application it is necessary to carry out a spatial transformation of the image using geometric correction.

Geometric correction is the suppression of measurement errors induced by the sensors and the satellite so that the data conforms to the required projection system. This is made possible by locating each pixel in its exact place in the cartographic system used [ESCADAFAL 1992]. This correction allows:
– unification of the cartographic system;
– the creation of ortho-images and mosaics;
– the combination of several images;
– better integration of the images in databases or GIS.

For our study, the images used presented by some number of deformations due to the system of collection, the relief and the curvature of the earth, making geometric correction essential. To correct the image, we collected ground control points (GCP) in the field with a Garmin 12 X portable GPS. The acquisition of these points was one of the most important operations in the process, as it affects directly the results of the geometrical correction. The three most important factors that must be considered are:
– the good accuracy in the location and determination of coordinates in the defined reference system;
– the good spatial distribution of points;
– a sufficient number of points.

To correct our image, we selected ten notable points that we could identify on the ground and on the satellite image to be corrected.

For geometric correction, we used a first degree polynomial model and nearest neighbour interpolation. The latter preserved the dynamics of the image and therefore was better adapted to our objective. The geometric correction was relatively accurate with a root mean square error (RMS) of less than 1 pixel so the location of a given target could be assessed with a satisfactory precision.

SUPERVISED IMAGE CLASSIFICATION OF ALSAT2

To identify the various classes of land use, we focused on specific computer processing techniques such as supervised multispectral classification. [ROBIN 2000].

MAXIMUM LIKELIHOOD CLASSIFICATION

This classification method is widely used in the field of satellite image [ESCADAFAL 1992; STRAHLER 1997]. The approach is based on a priori knowledge of field data. The previously identified field classes are analysed based on their spectral signatures (mean, variance and standard deviation).

Pre-processing of the Alsat 2 image, improvement of the radiometry and preparation of the information layers (Fig. 4).

The decision criterion is the probability that a pixel belongs to a specific class. The classification is made from the covariance matrices calculated for each learning class, between the radiometric bandwidths of the scene. There

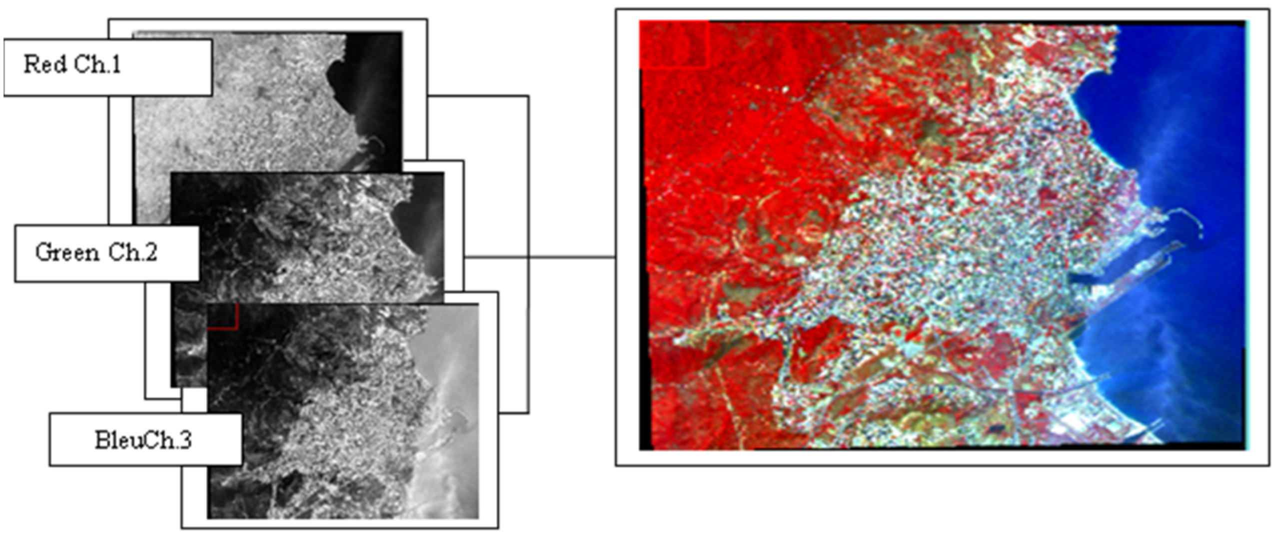

Fig. 3. Coloured composition, extraction and improvement of radiometry; source: own elaboration

