Application of SINTACS method to the aquifers of Piana di Palermo, Sicily, Italy

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RESUMEN

Piana di Palermo es caracterizada por la presencia de dos acuíferos diferentes: uno somero constituido por calcarenitas y otro profundo en rocas carbonatadas fracturadas. El acuífero calcarenítico presenta un bajo potencial hídrico comparado con el acuífero carbonático. El comportamiento químico del agua en ambos acuíferos refleja severos procesos como interacción agua-roca, intrusión marina, cambio iónico, etc. La aplicación del método SINTACS mostró que cerca del 80 % del área en estudio puede ser clasificada como de alta a muy alta vulnerabilidad.

PALABRAS CLAVE: Hidrogeología, vulnerabilidad acuifera, SINTACS, Piana di Palermo, Sicilia.

ABSTRACT

Piana di Palermo is characterized by the presence of two different aquifers: one shallow, constituted by calcarenites and the other deep in fractured carbonates. The calcarenitic aquifer presents a low potential compared to the carbonatic aquifer. The chemistry of the water in both aquifers reflects water-rock interaction, seawater intrusion, ionic exchange etc. The application of SINTACS method showed that about 80% of the study area can be classified as of high to very high vulnerability.

KEY WORDS: Hydrogeology, Groundwater vulnerability, SINTACS, Piana di Palermo, Sicily.

INTRODUCTION

The study area is Piana di Palermo, where the town is located, and part of the mountains surrounding it. Some calcarenitic aquifers are present, fed by underlying Mesozoic carbonatic structures. The Piana's substratum is complex and local heterogeneity complicates any attempt of proposing a simple model of the hydrogeological system. Unrestrained urbanization, uncontrolled exploitation and incorrect management of water resources have meant a severe deterioration in water quality and, in some zones, an increase in seawater intrusion.

Dynamic and functional analytical tools are currently being used to resolve environmental problems. These tools are suitable for land zoning where different degrees of sensitivity to natural and induced risk are present. The methodology employed enables us to classify the land and draw up thematic maps highlighting areas which need intervention.

In the recent years, the use of Geographic Information Systems (GIS) has grown rapidly in groundwater management and research. A GIS-managed hydrogeological database has been developed in order to back up data used in vulnerability-assessment techniques. The database contains the hydrogeological specificity of the Piana di Palermo environment. More than 2000 records relative to geognostic surveys, wells, hydrogeochemical analyses, spring discharge flows, thermo-pluviometric data, etc have been included. Integration of this data has enabled the realization of an intrinsic vulnerability to aquifer pollution map, using the parametric SINTACS R5 system.

GEOLOGICAL FRAMEWORK

Piana di Palermo extends for approx. 130 km^2 and is surrounded by a series of carbonatic Mesozoic reliefs of which a new structural model has been recently proposed (Figure 1). This model determines the hydrodynamics and the consequent feeding of the Piana. The structural building is formed by the overthrusted tectonic units (Abate *et al.*, 1978) which derive from the Miocenic deformation of calcareous dolomitic deposits (Carbonatic Panormide Platform) and calcareous dolomitic and calcareous siliceous clastic deposits (Imerese Basin).

