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Natural Hazards and Earth System Sciences

Historic records and GIS applications for flood risk analysis in the Salento peninsula (southern Italy)

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Abstract. The occurrence of calamitous meteoric events represents a current problem of the Salento peninsula (Southern Italy). In fact, flash floods, generated by very intense rainfall, occur not only in autumn and winter, but at the end of summer as well. These calamities are amplified by peculiar geological and geomorphological characteristics of Salento and by the pollution of sinkholes. Floodings affect often large areas, especially in the impermeable lowering zones. These events cause warnings and emergency states, involving people as well as socio-economic goods.

A methodical investigation based on the historic flood records and an analysis of the geoenvironmental factors have been performed, using a Geographic Information System (GIS) methodology for database processing in order to identify the distribution of areas with different risk degrees. The data, referring to events that occurred from 1968 to 2004, have been collected in a database, the so-called IPHAS (Salento Alluvial PHenomena Inventory), extracted in an easily consultable table. The final goal is the development of a risk map where the areas that are affected by floodings are included between small ridges, the so-called "Serre". More than 50% of the Salento peninsula shows high or very high risk values. The numerous maps that were utilized and generated represent an important basis in order to quantify the flood risk, according to the model using historic records.

1 Introduction

1.1 Foreward

This paper has been extracted from a PhD thesis submitted in the Department of Geology and Geophysics of Bari University and deals with flood phenomena which occur periodically in the Salento peninsula (southern Italy), causing warning and emergency states to the population and economic activity.

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1.2 Geological and geomorphological settings

The Salento peninsula, the southeast portion of the Apulia region (southern Italy), covers 7000 km^2 of area and stretches over 150 km between the Ionian and Adriatic seas (Fig. 1). The peninsula includes two extreme geographical points: the Punta Palascìa, near *Capo d'Otranto* and the Punta Rìstola, near *Capo S. Maria di Leuca*, in the final strip of the Apulia region.

Geologically, the substratum of the Salento peninsula is a carbonatic shelf, 6000 m thick, represented by limestone, dolomitic limestone and dolomite strata, originating from the Jurassic to the Upper Cretaceous (Maastrichtian) periods (Ricchetti, 1988; De Giorgi, 1884, 1922, 1960). In the lowering zones, there are impermeable mio-plio-pleistocenic sediments with clay insertions which stand on limestone, dolomitic limestone and dolomite (Ciaranfi et al., 1988; Largaiolli et al., 1969) (Fig. 2).

Morphologically, the Salento area is a flat area with elevations just above sea level. It is characterized by small ridges, the so-called "Serre salentine", extending in a SE-NW direction (Martinis, 1962, 1967a, b, 1970). They had originated by tectonic stresses acting during the Cretaceous period until the Upper Pleistocene period, mainly along SSE-NNW and SSW-NNE directions, resulting in slopes of normal fault and, therefore, Horst and Graben structures (Battista et al., 1985) (Fig. 3).

The landforms described represent the main aspect of "Terra d'Otranto", but not the only one: in fact, also the rainfall effects and karstic phenomena are easily recognizable in this landscape.

Furthermore, on the Salento peninsula two kinds of streams can be distinguished: on the one hand, an endoreic type, which is comprised by relatively wider canals and on the other hand, an exoreic one, which is represented by small canals, but hierarchized (Battista et al., 1985). The endoreic

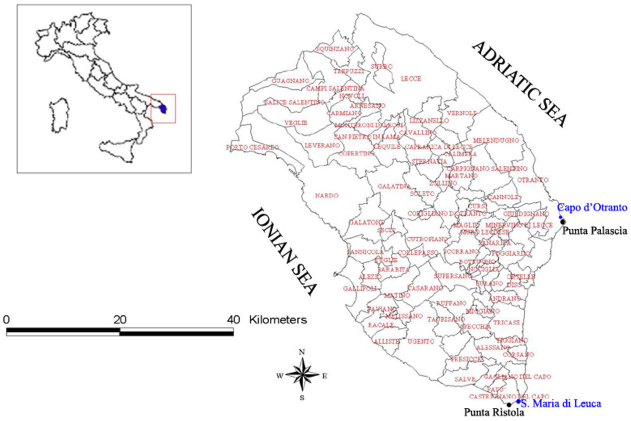

Fig. 1. Municipal limits.

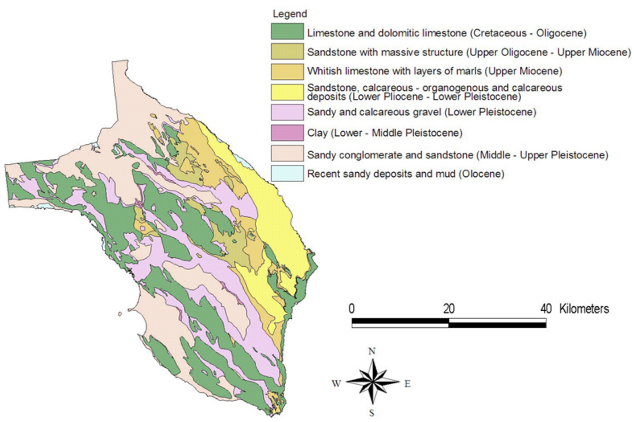

Fig. 2. Geolithological map of Salento peninsula.

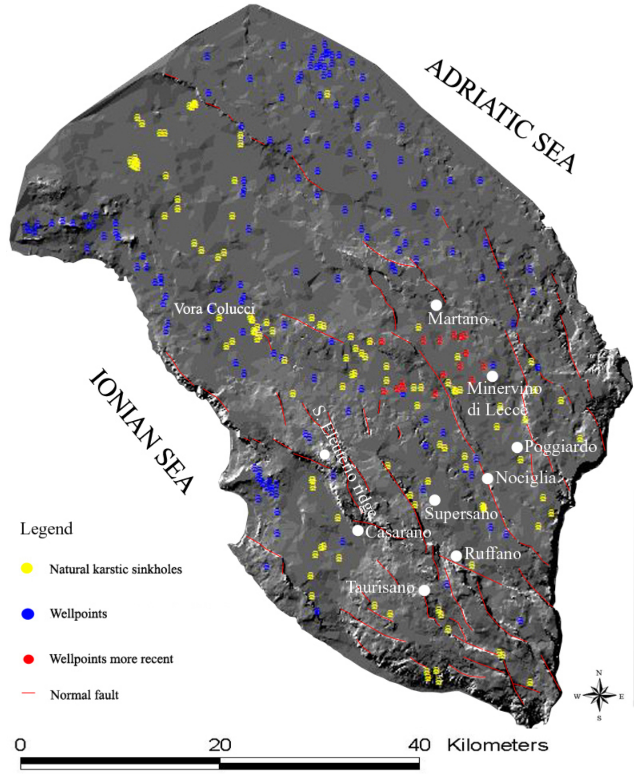

Fig. 3. DTM (Digital Terrain Model) of Salento peninsula from the isolines of 1956.