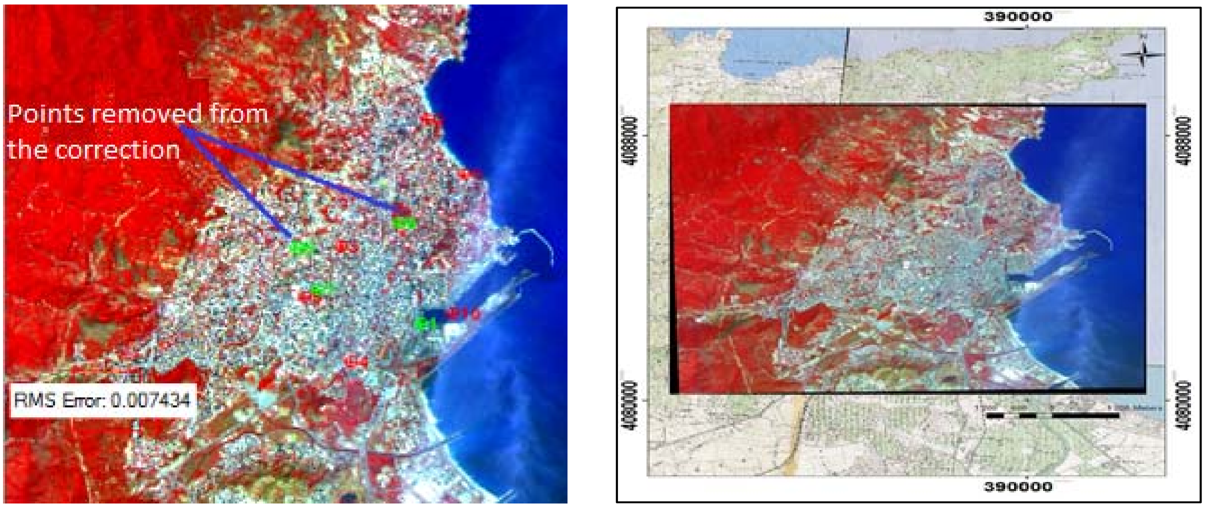

Fig. 4. Geometric correction of the Alsat-2 image; source: own study

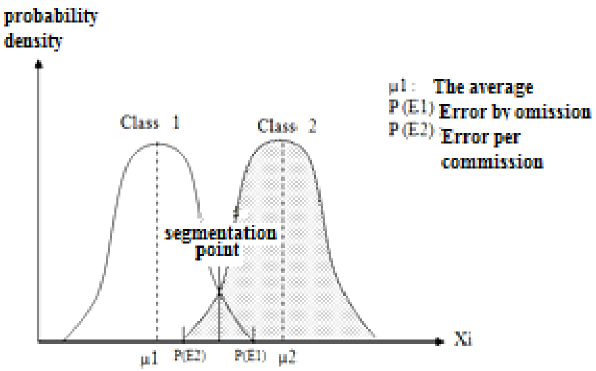

Fig. 5. Segmentation of the spectral space by the maximum likelihood; source: BONN, ROCHON [1992]

are two main requirements for the maximum likelihood classification (Fig. 5) which should be noted, namely:

