GIS GENERATED GEOENVIRONMENTAL HAZARD MAPS SUPPORTING TERRITORIAL PLANNING. AN EXAMPLE FROM THE PROVINCE OF PISA (ITALY)

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Summary

Italian Provinces arrange planning tools named "Piani Territoriali di Coordinamento" indicating general criteria of land use. The Province of Pisa PTC is based on physical knowledge of territory as essential assumption for correct planning. This choice stems from dramatic experiences (e.g. flooding of urban areas, acquifer pollution, ...) related to erroneous or insufficient evaluation of the geoenvironmental aspects. Most recurring geoenvironmental hazards of the Pisa Province can be categorized under three main themes, for which - operating an important distinction between "pericolosity" of a given "event" (negatively valued, inducing a damage) and "vulnerability" of a given "resource" (positively valued, referring to its value) - the following maps have been drawn:
Geomorphological Pericolosity (landslides, rivercourse modification, subsidence);
Hydraulic Pericolosity (historical memory of ancient floods, probabilistic maps of flooded plains);
Hydrogeological Vulnerability (estimate of groundwater resources and their local exposure).

Legends of these maps are graduated on four intensity levels of the phenomena and arranged to successive numerical GIS elaborations:
Class 1 - Not Relevant: *impossible event - absent or not recoverable resource;*
Class 2 - Low: *apparently not involved;*
Class 3 - Medium: *variable degree of event probability - resource protection;*
Class 4 - High: *active event - exposed resource.*

Information supporting the maps derives from GIS elaborations of fundamental coverages such as the Geological Map and the Digital Terrain Model; in order to improve the reliability and detail of the maps, specific elaborations of data deriving from geological databases have been added. At the same time, an analysis of the most frequent urbanistic destinations has been carried out. Their specific characteristics of vulnerability, with regard to geomorphological or hydraulic pericolosity, or of pericolosity, with regard to hydrogeological vulnerability, have been synthesized in matrices giving the associated "risk level". Risk levels correspond to definite general main lines:
Level I, Minimum: the area is suitable for the realization of the project;
Level II, Low: the project is realizable after local investigations confirming the low level of risk;
Level III, Medium-High: the project is possible under defined conditions and detailed investigations;
Level IV, Excessive: no feasibility.

From an operating point of view, "union" of the three pericolosity-vulnerability maps with the urbanistic destinations coverage is carried out making use of the GIS procedures; successively, by simple database operations, the risk levels previously defined are associated to the obtained polygons.

1. Introduction

According to the Italian national law n° 142/1990 Provinces arrange planning tools named "Piani Territoriali di Coordinamento" indicating general criteria of land use. The principal aim of this planning act is to find better localization for anthropic activities in environmental context. The PTC of the Province of Pisa is based on physical knowledge of territory as essential assumption for correct planning. This choice stems from dramatic experiences (e.g. flooding of urban areas, aquifer pollution) related to erroneous or insufficient evaluation of geoenvironmental aspects.

2. Physical characteristics of the Pisa Province territory

The Pisa Province territory covers an area of about 2,200 square kilometers. Arno is the most important river, which runs along the provincial territory for about 65 kilometers before flowing into the Thyrrenian sea near Pisa. Many other rivers, some of them very important but characterized by torrential regimen, are present.

In the northern part of the province mountains are represented by the Monti Pisani group which culminates with Monte Serra (918 m above sea level); in the southern part there are the Chianni-Castellina mountains (875 m a.s.l.). The hilly district is very extended and developed, principally south of Arno river, including most of the provincial territory. Plains are limited to the old and recent alluvial deposits of the rivers, besides Pisa coastal plain and some marshy areas (Bientina, Fucecchio and Massaciuccoli).

In the Pisa province territory almost all the geologic formations of the Northern Apennines are represented, dated from Permian-Carboniferous to Quaternary; the lithological variability of the formations is really remarkable, due to the presence of quarzitic and carbonatic metamorphic rocks (Monte Pisano), turbiditic sandstones, carbonatic, cherty and igneous rocks, shales with calcareous and arenaceous levels, clayey, sandy and evaporitic sediments, alluvial and marshy deposits of silt, clay, sand, gravel and peat nature.

The little distance from the sea and the orographic situation (characterized by a scarcely developed altimetric outline) directly influence the climate. Precipitations are mainly represented by rainfall with maxima concentrated in the most continental zones and minima in the meridional part. The rainfall distribution during the year is irregular: autumn precipitations predominate, while during summer those are poor with long periods of absolute drought. Autumn rainfalls are often very intense and greatly concentrated.

Active volcanic phenomena are not present in the province; an important high enthalpy geothermal area is instead present in the meridional part of the province, exploited in the past to extract boric products and now to produce electric energy. According to historical and geodinamic data, most intense seismic phenomena are localized in a southern restricted zone (Fine and Cecina valleys), where in 1846 an intense earthquake occurred.