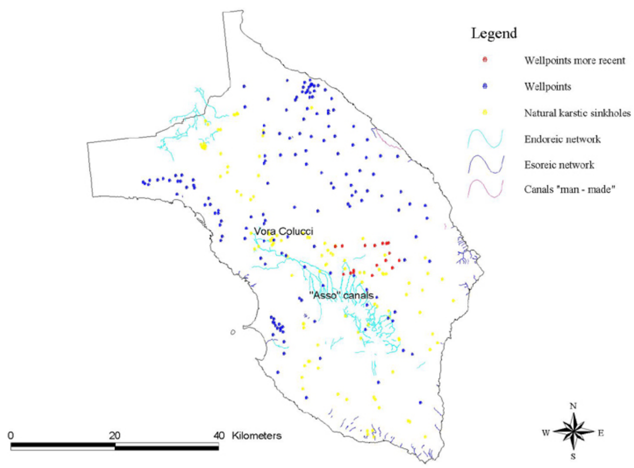

Fig. 4. Location of karstic sinkholes, wellpoints and main drainage canals.

network, represented by canals, the so - called "Asso" canals, is asymmetric and aligned along a SSE-NNW direction. It is converging towards a natural karstic sinkhole, the so - called "Vora Colucci", near Leverano municipality. The channels in the exoreic network, in turn, are in many places deep and located in the coastal zone. This network is conditioned by tectonic stresses. Numerous small valleys are parallel to each other, but perpendicular to the coastline (Fig. 4).

These peculiar geological and morpho-structural characteristics make some areas of the Salento peninsula susceptible to floodings, mainly when the rainfall is very intense.

1.3 The rainfall distribution on the Salento peninsula

Rainfalls that are very intense but short are the main cause of flood occurrences. Generally, the climate of the Salento peninsula can be defined as "Mediterranean". The rainfall is not homogeneous, so that areas with different rainfall distributions can be recognized in the Salento peninsula. This concept has been exposed already by De Giorgi (1884), Colamonico (1917, 1956), Bissanti (1968) and subsequently by Zito et al. (1988). The processing of rainfall data shows that high values of annual mean rainfall are concentrated in the eastern part of Salento, where 790 mm/year of rainfall are registered on average. On the other hand, low values of mean annual rainfall are concentrated (590 mm/year) in the western part (Fig. 5). Figure 5 was obtained by an interpolation method in a GIS (Geographic Information System) software and depicts the distribution of mean annual rainfall values and the location of 14 pluviometric stations, continuously in operation since 1921. However, recently, the average rainfall has strongly decreased, giving rise to a long period of drought

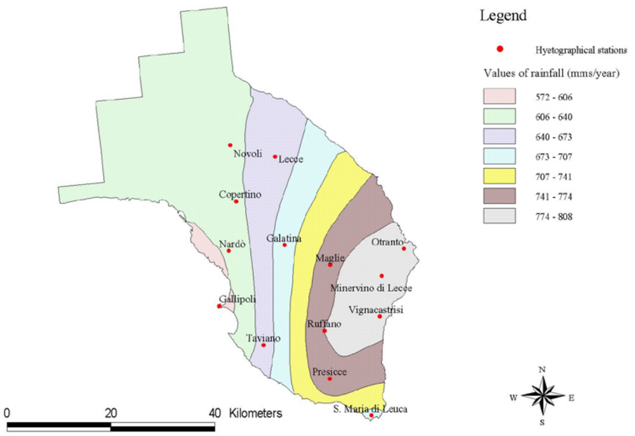

Fig. 5. Rainfall map of Salento peninsula.

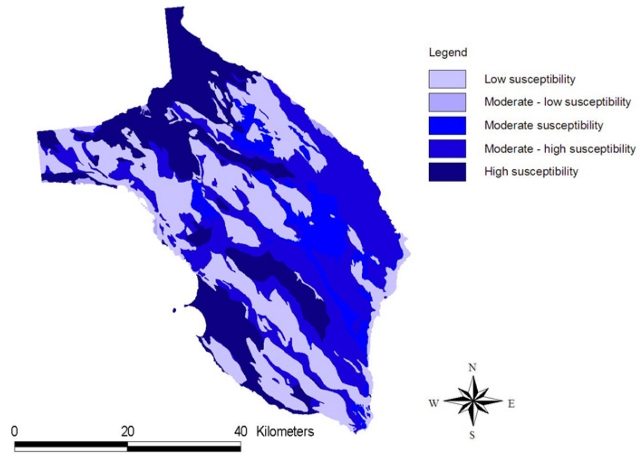

Fig. 6. "Susceptibility to flood" map of Salento peninsula.

(Arnell, 1999). The results obtained from a recent study of Zito (1989) show that drought periods of 50 consecutive days occur very frequently in summer, in the Salento peninsula. For instance, at Gallipoli municipality, these drought spells occur every two years, while at Otranto municipality, every 3.1 years. Therefore, the Salento area actually shows climatic characteristics which can be defined as almost semi-arid (temperatures over 40°C and insufficient precipitation); the dryness is concentrated in the summer months, whereas the rainfall is mainly concentrated in autumn-winter, but also at the end of summer (Battista et al., 1987).

However, in Salento, the meteorological changes are very frequent, giving the climate a characteristic of an "unstable whim", already recognized by Costa (1834), two centuries ago.

2 Methods

In a similar study of flood hazard and risk, a methodical investigation based on the historic flood records (Cook, 1987; OFDA, 1996; CNR – GNDCI, 1998; Spaliviero, 2003) and an analysis of the geoenvironmental factors have been performed (Bersani, 2004). Such an analysis is undertaken through the mapping of these geoenvironmental factors, where the classes are defined by numerical indices. This model has been improved by means of techniques and instruments of data acquisition: particularly, through the development of statistical packages applied to the different factors as well as through GIS softwares, used for the management and processing of georeferenced data for large areas (Johnston, 1998; Meijerink et al., 2003; Daniels, 2003). Consequently, the method can be articulated in five research phases:

– Identification of the flood distribution at a scale of 1:25,000 (maps showing flood susceptibility and flood locations);

– Detailed study of geoenvironmental factors and causes determining the natural disasters;

– A "return times" calculation;

– Identification of the elements at risk and vulnerability, depending on the expected damage;

– Analysis of the flood risk, expressed by indices.