❖ the assumption of a Gaussian distribution of the radiance values for each land-use class (training areas);
❖ the selection of training areas, based on knowledge of the ground truth, with the following criteria:
  - homogeneity;
  - the representativeness of the taxon considered;
  - a large enough size so that samples can be spotted on the image without difficulty and without risk of generating spatial heterogeneity;
  - a sufficient number (from 3 to 5 samples for each class) so that to avoid selecting a statistically isolated sample.
  - a complete classification is thus made in two phases:
  - a learning phase which consists of defining in a working image the geographical position of the classes, based on:
    – mean: a single value, which best sums up a set of given radiometry values;
    – standard deviation: the smaller the sample, the more homogeneous the sample;
    – covariance and correlation: an image is more interesting to observe if the information is more contrasted. The variance can serve as a measure for this wealth of information. If we have no prior information to guide us in the choice of bandwidths, it will be interesting to opt for the classes that are as uncorrelated as possible;
  - the classification itself assumes that the multispectral distribution [CNES 1999] for each class is a multidimensional Gaussian; the aim of this method is to assign each pixel to the class where it has the strongest probability of belonging.

$$P(C_i/x) = \frac{P(x/C_i)P(C_i)}{P(x)} \quad \text{(Bayes theorem)} \qquad (1)$$

Where: $P(C_i/x)$ = the a posteriori probability of pixel x coming from class i; $P(x/C_i)$ = the a priori probability of pixel x belonging to class i; x belongs to the class i.

So $P(C_i/x) > P(C_j/x)$

Which amounts to writing:

$$P(x/C_i)\cdot P(C_i) > P(x/C_j)\cdot(P(C_j) \qquad (2)$$

In practice

$$P(C_i) = P(C_j) \qquad (3)$$

From where

$$P(x/C_i) > P(x/C_j) \qquad (4)$$

By positing the Gaussian hypothesis, $P(X/C_i)$ is written as a function of the probability density.

$$P(X/C_i) = \frac{1}{2^{K/2}|\Sigma_i^{-1}|} \exp -0.5(X - \overline{X_i})T\, \Sigma_i^{-1}(X - \overline{X_i}) \qquad (5)$$

Where: K = number of channels; Σ_i^{-1} = variance matrix – covariance; $\overline{X_i}$ = average for class i; X = vector of observation.

CLASSIFICATION USING THE MAXIMUM LIKELIHOOD ALGORITHM

This classification is based on a priori knowledge of the area to be mapped. Its main characteristics are that (1) classes and their spectral characteristics are defined prior to classification; and (2) the classes are defined on the basis of training zones which are representative samples of the classes (Fig. 6).