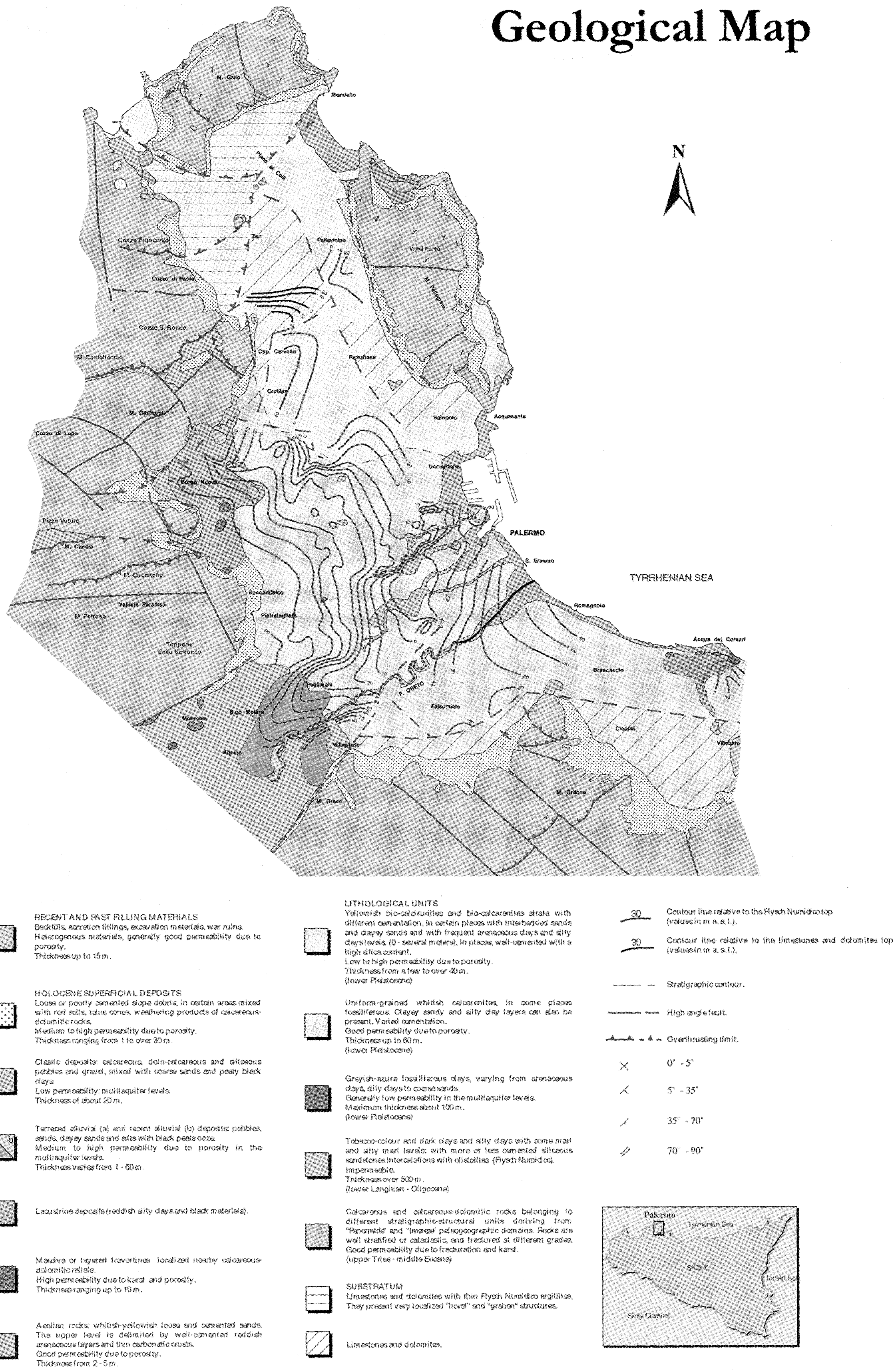
Geological Map
N
M. Gallo
Mondello
Piana dei Colli
Zen
Pallavicino
V. del Porco
M. Pellegrino
Cozzo Finocchio
Cozzo di Paola
Cozzo S. Rocco
M. Castellaccio
Osp. Cervello
Resuttana
Cruillas
M. Gibilforni
Cozzo di Lupo
Sampolo
Acquasanta
Uccirdone
Borgo Nuovo
Pizzo Vuturo
M. Cuccio
PALERMO
S. Erasmo
TYRRHENIAN SEA
M. Cuccitello
Boccadifalco
Vallone Paradiso
M. Petroso
Pietratagliata
Romagnolo
Timpone delle Setrocco
Acqua dei Corsari
Brancaccio
Pagliarelli
F. ORETO
Falsomiele
Monreale
B.go Molara
Ciaculli
Villabate
Aquino
Villagrazia
M. Griffone
M. Greco
RECENT AND PAST FILLING MATERIALS
Backfills, accretion fillings, excavation materials, war ruins.
Heterogenous materials, generally good permeability due to porosity.
Thickness up to 15 m.
HOLOCENE SUPERFICIAL DEPOSITS
Loose or poorly cemented slope debris, in certain areas mixed with red soils, talus cones, weathering products of calcareous-dolomitic rocks.
Medium to high permeability due to porosity.
Thickness ranging from 1 to over 30 m.
Clastic deposits: calcareous, dolo-calcareous and siliceous pebbles and gravel, mixed with coarse sands and peaty black clays.
Low permeability; multiaquifer levels.
Thickness of about 20 m.
Terraced alluvial (a) and recent alluvial (b) deposits: pebbles, sands, clayey sands and silts with black peats ooze.
Medium to high permeability due to porosity in the multiaquifer levels.
Thickness varies from 1 - 60 m.
a
b
Lacustrine deposits (reddish silty clays and black materials).
Massive or layered travertines localized nearby calcareous-dolomitic reliefs.
High permeability due to karst and porosity.
Thickness ranging up to 10 m.
Aeolian rocks: whitish-yellowish loose and cemented sands. The upper level is delimited by well-cemented reddish arenaceous layers and thin carbonatic crusts.
Good permeability due to porosity.