The initial phase of this research effort has entailed the creation of an alphanumerical database, the so-called IPHAS (Salento Alluvial PHenomena Inventory), in which the municipalities affected by floodings in the time interval from 1968 to 2004 have been catalogued. For the data processing, data of the AVI (Italian Vulnerable Areas) project of CNR-GNDCI (National Council of Research) for the time interval of 1968–1999 as well as data of local/national newspapers ("Gazzetta del Mezzogiorno", "Quotidiano di Lecce", "La Repubblica" and "Il Messaggero") and data of a field survey conducted for the subsequent time interval 1999–2004, have been taken into account and integrated. A map showing flood susceptibility has been computed (Fig. 6). The production of this map has considered the environmental factors leading to floods (lithology and the fracture network of the stratigraphic units, slope and runoff) and is used to create digital models in order to attribute susceptibility rates. The environmental susceptibility is given by the addition of susceptibility rates (Carrozzo et al., 2003). In addition, a flood location map (Fig. 7) at a scale of 1:25 000 has been mapped over the DTM. These maps, supported by a geolithological map, permeability map and rainfall map, have allowed to identify the hazard factor and the hazard areas. With regard to the flood vulnerability factor, the land – use map was linked with the flood location map and the 'susceptibility to flood' map. By crossing hazard and vulnerability factors, and subsequently using indices obtained from the ArcGIS 8.3 software in order to identify the risk classes, the flood risk was mapped. Furthermore, this developed model has been based on a field survey, an aerial photos study, an interpretation of a DTM sequence and rainfall data analysis. Mean annual and hourly rainfall data were compiled for the time period of 1968 until 1996. Rainfall data from 1996 until today were

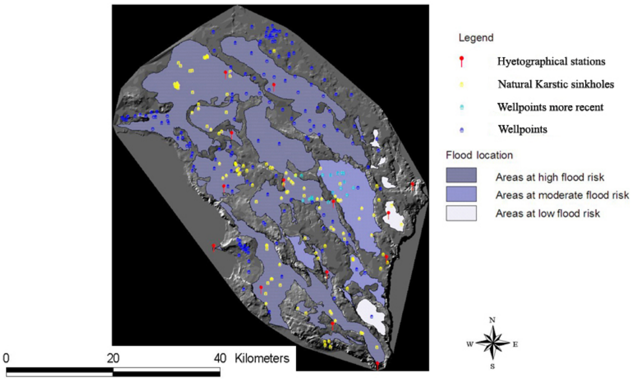

Fig. 7. Flood location map on DTM (Digital Terrain Model) of Salento peninsula.

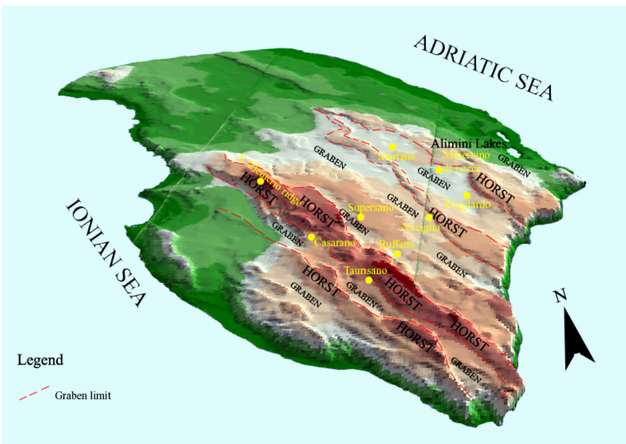

Fig. 8. DTM (Digital Terrain Model) of Salento peninsula from the isolines of 1976.

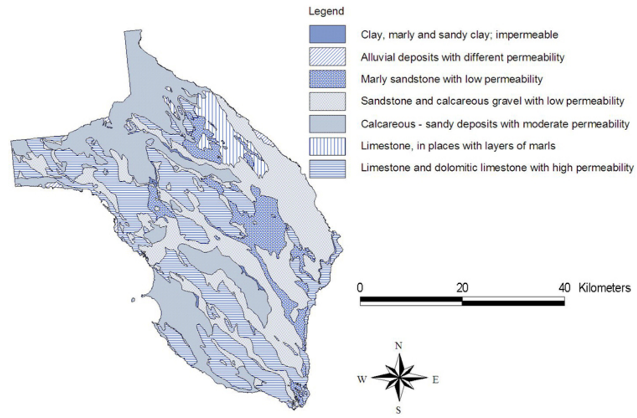

Fig. 9. Sketch of permeability map of Salento peninsula.

not available. With regard to the DTM sequence, the first one (Fig. 3) is computed from the isolines of an aerial photos survey of 1956, while the second one (Fig. 8) is computed from the isolines of an aerial photos survey of 1976. The difference between the DTMs shows the topographical evolution of Salento in time and space. In fact, small differences can be observed, mainly below the ridges. These differences probably are due to agricultural and pastoral activity as well as waterflows. In fact, very intense rainfall erodes the alluvium of a slope fault. The alluvium, transported by water, is redeposited in the lowering zones, filling them slowly and entirely after each flood event. This observation of a continuous slow migration of the lowering zones is important in order to classify the floodings, mainly in terms of the morphometry of floodings and the hydraulic parameters and characteristics (Forte, 2005).

An inspection of the DTM of Fig. 8 reveals that the morphology includes Horst and Graben structures, two lowering zones generated by tectonic stresses and presently occupied by lakes, the so-called Alimini lakes. In turn, an inspection of the 3D model of Fig. 3 reveals the topography of Salento, with a double system of normal faults and the distribution of the mainly karstic sinkholes and wellpoints. Even though Salento is a karstic region, practically without streams, some areas are periodically inundated because the sinkholes and drainage canals, frequently polluted, do not allow for the absorption or further conveyance of rainfall. The floodings cause damage to economic goods in the urban and suburban areas that are located in the lowering zones, where impermeable sediments, such as silt and clay, hinder floods (Fig. 9).

3 Results

3.1 Flood hazard assessment

Hazard mapping is an essential step in the determination of the past and potential locations of flooded areas (Landesman, 2001). With regard to the evaluation of the environmental hazard, a model in GIS software based on index assessment has been adopted in the past (Bolt, 1975). Such an approach takes into consideration the environmental factors causing the flood conditions (Carrozzo et al., 2003). These are the following: 1) permeability of lithological units; 2) slope and 3) flood location.

With regard to the hazard index of permeability of the lithological units, the floodings occur on every lithological unit. However, the floodings are more extensive on silt and clay than on limestone and sandstone, resulting in higher index values for the silt and clay units. With respect to the hazard index of slope, the floodings occur more frequently on flat areas than on slopes, thus leading to higher index values for flat areas. Finally, with regard to the hazard index of flood location, the distance from drainage canals and sinkholes/wellpoints has been considered. Areas nearest to sinkholes/wellpoints and drainage canals are more frequently flooded and, therefore, the index of hazard is assigned a higher value (Mijatovic, 1987; Molina et al., 1987; Andah et al., 1998; Hudson, 2003).