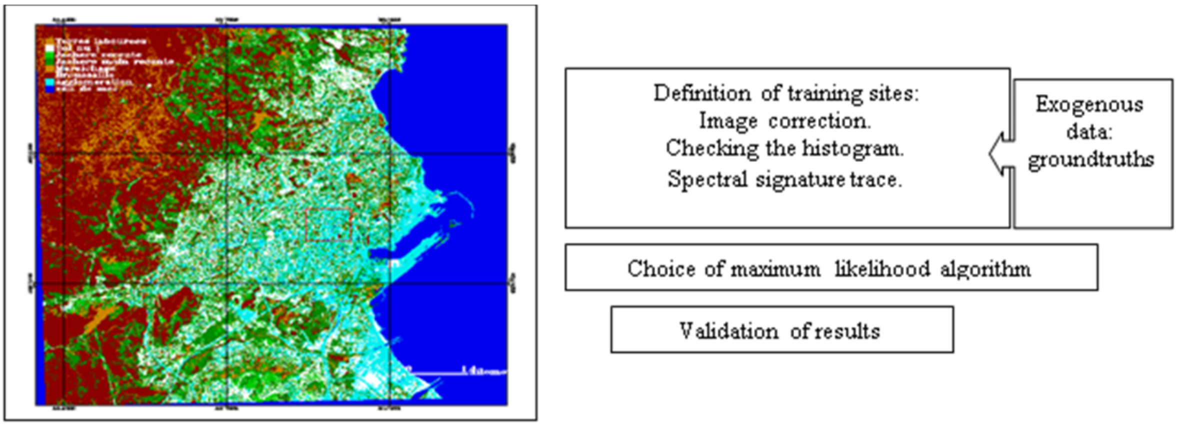

Fig. 6. The maximum likelihood supervised classification; source: own study

DESCRIPTION OF CLASSES

Classes were described using statistical parameters (mean, minimum, maximum, variance) calculated from the training areas on the image, as depicted on Figure 6. If we take the example of the agglomeration sample, we will note that it has an important standard deviation in the different channels, which may cause problems in the classification and may confuse certain classes with one another. For this reason, we chose the most homogeneous sample possible, which separates this class from the others.

Table 1. Statistical parameters of some samples

Band	Min	Max	Mean	Standard deviation
Sample agglomeration				
4	212	255	248.11	4.15
3	228	255	251.85	2.31
1	232	255	252.47	3.99
Sample fallow soil				
4	47	54.15	50.58	2.50
3	166	205.00	187.44	1.50
1	52	68.30	60.16	1.68

Source: own elaboration.

The sample of fallow soil is well represented in both channels 1 and 4. It has a standard average deviation (Band 4 = 2.5509928, Band 1 = 1.675641) and represents an acceptable standard deviation in Band 3.

VEGETATION INDEX AND BRIGHTNESS INDEX

Using the *NIR* (near infrared) and *IR* (infrared) bands of Alsat-2, the plant tissue represented in black (Fig. 7) [PUECH, BAILLY 2003].

$$NDVI = (NIR - R) / (NIR + R) \quad (6)$$

By using the *NIR* and *IR* bands of Alsat2 the urban fabric represented in white (Fig. 8), this index is therefore sensitive to the brightness of the soils [AUZET 1987].

$$IB = \sqrt{R^2 + NIR^2} \quad (7)$$

The vegetation cover makes it possible to organize the flow of water and also to limit the concentration of runoff. Various structures exist to retain water, at least temporarily, from the upstream areas of the watershed, which limit the peak flows and avoid the incision of the concentration zones [ROBIN 2000] and, if necessary, causes the sedimentation of solids [SCHAEFLI, GUPTA 2007].

DIGITAL TERRAIN MODEL (DTM)

The DTM digital elevation model altitude grid allowed us to delimit the watersheds and the hydrographic networks entering the perimeter [NASH, SUTCLIFFE 1970] of the city of Annaba. The resultant product can be used for multiple applications. In our case [MCCUEN *et al.* 2006], we used it to identify the area subject to flood risk as well as for the spatial integration of values (degrees of risk).

MODELING AND MULTI-CRITERIA SPATIAL ANALYSIS

The use of ArcGIS spatial analysis requires the use of criteria that reinforce or reduce the relevance of a particular alternative to the activity considered [ARNOLD *et al.* 1998; GENDREAU 1999]. These criteria can be expressed on a continuous scale of measurement. For example, the lower the slope of the terrain, the higher will be the human pressure. The most important step for data modelling is to identify the different criteria that can be considered by the combination in the weighted analysis. The identification of criteria was based on the consideration of the watershed characteristics and the geographical conditions [DESACHY 1980].

In this first part of the work, we tried to integrate all the information extracted from the satellite imagery database and the various maps cited in the processing chain to improve the quality of data and help decision-making for flood control measures (Fig. 9–11). Dataset given by KASHID *et al.* [2010] was prepared for integration into the GIS in ArcGIS. Preferences for the analytic hierarchy process (AHP) method varied between 1 and 9 according to the Saaty scale [BENSAID *et al.* 2007].