Thickness from 2 - 5 m.
LITHOLOGICAL UNITS
Yellowish bio-calcirudites and bio-calcarenites strata with different cementation, in certain places with interbedded sands and clayey sands and with frequent arenaceous clays and silty clays levels. (0 - several meters). In places, well-cemented with a high silica content.
Low to high permeability due to porosity.
Thickness from a few to over 40 m.
(lower Pleistocene)
Uniform-grained whitish calcarenites, in some places fossiliferous. Clayey sandy and silty clay layers can also be present. Varied cementation.
Good permeability due to porosity.
Thickness up to 60 m.
(lower Pleistocene)
Greyish-azure fossiliferous clays, varying from arenaceous clays, silty clays to coarse sands.
Generally low permeability in the multiaquifer levels.
Maximum thickness about 100 m.
(lower Pleistocene)
Tobacco-colour and dark clays and silty clays with some marl and silty marl levels; with more or less cemented siliceous sandstones intercalations with olistolites (Flysch Numidico).
Impermeable.
Thickness over 500 m.
(lower Langhian - Oligocene)
Calcareous and calcareous-dolomitic rocks belonging to different stratigraphic-structural units deriving from "Panormide" and "Imerese" paleogeographic domains. Rocks are well stratified or cataclastic, and fractured at different grades.
Good permeability due to fracturation and karst.
(upper Trias - middle Eocene)
SUBSTRATUM
Limestones and dolomites with thin Flysch Numidico argillites, They present very localized "horst" and "graben" structures.
Limestones and dolomites.
30
Contour line relative to the Flysch Numidico top (values in m a. s. l.).
30
Contour line relative to the limestones and dolomites top (values in m a. s. l.).
Stratigraphic contour.
High angle fault.
Overthrusting limit.
0° - 5°
5° - 35°
35° - 70°
70° - 90°
Palermo
Tyrrhenian Sea
SICILY
Ionian Sea
Sicily Channel