Commencing with these literature data, the characteristics of rainfall (mainly very intense but short rainfall, expressed as average monthly rainfall) have been considered in order

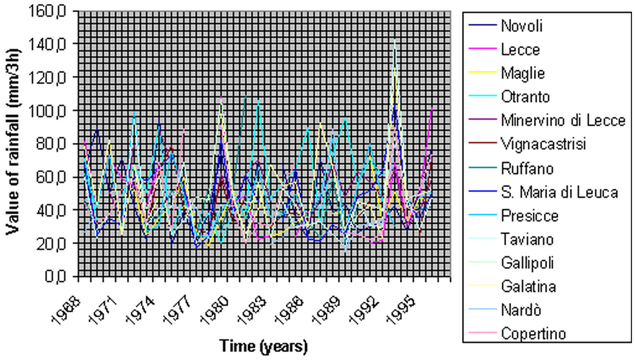

Fig. 10. Annual trend of rainfall with reference to a time period of 3 h.

Table 1. Values of return time (T_r, in years) and number of flood events (N) extracted from "IPHAS" historic database.

	T_r	N		T_r	N
Acquarica del Capo	12	3	Monteroni di Lecce	12	3
Alessano	18	2	Morciano di Leuca	18	2
Alliste	18	2	Muro Leccese	12	3
Aradeo	12	3	Nardò	5.1	7
Calimera	36	1	Nociglia	12	3
Campi Salentina	7.2	5	Novoli	18	2
Caprarica di Lecce	36	1	Otranto	36	1
Carmiano	18	2	Parabita	36	1
Casarano	9	4	Patù	36	1
Castrì di Lecce	36	1	Poggiardo	6	6
Castro	36	1	Porto Cesareo	18	2
Cavallino	9	4	Presicce	36	1
Collepasso	12	3	Racale	18	2
Copertino	5.1	7	Ruffano	9	4
Corigliano d'Otranto	18	2	SanCesario di Lecce	36	1
Corsano	18	2	San Donato di Lecce	18	2
Cutrofiano	36	1	San Foca	36	1
Galatina	7.2	5	San Pietro in Lama	36	1
Galàtone	18	2	Salice salentino	18	2
Gallipoli	4	9	San Cassiano	36	1
Giurdignano	3	1	Sanarica	12	3
Lecce	2.4	15	Scorrano	7.2	5
Lequile	36	1	Soleto	18	2
Leverano	9	4	Spongano	36	1
Lizzanello	18	2	Squinzano	5.1	7
Lucugnano	36	1	Sternatìa	18	2
Maglie	4.5	8	Supersano	9	4
Marina di Sant'Isidoro	36	1	Surbo	9	4
Marina di Torre Lapillo	12	3	Taurisano	12	3
Marittima di Diso	36	1	Trepuzzi	18	2
Martano	12	3	Tricase	7.2	5
Martignano	36	1	Tuglie	36	1
Matino	18	2	Ugento	12	3
Melendugno	36	1	Uggiano La Chiesa	18	2
Melissano	7.2	5	Veglie	36	1
Minervino di Lecce	36	1	Vèrnole	12	3

Table 2. Values of frequency (F_r) of floodings.

	F_r		F_r
Acquarica del Capo	0.083	Monteroni di Lecce	0.083
Alessano	0.055	Morciano di Leuca	0.055
Alliste	0.055	Muro Leccese	0.083
Aradeo	0.083	Nardò	0.196
Calimera	0.027	Nociglia	0.083
Campi Salentina	0.138	Novoli	0.055
Caprarica di Lecce	0.027	Otranto	0.027
Carmiano	0.055	Parabita	0.027
Casarano	0.111	Patù	0.027
Castrì di Lecce	0.027	Poggiardo	0.166
Castro	0.027	Porto Cesareo	0.055
Cavallino	0.111	Presicce	0.027
Collepasso	0.083	Racale	0.055
Copertino	0.196	Ruffano	0.111
Corigliano d'Otranto	0.055	S.anCesario di Lecce	0.027
Corsano	0.055	San Donato di Lecce	0.055
Cutrofiano	0.027	San Foca	0.027
Galatina	0.138	San Pietro in Lama	0.027
Galàtone	0.055	Salice salentino	0.055
Gallipoli	0.250	San Cassiano	0.027
Giurdignano	0.027	Sanarica	0.083
Lecce	0.416	Scorrano	0.138
Lequile	0.027	Soleto	0.055
Leverano	0.111	Spongano	0.027
Lizzanello	0.055	Squinzano	0.196
Lucugnano	0.027	Sternatìa	0.055
Maglie	0.222	Supersano	0.111
Marina di Sant'Isidoro	0.027	Surbo	0.111
Marina di Torre Lapillo	0.083	Taurisano	0.083
Marittima di Diso	0.027	Trepuzzi	0.055
Martano	0.083	Tricase	0.138
Martignano	0.027	Tuglie	0.027
Matino	0.055	Ugento	0.083
Melendugno	0.027	Uggiano La Chiesa	0.055
Melissano	0.138	Veglie	0.027
Minervino di Lecce	0.027	Vèrnole	0.083

to assess the flood hazard. A rainfall time interval of 3 h has been employed in the analysis (Fig. 10). In fact, during this time interval the maximum rainfall intensity can be obtained, as well as the return time T_r (Table 1). T_r represents the average period of time expected to elapse between occurrences of flood events with a given severity or higher at a particular location. T_r was computed on the basis of the number of events occurred for each municipality in the time interval from 1968 to 2004. The frequency F_r is inversely proportional to the return time (Table 2). The return time and the frequency are computed using

$$Tr = \frac{\Delta T}{N} \tag{1}$$

$$Fr = \frac{1}{Tr} \tag{2}$$

respectively. Although there are numerous methods to calculate the return period, for this specific study, based on historic records processing, it has been easier to use Eq. (1) in order to bypass the concept of probability of occurrence of floods. In fact, the return time represents the mean value of the time interval between two subsequent flood events.

On the other hand, the frequency has been computed from the data of the IPHAS report database. More precisely, this

Table 3. Matrix rainfall intensity – frequency.

	50	100	150	
5	*55*	*105*	*155*	
10	*60*	*110*	*160*	Frequency
15	*65*	*115*	*165*	
	Rainfall intensity			

has been accomplished by counting how many times N a given municipality has been affected by floodings in a time interval of ΔT=37 years (1968–2004) (Table 1).

Three classes of intensity can be distinguished, by considering a time interval of 3 h and the mean value of rainfall per hour:

– Municipalities that register values of rainfall until 16.6 mm/h – low intensity class;

– Municipalities that register values of rainfall from 16.6 mm/h to 33.3 mm/h – moderate intensity class;

– Municipalities that register values of rainfall from 33.3 mm/h to 50 mm/h – high intensity class.

Likewise for the rainfall frequency, there are three classes, by considering the number of flood events that had occurred in a given municipality:

– Municipalities that register cases of floods until 5 times – low frequency;

– Municipalities that register cases of floods until 10 times – moderate frequency;

– Municipalities that register cases of floods until 15 times – high frequency.

For example, it is quite natural to think that for an area having a frequency value of "15" and a mean value of rainfall intensity of 50 mm/h, the hazard value will be higher than for an area having a frequency value of "5" and a mean value of rainfall intensity of 16.6 mm/h.