Fig 7. Normalized difference vegetation index (*NDVI*) classes; source: own elaboration

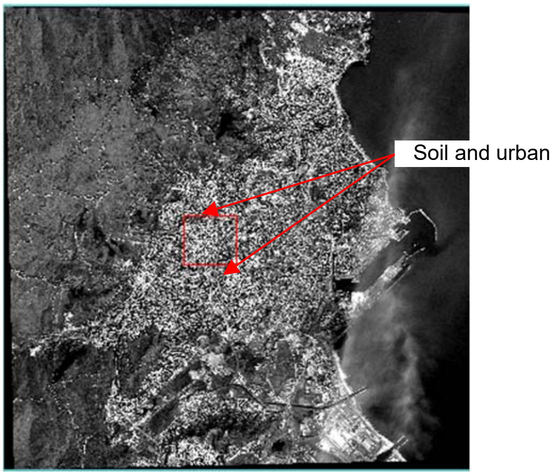

Fig. 8. Brightness index (*IB*) classes; source: own elaboration

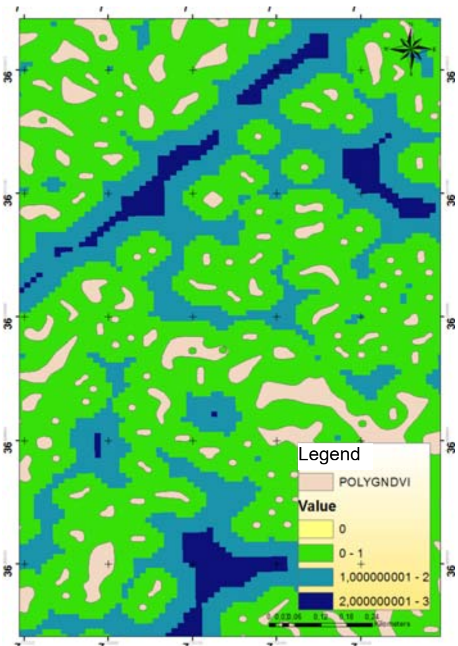

Fig. 9. Proximity criterion with respect to built-up areas; source: own elaboration