In the region the most dramatic alluvial event of the century is represented by the 1966 Arno flood that extensively interested the cities of Florence, Pisa, Pontedera and surrounding countries. This phenomenon was caused by prolonged and intense rains contemporary falled in the entire Arno hydrographic basin. Recent flood occurred during 1991, 1992 and 1993 autumns in smaller basins as a result of localized and very intense rainfalls.

Several ancient urban agglomerates, dating since etruscan times (the most famous of which is Volterra), were built on arenaceous and sandy culminations of hills mainly of clay nature; this geological situation determinates the progressive development of numerous landslides involving suburbs of the towns.

Remarkable groundwater pollution is generally localized in correspondence of the main industrial agglomerates and of the oldest municipal solid waste landfills; phreatic groundwaters of the principal alluvial plains are practically everywhere contaminated due to the high urbanization degree.

3. Pericolosity and vulnerability maps

The physical elements above outlined determine the landscape and the environmental features of the Pisan territory; they condition evolutive phenomena peculiar of natural dynamics, interacting with the anthropic modifications.

In order to support a correct planning and development of human activities involving the territory, with the aim to synthesize the most significant aspects of the natural physical context of the province and the phenomena controlling its evolution, the three following themes have been considered:

- geomorphological stability, essentially ascribing to erosive phenomena and landslides and to compressibility of the flat areas;
- water stagnation and fluvial dynamic related to flooding of the alluvial plains;
- rocks permeability and aquifers hydrogeology, for the groundwater resources preservation.

The analysis of these three themes brought, through the acquisition and elaboration of basic data increasing the provincial geological data base (geological, geomorphological and hydrogeological maps, geoenvironmental hazard maps of limited zones; landslides, quarries, landfills; topographic sections, historical flows and floods of the main rivers; geognostic and stratigraphic reports, wells, detailed studies submitted to local authorities, ...) to the realization of three maps called:

- Geomorphological pericolosity map
- Hydraulic pericolosity map
- Hydrogeological vulnerability map

The first two maps are called of the PERICOLOSITY because the considered phenomenologies are directly accountable for damage of human activities. The maps derive from a zoning based on the probability and intensity of occurrence of the natural phenomena in the different areas.

The third map is called of the VULNERABILITY, as in this case it is the natural groundwater resource that may be "damaged" from human activities. This map, similarly to the others, derive from individuation of zones characterized by different degrees of protection of the resource.

Informations supporting the elaboration of the pericolosity-vulnerability maps differ in relation to the detail level of the data available in each physiographic area; for example, data in urbanized alluvial plains are very abundant, permitting elaborations at a large scale, while in mountainous areas, where anthropic presence is lower and only few data are disposable, elaborations are necessarily made at a lower scale; moreover a most accurate detail has been achieved for the critical situations.

The maps have been elaborated recognizing different intensity degrees of the considered phenomena, according to the following methodology:

- definition of zoning criteria for the individuation of areas in which the phenomena are the most intense (Class 4 - HIGH: *active event - exposed resource*. Active landslides, lowlands and areas flooded by ordinary floods, exposed aquifers); these areas have been investigated very thoroughly;
- definition of zoning criteria for the individuation of areas where the phenomena are believed impossible or not relevant (Class 1 - NOT RELEVANT: *impossible event - absent or not recoverable resource*. Stable areas, hilly or mountainous areas, low-permeability rocks); in these areas detailed studies are not carried out;
- definition of semiquantitative zoning criteria for the individuation of areas in which the phenomena intensity approach that of the Class 4 (Class 3 - MEDIUM: *variable degree of event intensity and probability or resource protection*); three thresholds are defined to graduate the phenomena intensity (Sub-classes 3a, 3b and 3c);
- in the remaining areas a low intensity of the phenomena has been recognized (Class 2 - LOW: *low intensity event - high resource protection*).

Utilizing this methodology numerical legends, predisposed to successive GIS elaboration, have been realized for the three maps.

Zones with high and medium pericolosity-vulnerability (classes 4 and 3c) and the main alluvial plains, in which detailed studies have been executed (hydrogeologic, geotechnic, hydraulic), have been digitized at 1:10,000 scale and successively georeferenced in the Gauss-Boaga national reference system.

As far as the remaining lower pericolosity-vulnerability zones are concerned, an analysis of geological maps (acquired at 1:25,000 scale) and related legends has been carried out, in order to obtain some different coverages; this analysis permitted a classification of the geological formations with the aim to emphasize their technical characteristics, such as lithology, permeability, sedimentology, structure and geotechnic.

Besides from the Digital Terrain Model (available at different detail of scale) an automatical contouring of the clivometric map has been obtained. From the union between the geological-technical coverages and the clivometric one, medium-low classes (1, 2, 3a and 3b) of the three pericolosity-vulnerability maps have been originated.

To obtain the definitive coverages, the digitized polygons corresponding to the high-medium pericolosity-vulnerability areas have been added to the previous coverages by an updating procedure.

GIS tools, in this case the Arc-Info software, make possible to run in the meantime informations coming from different detail of scale. For instance, the general classification of the territory in function of an overall propension to geomorphological pericolosity (classes 1, 2, 3a and 3b; scale 1:25,000) can be usefully combined with punctual mapping of landslides pericolosity (classes 4 and 3c), generally reported upon 1:5.000 or 1:10.000 topographic maps.