Subsequently, the matrix "rainfall intensity-frequency" was developed (Table 3), obtaining nine indices with different hazard degrees for mapping the hazard factor (Fig. 11). Furthermore, the indices obtained by matrix computation do not give the absolute value and include some degree of subjectivity. Similarly, the areas with different hazard degrees, obtained by data processing in the ArcGIS software, do not have absolute values, but have a continuous evolution in time and space.

The derived classes in Fig. 11 show that more than 50% of Salento has high or very high index values of environmental hazard, located mainly between the small ridges, the so-called "Serre" and in the eastern part where the rainfall exhibits maximum values.

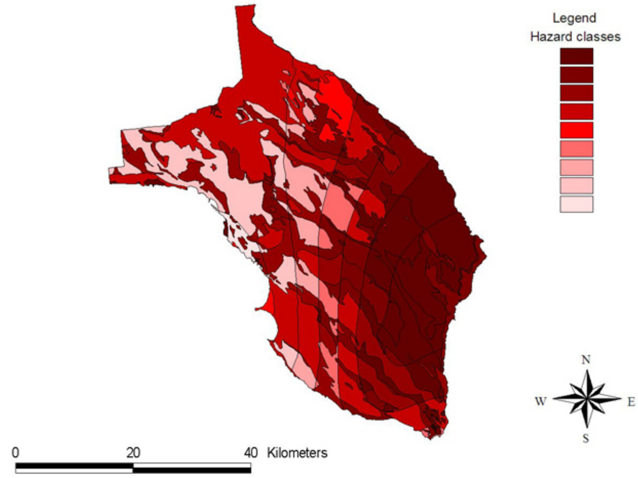

Fig. 11. Hazard flood map of Salento peninsula.

3.2 Flood vulnerability assessment

For the flood vulnerability assessment, the rainfall intensity has been linked to the socio–economic element at risk, distributed on the Salento peninsula and identified in the database IPHAS, under the so-called scheme "DAMAGES" (APAT, DDS (SGI), 2001) (Table 4). Where it was possible, the quality of each element has been considered (Downing, 1991). Each census application form, referring to a particular flood case in a given municipality, has it own assessment of the partial "damage degree". Therefore, the total "damage degree", calculated for each municipality in the time interval 1968–2004, is the average of the partial "damage degrees" (Wang et al., 1999).

As can be seen from the list below, the vulnerability and the damage degree have been divided into nine classes. Every element at risk has an aesthetic damage, for instance, when the function of the element affected by flooding is not impaired. When the element at risk is not functioning, it is classified as a structural damage. The different damage degrees are the following:

– No damage,

– Low aesthetic damage,

– Moderate aesthetic damage,

– High aesthetic damage,

– Low structural damage,

– Moderate structural damage,

– High structural damage,

– Dangerous damage,

– Very dangerous damage.

Table 4. Field "damage" extracted from the "IPHAS" historic database.

Field "DAMAGE"							
Kind of damage	☐ direct						
People ☐	☐ **deads N.**	☐ **Injuries N.**	☐ **evacuated N.**	☐ **at risk N.**			
Buildings ☐	☐ **private N.**	☐ **public N.**	☐ **private at risk N.**	☐ **public at risk N.**			
Costs (ML.)	**Goods**	**Activities**	**Total**				
	Degree		**Degree**		**Degree**		**Degree**
Municipality	☐	**Struct. of publ. service**	☐	**Cultural goods**	☐	**Roads**	☐
larger town		hospital		monuments		autostrada	
little town		barracks		historic–architectonic goods		of the state	
farmhouses		school		museums		provincial	
scattered houses		library		works of art		municipal	
Economic activity	☐	public administration center		**Service infrastructure**	☐	rural	
commercial areas		church		aqueduct		**Setting up works**	☐
working areas		sport system		drains		canal control	
manufacturing system		cemetery		electric lines		slope strengthening	
chemical system		power station		telephone linees		protection works	
quarrying system		naval port		gasduct			
zootechnical system		bridge or viaduct		oil pipeline		***Canals*** ☐	
Agricultural land	☐	tunnel		canalizations		**Name**	
spread		penstock		line systems			
spread at trees		railway station		**Rail roads**	☐		
specialized farming		water basin		high velocity			
meadow		dam		2 or more tracks		**Damage:** ❍ potential	
wood		incinerator		Single - track		❍ deviation	
reafforestation		dump		urban network		❍ partial damming	
		depurator		rail road		❍ total damming	
Damage degree: N = ***No damage***; E = ***Low aesthetic damage***; E' = ***Moderate aesthetic damage***; E''= ***High aesthetic damage***;							
F = ***Low structural damage;*** **F' =** ***Moderate structural damage;*** **F'' =** ***High structural damage***; **G =** ***Dangerous damage;*** **G' =** ***Very dangerous damage***							

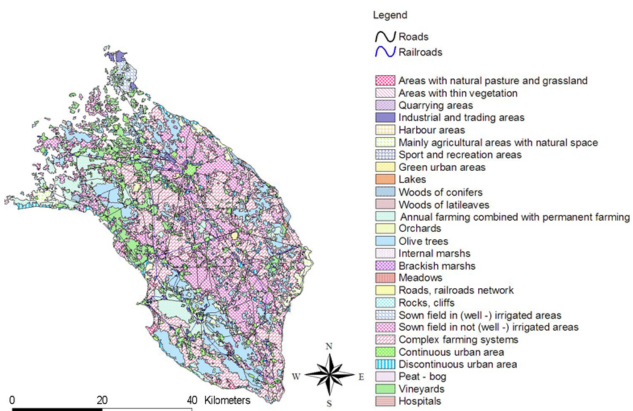

Fig. 12. Elements at Risk map of Salento peninsula.

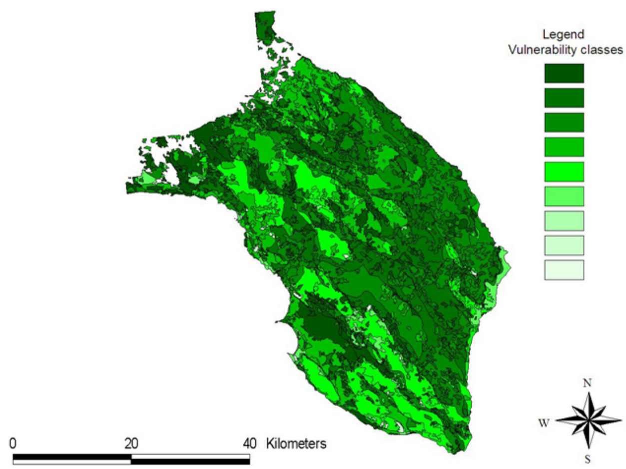

Fig. 13. Flood vulnerability map of Salento peninsula.