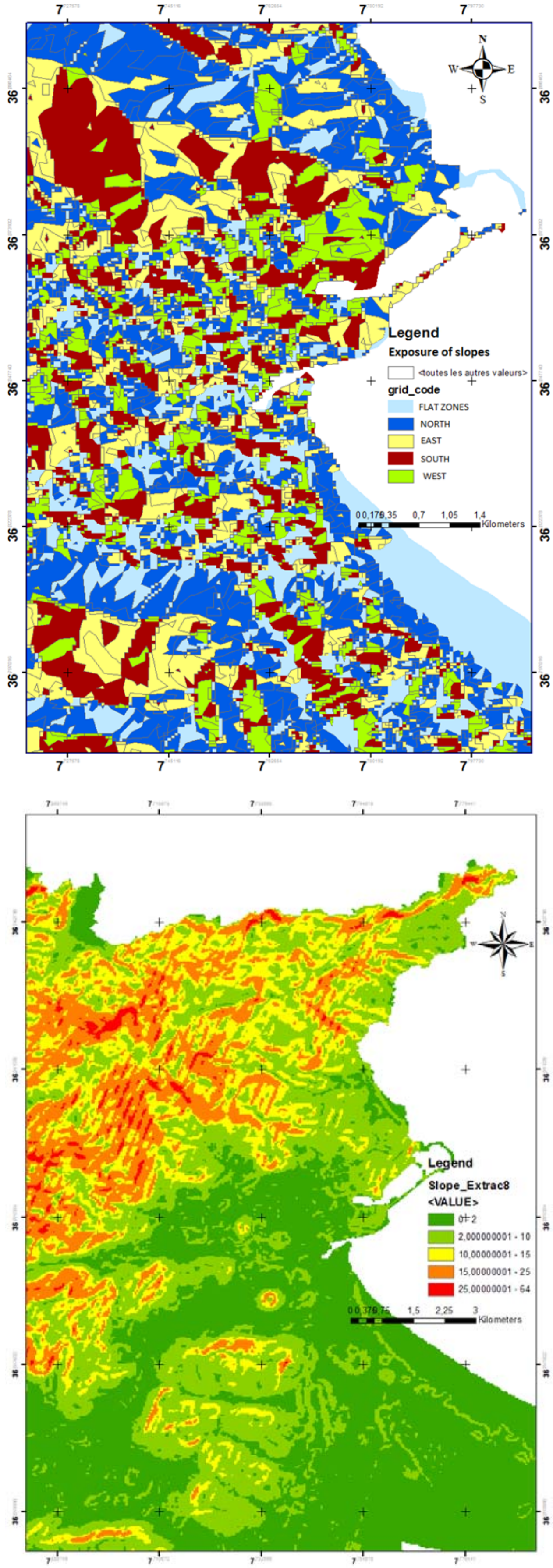

Fig. 10. Maps of slopes and the elements from the digital terrain model – DTM ArcGIS10.4; source: own elaboration

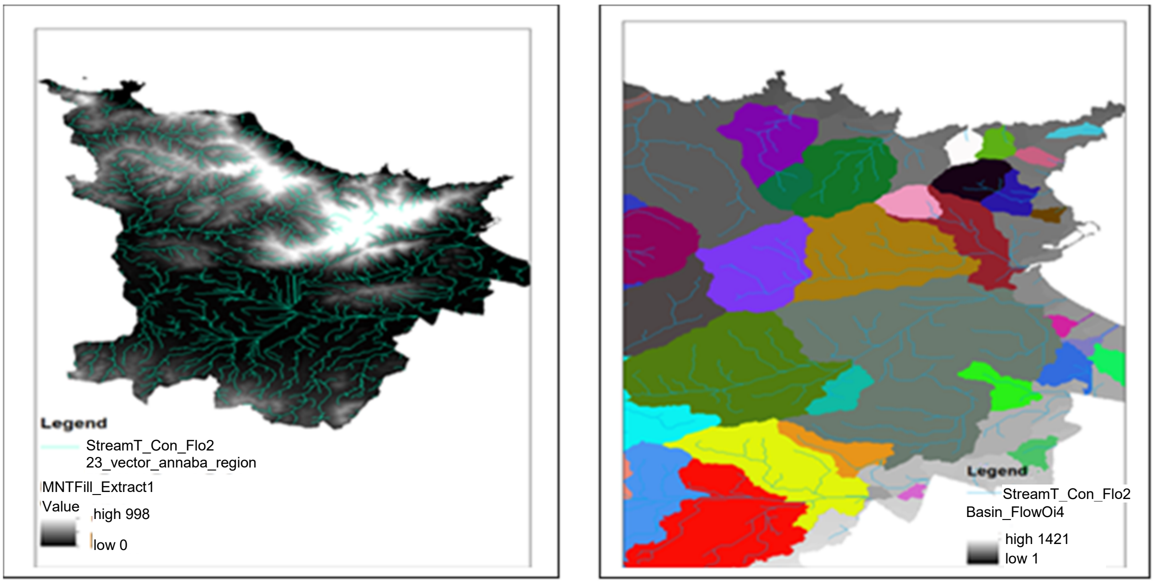

Fig. 11. Extraction of the hydrographic network and delimitation of watersheds by digital terrain model (DTM); source: own elaboration