As far as possible, informations have been maintained in an unique coverage, with value of the Arc-Info "fuzzy tolerance" of polygon topology mediate from different exigencies. A good compromise has been fixed in the value of 5 meters, having in this manner an adequate accuracy of restitution and, contemporary, not too bulky data files.

The three maps make up on the whole the PHYSICAL INTEGRITY coverage. GIS facilities make possible to do recurrent operations of updating, warranting for the continuous grow up of the technical and scientific contents of this territorial database.

4. Hazard maps

For the automatic derivation of GEOENVIRONMENTAL HAZARD MAPS, a specific application in the Arc-Info programming language (AML) that gives quick and useful answer to the planner, who not necessarily must be a specialist in geoenvironmental sciences, has been developed.

Risk evaluation regards the amount of possible damage to anthropic activities, as result from the analysis of the "risk scenarios" where human activities and natural processes interact.

For the realization of the Hazard Maps it has been necessary to classify the forecast destinations of the territory, according to the general classification of homogeneous zoning, as given from the Italian town-planning law n° 765/67.

Risk levels related to the above destinations derive from the combination with the zoning of the Physical Integrity Maps; this procedure has been carried out by appropriate "Geoenvironmental Risk Matrices" a synthetic example of which is successively reported.

TERRITORIAL ZONING	PLANNED ACTIVITIES	GEOMORPHOLOGICAL RISK Pericolosity class						HYDRAULIC RISK Pericolosity class						HYDROGEOLOGICAL RISK Vulnerability class					
		1	2	3A	3B	3C	4	1	2	3A	3B	3C	4	1	2	3A	3B	3C	4
Historical agglomerates	*Upkeep and restoration*	I	I	II	III	III	III	I	I	I	II	III	III	I	I	I	II	III	III
Existing residential zones	*New buildings*	I	I	II	III	IV	IV	I	I	II	III	IV	IV	I	II	III	III	IV	IV
Expanding residential zones	*New buildings*	I	II	III	III	IV	IV	I	II	III	III	IV	IV	I	II	III	III	IV	IV
Productive zones	*Industrial and artcraft installations*	I	II	III	III	IV	IV	I	II	III	III	IV	IV	I	II	III	III	IV	IV
"	*Quarries*	I	II	III	III	III	III	I	I	II	III	IV	IV	I	II	III	IV	IV	IV
Rural zones	*Ordinary soil cultivation*	I	I	III	III	III	III	I	I	I	I	III	IV	I	I	II	II	III	III
"	*Sylviculture*	I	I	I	I	III	III	I	I	I	I	III	IV	I	I	I	II	III	III
Equipment and services of public interest	*Public buildings (churches, schools, hospitals, etc)*	I	II	III	III	IV	IV	I	II	III	III	IV	IV	I	II	III	III	IV	IV
"	*Graveyards*	I	II	III	III	IV	IV	I	II	II	III	IV	IV	I	II	III	IV	IV	IV
"	*Municipal solid waste landfills*	I	II	III	III	IV	IV	I	II	III	IV	IV	IV	I	II	III	IV	IV	IV
"	*Technological network (pipelines, power lines, waterworks, ...)*	I	II	III	III	IV	IV	I	I	II	III	III	III	I	II	II	III	IV	IV
"	*Railways and roads*	I	II	III	III	IV	IV	I	I	II	III	III	III	I	I	I	II	III	III

Table 1. Synthetic matrix of geoenvironmental risk levels.

Matrices define four risk levels to which correspond the following Pisa PTC general directives:

- Level I, MINIMUM risk: the area is suitable for the realization of the project;
- Level II, LOW risk: the project is realizable on the basis of local investigations confirming the low level of pericolosity or vulnerability of the site;
- Level III, MEDIUM-HIGH risk: realizations are possible under defined conditions regarding detailed investigation of involved phenomena and project regulations;
- Level IV, EXCESSIVE risk: no feasibility.

From an operating point of view the Physical Integrity coverages undertaken to the Arc-Info union procedure. An additional coverage of polygons or arcs, representing the urbanistic destinations, is added by a further union procedure. Successively, by simple database operations, the risk levels previously defined in the matrices are associated to the polygons resulting from the union procedures.

5. Conclusions

The Pisa Province PTC, based on physical knowledge or territory, has been realized by methodologies and with contents both innovative for Italy; extensive use of GIS elaborations has permitted to analyze a vast territory and to conclude the work in short times (one year, in spite of the Italian bureaucratic delays !). Besides, the obtained results largely derive from the existence of the geological database and the Province Geological Map covering all the territory, which the most part of the Physical Integrity coverages has been automatically derived from. The Pisa Province PTC allows the co-ordination of the urban development plans; in addition it constitutes a powerful tool to recognize the prevailing territorial vocations with regard to planned destinations, the priorities for the reclaiming of degraded zones and the protection of existing human activities and their development.