Cartographically, the flood location map obtained by a field survey and 'susceptibility to flood' map obtained by the DTM study have been considered as well as the 'elements at risk' map with a mapping of roads and railroads (Fig. 12). Using the "overlay mapping" method through a "map query" function, the flood vulnerability map (Fig. 13) was calculated, where nine classes with different vulnerability degrees are represented.

Each class has one fictitious multiple of three indices in order that the vulnerability factor is numerically defined by values. The indices are linked with a matrix of hazard values in order to calculate the risk factor.

An inspection of Fig. 13 reveals that more than 50% of Salento has high or very high values of the vulnerability factor, also according to the values of environmental hazard. These areas are located mainly between the ridges and in the eastern part of Salento. In addition, the elements which are mostly damaged by floods, according to the elements at risk distribution of the Corine Landcover Project (1999) are the following:

1. Olive trees and tobacco, mainly cultivated in the graben areas, represent a very important regional economic resource;

Table 5. Matrix of hazard – vulnerability factors.

	55	*60*	*65*	*105*	*110*	*115*	*155*	*160*	*165*	
3	58	63	68	108	113	118	158	163	168	
6	61	66	71	111	116	121	161	166	171	
9	64	69	74	114	119	124	164	169	174	
12	67	72	77	117	122	127	167	172	177	Vulnerability
15	70	75	80	120	125	130	170	175	180	
18	73	78	83	123	128	133	173	178	183	
21	76	81	86	126	131	136	176	181	186	
24	79	84	89	129	134	139	179	184	189	
27	82	87	92	132	137	142	182	187	192	
					Hazard					

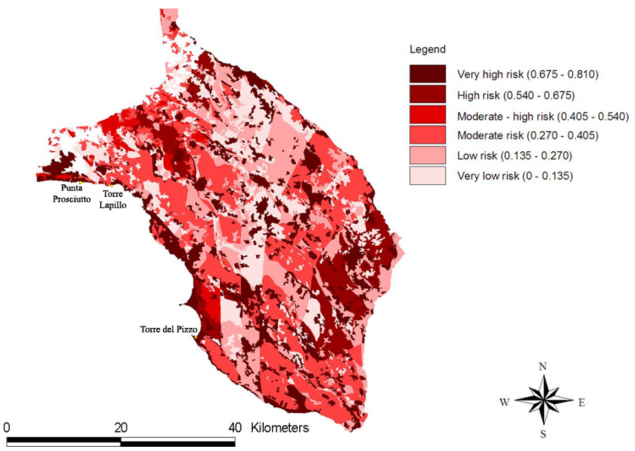

Fig. 14. Flood risk map of Salento peninsula.

2. Vineyards, located throughout but in small areas;

3. Annual farming combined with a permanent farming or complex farming system, represented by very large areas in Fig. 12;

4. Continuous/discontinuous urban areas, roads and railroads and urban/industrial areas.

5. Cultivated fields, covering large areas and located in non-irrigated zones.

Therefore, floodings affect very large agricultural areas, as well as urban/industrial areas, especially if located in the impermeable lowering zones (Khan, 2005). Obviously, the vulnerability assessment has always some degree of uncertainty and must be estimated on a case by case basis, element by element, being variable because of the parameters involved. For simplification purposes, a general subdivision of the elements at risk is considered in Table 4.

3.3 Flood risk assessment

The definition of *Risk* given by U.N.D.R.O. (United Nations Disaster Relief Office), UNESCO's Office for Disaster control, needs to be recalled at this point (Coburn et al., 1994). As stated before, the flood risk R is a scalar quantity which links the hazard factor, defined as the probability that a flood occurs in a given area with a determined return period, to the vulnerability factor, that is the propensity of an element (urban and industrial areas, agricultural areas, extraurban infrastructures; historical, artistic and environmental goods) to resist a particular flood (Green et al., 1989).

In order to calculate the risk factor, the hazard factor has been linked to the vulnerability and expected damage factors, according to the matrix. Subsequently, the indices, defining the areas which are characterized by a risk value, are computed (Gisotti et al., 2000) (Table 5).

Such a table shows a matrix represented by 81 indices, which in turn shows municipal areas of Salento with different flood risk values, due to flash floods.

One may think of the indices as expressed percent values, with a variability range between 1% and 81% (the matrix is represented by nine hazard indices and nine vulnerability indices). The choice of a variability range between 1–81% is not arbitrary, but justified by simplicity of computation.

Table 6 gives the percent values of flood risk, calculated for each municipality of Salento and referring to the agricultural and urban/industrial areas. The risk values obtained have some degree of uncertainty, essentially due to the subjectivity of the operator with regard to the hazard and vulnerability indices assessment (particularly for the vulnerability function, the choice of social and economic elements and its association in classes has been highly approximate and, since the elements at risk are numerous, the vulnerability assessment has been difficult).

The thematic map (Fig. 14) shows that the flood risk values have been grouped into six classes, conferring a value range between 0 and 0.81. The indices of the hazard – vulnerability matrix have been inserted and processed with the ArcGIS software in order to calculate the flood risk (Carrozzo et al., 2003; Forte, 2005).

Table 6. Index values of Risk (R_w) with reference to agricultural areas and urban/industrial areas.

	R_w agricultural	R_w urban/industrial		R_w agricultural	R_w urban/industrial
Acquarica del Capo	0.55	0.52	Monteroni di Lecce	0.43	0.25
Alessano	0.40	0.36	Morciano di Leuca	0.42	0.30
Alliste	0.33	0.38	Muro Leccese	0.37	0.35
Aradeo	0.35	0.40	Nardò	0.68	0.70
Calimera	0.32	0.40	Nociglia	0.67	0.60
Campi Salentina	0.81	0.80	Novoli	0.60	0.66
Caprarica di Lecce	0.40	0.40	Otranto	0.21	0.20
Carmiano	0.67	0.60	Parabita	0.40	0.36
Casarano	0.65	0.60	Patù	0.34	0.33
Castrì di Lecce	0.55	0.33	Poggiardo	0.60	0.53
Castro	0.35	0.33	Porto Cesareo	0.70	0.65
Cavallino	0.55	0.33	Presicce	0.46	0.40
Collepasso	0.33	0.33	Racale	0.42	0.37
Copertino	0.75	0.60	Ruffano	0.66	0.60
Corigliano d'Otranto	0.33	0.33	SanCesario di Lecce	0.30	0.33
Corsano	0.43	0.40	San Donato di Lecce	0.36	0.34
Cutrofiano	0.45	0.40	San Foca	0.52	0.46
Galatina	0.72	0.66	San Pietro in Lama	0.35	0.33
Galàtone	0.60	0.66	Salice salentino	0.36	0.28
Gallipoli	0.81	0.64	San Cassiano	0.73	0.45
Giurdignano	0.68	0.50	Sanarica	0.31	0.28
Lecce	0.74	0.63	Scorrano	0.68	0.66
Lequile	0.55	0.41	Soleto	0.24	0.13
Leverano	0.70	0.76	Spongano	0.39	0.38
Lizzanello	0.52	0.66	Squinzano	0.65	0.52
Lucugnano	0.55	0.50	Sternatìa	0.45	0.33
Maglie	0.64	0.64	Supersano	0.56	0.53
Marina di Sant'Isidoro	0.40	0.66	Surbo	0.55	0.47
Marina di Torre Lapillo	0.81	0.80	Taurisano	0.52	0.46
Marittima di Diso	0.37	0.50	Trepuzzi	0.54	0.47
Martano	0.62	0.40	Tricase	0.60	0.62
Martignano	0.43	0.48	Tuglie	0.39	0.46
Matino	0.52	0.50	Ugento	0.62	0.70
Melendugno	0.43	0.38	Uggiano La Chiesa	0.58	0.47
Melissano	0.63	0.54	Veglie	0.57	0.58
Minervino di Lecce	0,57	0,50	Vèrnole	0.63	0.68