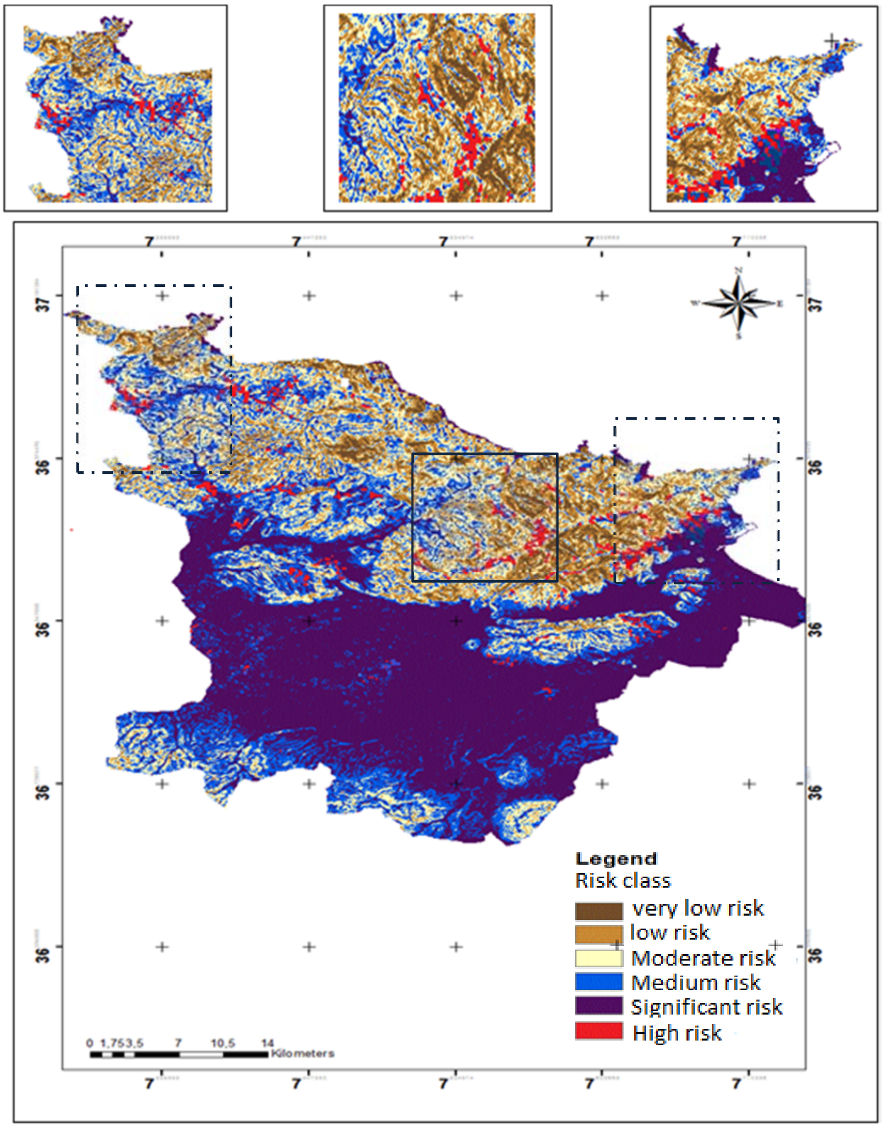

Fig. 12. Flood risk map obtained using the proposed modelling solution; source: own elaboration

The coherence index for the verification of the weight matrices AHP coherence ratio was $Cr < 0.10$ [REINELT *et al.* 1991]. The standardization of the various layers of information consisted of unifying the scales of the values and the spatial resolution of the images. The design standards for databases have been respected, in particular for the logical consistency and the redundancy control.

DISCUSSION

The risk of damage (low, medium or high) due to flooding by stream flows from the combination of the various criteria was integrated into the multi-criteria combination using products derived from the Alsat-2 image and the hydrological parameters. The risk of damage will be high for a house situated in a high hazard zone and, conversely, the risk of damage will be low for a grass land in a low hazard area.

Figure 12 confirms the accuracy of our results, given that high-risk areas are located near the main watercourse and in zones that are less permeable and less rugged and, therefore, the most urbanized.

RESULT AND DISCUSSION (PART ONE OF THE PROCESSING CHAIN)

The use of ESRIArcGis spatial analysis requires the use of criteria that reinforce or reduce the relevance of a particular alternative to the activity in question. These criteria can be expressed on a continuous measurement scale. For example, we can estimate that the lower the slope of the terrain [SAGHAFIAN *et al.* 2008] the stronger the human pressure.