Fig. 1.

The field evidence (Catalano and Di Maggio, 1996) shows the Imerese unit overlaying the Panormide one. The early tectonic phase is evident, dating post Miocene with NW-SE folds direction, determining the original structural building. In the structural building of the Monti di Palermo (Contino *et al.*, 1998), three tectonic Imerese Units and three Panormide Tectonic Units have been identified.

The extensional Plio-pleistocenic tectonics have dissected the structures and progressively lowered them towards the Thyrrenean Sea. In the Piana di Palermo area, the overthrust of the Imerese unit on the Panormide one is masked by the Pleistocenic deposits with variable thicknesses, up to a maximum of 150 m of calcarenite and/or sandy clays and silt. In order to identify the lithological and structural nature of calcarenite substratum of the Piana, which is characterized by its morphostructural complexity, more than 2000 drilling and well data have been analyzed (Calvi *et al.*, 1998; Cusimano and Gatto, 2000). These analyses have revealed a general presence of marly-clayey deposits with some intercalation of quarzarenites (Numidian Flysch, Oligo-Miocene) which in some areas exceed thicknesses of 400 m. In other zones of the Piana, especially near to the piedmont bands, the whitish or yellowish calcarenite lean directly onto the lowered collapsed carbonatic block.

The roof of the Numidian complex can be reached at different depths, below the calcarenitc cover. In others areas of the Piana such covers are reduced or even absent, following the irregular configuration of the substratum, which is characterized by several shape types horst graben. The other terrains present in the Piana are constituted by recent continental deposits (debris mixed with residual red soils, old and recent alluviums of old riverbed water courses and Oreto river, travertine, palustrine, and lacustrine muds) and backfill.

HYDROGEOLOGICAL FRAMEWORK

In the Piana di Palermo is possible to identify vertical aquifer stratification (Figure 2):

- A shallow aquifer constituted by whitish or yellowish organogenic calcarenites with sand intercalations and/or sandy-silt, with conglomeratic levels at its base and with occasional or repeated levels prevalently silty-clayey which determine the conditions of semi-confinement of the host aquifer.

- A deep aquifer, a non confined unit in fractured carbonates (Mesozoic carbonates and dolomites).

In some sectors of the Piana, between the two aquifers, it is possible to find, with variable thicknesses, Numidian Flysch terrains and clayey-sandy-silty Pleistocenic successions. The calcarenitic aquifer has a low potential compared to the deep carbonatic one. This aquifer, no longer exploited for drinking use, plays a relevant role in the regional hydrodynamics for the following reasons:

- It interferes, directly and indirectly, with urban infrastructure;

- It receives polluting fluids of various types; it stores and transports them towards the stratum/lower slope, in the direction of the deep aquifers and the sea;

- It hosts the sewage system manifold, the conduits of the pipeline network and the subterranean excavations created in various historical periods (qanats, "scirocco" rooms, crypts, catacombs, subterranean canals and caves, etc);

- It ensures locally relatively important flows, used for industrial and agricultural purposes.

Currently, there are only a few and scattered data regarding the deep carbonatic aquifer because almost all the wells intercept the saturated zone of the calcarenitic aquifer or reach the roof of the impervious terrains of Numidian Flysch.

The hydrostructures feeding the Piana aquifers

The structural geological analysis, information deduced from deep well stratigraphy, piezometrical and hydrogeochemical surveys have enabled the identification of hydrostructures with independent behavior and which are responsible for the subterranean feeding of the aquifers located in the Piana (Cusimano, 1987; Calvi *et al.*, 1998). Preceding from north to south it is possible to recognize the following hydrostructures:

- Monte Gallo, characterized by a flux with S-N direction which counters seawater intrusion;

- Monte Castellaccio, feeding the calcarenitic aquifer present in the Piana dei Colli;

- Pizzo Vuturo - Monte Pellegrino which, hydraulically connected with the sea, is characterized by a marine intrusion wedge which influences the calcarenitic aquifer;

- Monte Cuccio. The equilibrated hydrologic balance carried out for the entire hydrostructure may show hydraulic isolation. Furthermore, the Cl content, never exceeding 1 meq/l confirms this hypothesis;