4 Discussion and conclusions

The methodology adopted for flood risk analysis in the Salento peninsula, according to the historical model and the study of DTM sequence, where the lowering zones affected by floodings can be seen, allows to identify the hazard and total risk areas in the study area. In particular, the DTM sequence shows an increase of the surface of the Graben structures and, therefore, an increase of the surface of the flooded areas. For example, in the time interval from 1956 to 1976, the Graben area included between the Supersano, Ruffano and Nociglia municipalities was increased by approximately 1 km^2, such as calculated by the GIS software. In addition, during the same time interval, other lowering zones in the S. Eleuterio - Casarano - Taurisano Graben, such as the lowering zones of Poggiardo – Minervino di Lecce – Martano Graben, have increased their surface area because the alluvium was accumulated from erosion by rainfall water impacting other zones (Figs. 3 and 8).

The application of this developed methodology can be considered to be quite satisfactory, given that the basic inventory maps were very good.

An inspection of Figs. 11 and 14 reveals that the flood hazard analysis has produced an inhomogeneous distribution of the flood risk values in the study area and, consequently, the highest values are located:

- In the graben area of the SW and SE (Fig. 15).

- Along the coast at W, from Torre del Pizzo (near Gallipoli town, Fig. 16) to Porto Cesareo, at NW and, furthermore, towards Torre Lapillo and Punta Prosciutto (NW part).

Fig. 15. Damages to agricultural area (vineyards) due to flash flood at Galàtone municipality.

The map processing and analysis show moderate to high values of flood risk, conferring a remarkable importance to the moderate class of risk, which represents almost 50% of the area. Just the Horst and NE areas show low and moderate to low values because the geological and geomorphological characteristics tend to prevent flood occurrences. Furthermore, since it was not possible to make forecasts for areas not struck by floods, it was hence not possible to assess the flood hazard and risk in these areas. Nevertheless, the study carried out at a scale of 1:25 000, according to the guidelines of the Italian law 183/89 (Soil Defense), law 180/98 (mapping of areas at hydrogeological risk) and law 365/2000 (intervention measures of areas affected by floods), is an important tool that the government agencies should consider in order to correctly undertake management and intervention planning, whose purpose is to prevent and/or mitigate the flood risk.

In addition, with regard to the risk assessment of the elements involved, it is necessary to use detailed technical maps (with a scale of 1:5000) which are presently not available for the study area.

Often, however, these types of studies are not addressed to set - up an intervention policy to prevent and/or mitigate the flood risk. There are many reasons for this, often unjustified, which can be one or a combination of the following:

Fig. 16. Big flood at Torre del Pizzo, near Gallipoli municipality. Continental waters flow towards the sea, dragging cars and housescontent.

1) incorrect management of funds, 2) extended delay of the Government to set-up the different phases in an intervention planning and/or 3) negligence of the Government to enforce laws addressing environmental protection (ICGPSIA, 1995).

As a general rule, it is also opportune to consider the more catastrophic events in order to identify the behaviour of the floods and their interaction with the geological and geomorphological environment, analysing always the minimum thresholds of the precipitation and the way in which they manifest themselves.

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References

Andah, K. and Umbertini, L.: Confronting hydrogeological disaster in a vulnerable environment, in: Managing hydrogeological disasters in a vulnerable environment, edited by: Andah, K., CNR-GNDCI & UNESCO, Int. Hydrogeol. Progr., Perugia, 33–68, 1998.

Agency for Environmental Protection and for Technical Surveys: Department of Soil Defence, National Geological Survey (in Italian: APAT, DDS (SGI) (Agenzia per la Protezione dell'Ambiente e per i Servizi Tecnici, Dipartimento Difesa del Suolo, Servizio

Geologico d'Italia)): Scheme of application form of "IFFI Project (Inventario Fenomeni Franosi in Italia)", Roma, 2001.

Arnell, N. W.: The effect of climate change on hydrogeological regimes in Europe: a continental perspective, Global Environ. Change, 9, 5–23, 1999.

Battista, C., Boenzi, F., Fiore, S., Novembre, D., Palmentola, G., and Pennetta, L.: Lineamenti geografici del Salento leccese, Conv. Ann. del Gr. Naz. di Geogr. Fis. e Geomorf., Lecce, 1985.

Battista, C., Pennetta, L., Specchio, V., and Zito, G. M.: L'aridità del suolo nella Penisola Salentina, Quad. Ric. Centro Studi Geot. Ing., Lecce, 11, 259–274, 1987.

Bersani, P.: Tiber River at Rome: summer Floods and considerations on the maximum historical discharge, J. Tech. Environ. Geol., CNG, 2, 2004.

Bissanti, A.: Le piogge in Puglia, Ann. Fac. Econ. e Comm. Univ. di Bari, 23, 90, Bari, 1968.

Bolt, B. A.: Geological hazards: Earthquakes, Tsunamis, Volcanoes, Avalanches, Landslides, Floods, Springer, Berlin, 8, 328 pp., 1975.

Carrozzo, M. T., Delle Rose, M., De Marco, M., Federico, A., Forte, F., Margiotta, S., Negri, S., Pennetta, L., and Simeone, V.: Pericolosità ambientale di allagamento nel Salento leccese, Quad. di Geol. Appl., Serie AIGA, Roma, 1, 77–85, 2003.

Carrozzo, M. T. and Ruggero, L.: Descrizione climatica e paleoclimatica della Puglia, Atti 1° Workshop "Clima, Ambiente e Territorio nel Mezzogiorno", Taormina, 31–41, 1989.

Ciaranfi, N., Pieri, P., and Ricchetti, G.: Note alla Carta Geologica delle Murge e del Salento, Mem. Soc. Geol. It., 41, 449– 460, 1988.