The most important step for data modelling is that of identifying the different criteria that can be considered by the combination during the spatial analysis (weighted overlay). Criteria identification is based on consideration of the watershed characteristics and the geographical conditions [MARTIN *et al.* 2005]. In this study, we have been able to develop a methodology to achieve a knowledge objective of flood risk. This will help make the right planning choices to respect the diversity of issues along a watercourse and favouring regional planning that takes better account of the risk of flooding.

Finally, we concluded that the areas on the banks of the wadis are the most vulnerable flooding areas from the watersheds of the city of Annaba, Algeria. This vulnerability to flooding is linked essentially with the topography and incompetence of sanitation network.

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Faiza hassainia BOUZAHAR, Lahbaci OUERDACHI, Mahdi KEBLOUTI, Akram SEDDIKI

Wkład teledetekcji do hydrauliki i hydrologii, analiza i ocena numerycznego modelu terenu do mapowania ryzyka powodzi

STRESZCZENIE

Badanie ryzyka powodzi wymaga wiedzy o przestrzennej zmienności pokrywy roślinnej, terenu, klimatu i zmian wywołanych interwencją człowieka w zlewniach. Zwiększone potrzeby uczestników zrządzania gruntami oznaczają, że statyczne mapy nie spełniają już wymogów stawianych przez naukowców i decydentów. Potrzebny jest dostęp do danych, metod i narzędzi, aby wytworzyć złożone mapy niezbędne na różnych etapach oceny ryzyka. Dostępność teledetekcji o bardzo wysokiej rozdzielczości (VHSR) umożliwia wykrycie obiektów o rozmiarach człowieka i dlatego jest przedmiotem zainteresowania w badaniach aktywności antropogenicznej. Rozwój nowych metod i wiedzy z zastosowaniem szczegółowych danych przestrzennych w powiązaniu z GIS przynosi korzyści w analizie ryzyka. Istotnie, pozyskiwanie informacji (np. wskaźniki roślinne) o specyficznych procesach może być wykorzystane, podobnie jak inne zmienne, np. wysokość wody, prędkość przepływu, natężenie przepływu czy zasięg zalewu, do przewidywania potencjalnych skutków powodzi. Możliwość nakładania danych w GIS i wielokryterialna analiza przestrzenna umożliwia zidentyfikowanie stref powodziowych według poziomu zagrożenia, czyniąc ją użytecznym narzędziem w podejmowaniu decyzji.

Przedstawione badania prowadzono w zlewniach regionu Annaba we wschodniej Algierii. W trakcie wyboru kierowano się dostępnością danych (obrazy satelitarne, mapy, hydrologia etc.) i szczególnymi właściwościami hydrologicznymi (bliskość obszarów miejskich). Przyjęty model podzielono na dwie części. Pierwsza faza polegała na ustaleniu metodologii ochrony różnorodności biologicznej środowisk podmokłych i ochrony terenów zurbanizowanych przed powodzią. Dzięki wielokryterialnej analizie przestrzennej i możliwościom GIS utworzono mapę ryzyka powodziowego dla tak zdefiniowanej zlewni. W porównaniu z realiami terenowymi wynik okazał się satysfakcjonujący. Druga faza modelu polegała na integracji informacji katastralnych z mapą ryzyka powodzi uzyskaną w pierwszej części badań.

Podstawowym celem mapowania było przyczynienie się do rozwoju planów zarządzania ryzykiem powodziowym (ostatecznie: ograniczenia ryzyka). Etap mapowania zapewnił także ilościowe podstawy do dokładniejszej oceny podatności badanego terenu na zalanie.

Słowa kluczowe: *Annaba, dane katastralne, GIS, numeryczny model terenu, ryzyko powodzi, teledetekcja, VHSR, wielokryterialna analiza przestrzenna*