CNR (National Council of Research) – GNDCI (National Group for Hydrogeological Catastrophes Defence) (in Italian: CNR (Consiglio Nazionale delle Ricerche) – GNDCI (Gruppo Nazionale per la Difesa dalle Catastrofi Idrogeologiche)): AVI Project (Italian Vulnerable Areas): Census of Italian municipalities affected by landslides and floods, CNR, Perugia, 1998.

Coburn, A. W., Spence, R. J. S., and Pomonis, A.: Vulnerability and Risk Assessment, 2nd ed. Geneva: UNDP Disaster Management Training Programme, 69 pp., 1994.

Colamonico, C.: Aspetti geologici e geografici del Salento, Studi salentini, Galatina, 1, 11–19, 1956.

Colamonico, C.: Zone di piovosità e densità di popolazione nella Provincia di Lecce, Riv. Geogr. It., Firenze, Fig. 2, 24, 161–180, 1917.

Cook, J. L.: Quantifying peak discharges for historical floods, J. Hydrol., 37, 29–40, 1987.

Corine Project LU/LC (Land Use/Land Cover): Cartographical data of Land Use, 1999.

Costa, O. G.: Osservazioni meteorologiche fatte in Lecce (dal 1812 al 1824), Ann. Civ. Regno Due Sicilie, Napoli, 6, 5–10, (C 602), 1834.

Daniels, M. D.: Hydrological Applications of GIS, edited by: Gurnell, A. M. and Montgomery D. R., John Wiley and Sons, Chichester, 2000, 173 pages, Geomorphology, 54, 347–348, 2003.

De Giorgi, C.: Cenni di geografia fisica della provincia di Lecce, Tip. Ed. Salentina, Lecce, 1884.

De Giorgi, C.: Descrizione geologica e idrografica della provincia di Lecce, Ed. Salomi, Lecce, 1922.

De Giorgi, C.: Descrizione fisica geologica e idrografica della provincia di Lecce (a cura di A. Vignola), Centro Studi Sal., Tipografia Mariano, Galatina, 1960.

Downing, T. E.: Assessing socio – economic vulnerability to famine: frameworks, concepts and applications, FEWS Working Paper 2.1. USAID, 102 pp., Washington, 1991.

Forte, F.: GIS, aerial photos, remote sensing study for flood risk management and assessment, Case study of Salento peninsula, Southern Italy, PhD thesis in Geomorphology and Environmental Dynamics, 116 pp., Digilabs editor, Bari, 2005.

Gisotti, G. and Benedini, M.: Il dissesto idrogeologico: previsione, prevenzione e mitigazione del rischio. Nuova edizione aggiornata ed ampliata, Carocci editore, 595 pp., ill.; 24 cm – (Manuali del progettista (Carocci); 79), Roma, 2000.

Green, C. H. and Penning-Rowsell, E. C.: Flooding and the quantification of "intangibles", Journal of the Institution of Water and Environmental Management, 3, 27–30, 1989.

Hudson, P. F.: Floodplains: environment and process, Geomorphology, 56, 223–224, 2003.

ICGPSIA (Interorganizational Committee on Guidelines and Principles for Social Impact Assessment): Guidelines and Principles for Social Impact Assessment, EIA Review, 15, 11–43, 1995.

Johnston, A.: Geographic Information Systems in Ecology, Blackwell, Oxford, 1998.

Khan, S. D.: Urban development and flooding in Houston Texas, inferences from remote sensing data using neural network technique, Environ. Geol., 47, 1120–1127, 2005.

Landesman, L. Y.: Hazard assessment, Vulnerability analysis, Risk assessment and Rapid Health assessment, Public Health Management of Disasters, APHA, Washington DC, chapter 5, 57–72, 2001.

Largaiolli, T., Martinis, B., Mozzi, G., Nardin, M., Rossi, D., and Ungaro, S.: Note illustrative della Carta Geologica d'Italia – Foglio 214 "Gallipoli", Serv. Geol. It., 64 pp., Roma, 1969.

Martinis, B.: Lineamenti strutturali della parte meridionale della Penisola Salentina, Geol. Rom., Roma, 1, 11–23, 1962.

Martinis, B.: Sedimenti calabriani sulle Serre Calaturo e Castelforte (Penisola Salentina), Riv. It. Paleont. e Strat. LXXIII, Milano, 1023–1038, 1967a.

Martinis, B.: Note geologiche sui dintorni di Casarano e Castro (Lecce), Riv. It. Paleont. e Strat. LXXIII,Milano, 1–64, 1967b.

Martinis, B.: Note illustrative della Carta Geologica d'Italia. Foglio 223 "Capo S. Maria di Leuca", Serv. Geol. It., 64 pp., 1970.

Meijerink, A. M. J., De Brouwer, J. A. M., Mannaerts, C., and Valenzuela, C. R.: Flood study in the Meghna-Dhonagoda polder, Bangladesh, Introduction to the use of Geographic Information Systems for practical hydrology; UNESCO, International Hydrological Programme ITC, 2003.

Mijatovic, B. F.: Catastrophic flood in the polje of Cetinje in February 1986, a typical example of environmental impact of karst, Proceedings of "Karst hydrogeology: Engineering and environmental applications", Orlando, 299–303, 1987.

Molina, M. and McDonald, F.: Sinkhole management and flooding in Jamaica, Proceedings of "Karst hydrogeology: Engineering and environmental applications", Orlando, 293–298, 1987.

Newspaper "Il Messaggero": News about the floods occurred during the years 1968–2004, Roma.

Newspaper "La Gazzetta del Mezzogiorno": News about the floods occurred during the years 1968–2004, Bari.

Newspaper "La Repubblica": News about the floods occurred during the years 1968–2004, Roma.

Newspaper "Quotidiano di Lecce": News about the floods occurred during the years 1968–2004, Lecce.

OFDA (Office of the US Foreign Disaster Assistance): Disaster history, significant data on major disasters worldwide, 1900–1995, US Agency for International Development, Washington, 265 pp., 1996.

Ricchetti, G.: Carta Geomorfica del Salento Meridionale, Quad. Ric. Centro Studi Geot. Ing., 11, Lecce, 1988.

Spaliviero, M.: Historic fluvial development of the Alpine – foreland Tagliamento River, Italy, and consequences for floodplain management, Geomorphology, 52, 317–333, 2003.

Wang, R., King, L., and Jiang, T.: Flood vulnerability analysis and hazard management, Supported by GIS and remote sensing, Natural hazard Conference, Enschede, The Netherlands, 1999.

Zito, G. M., Ruggiero, L., and Zuanni, F.: Zone climatiche omogenee in Puglia, Atti 2° Colloquio "Approcci metodologici per la definizione dell'Ambiente fisico e biologico del Mediterraneo", Lecce, 15–40, 1988.

Zito, G. M., Ruggiero, L., and Zuanni, F.: Aspetti meteorologici e climatici della Puglia, Atti 1° Workshop "Clima, Ambiente e Territorio nel Mezzogiorno, Lecce, 1989.