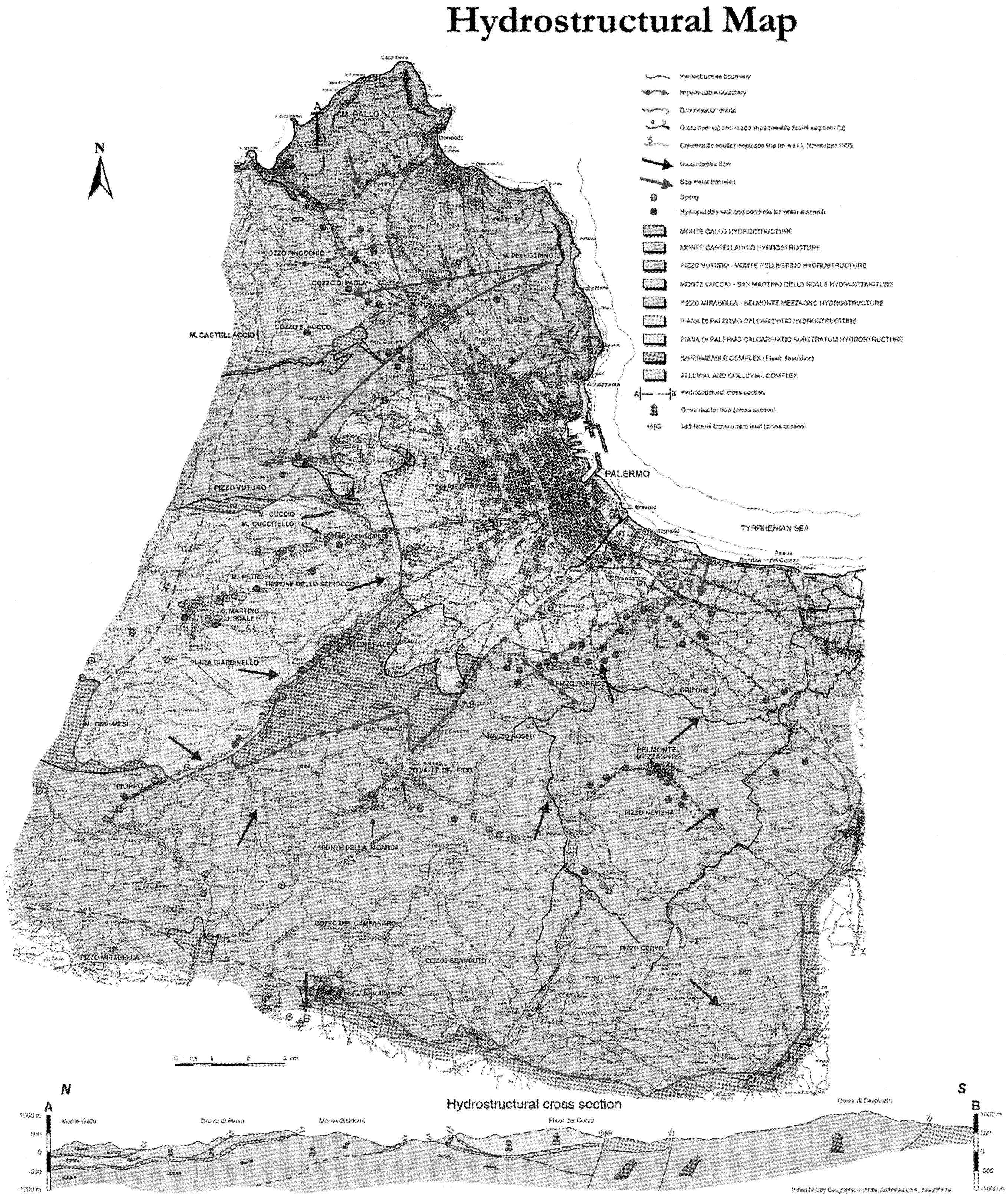
Hydrostructural Map
N
Hydrostructure boundary
Impermeable boundary
Groundwater divide
Orato river (a) and made impermeable fluvial segment (b)
Calcarenitic aquifer isopiestic line (m a.s.l.), November 1995
Groundwater flow
Sea water intrusion
Spring
Hydropotable well and borehole for water research
MONTE GALLO HYDROSTRUCTURE
MONTE CASTELLACCIO HYDROSTRUCTURE
PIZZO VUTURO - MONTE PELLEGRINO HYDROSTRUCTURE
MONTE CUCCIO - SAN MARTINO DELLE SCALE HYDROSTRUCTURE
PIZZO MIRABELLA - BELMONTE MEZZAGNO HYDROSTRUCTURE
PIANA DI PALERMO CALCARENITIC HYDROSTRUCTURE
PIANA DI PALERMO CALCARENITIC SUBSTRATUM HYDROSTRUCTURE
IMPERMEABLE COMPLEX (Flysch Numidico)
ALLUVIAL AND COLLUVIAL COMPLEX
Hydrostructural cross section
Groundwater flow (cross section)
Left-lateral transcurrent fault (cross section)
M. GALLO
M. PELLEGRINO
COZZO FINOCCHIO
COZZO DI PAOLA
COZZO S. ROCCO
M. CASTELLACCIO
PALERMO
TYRRHENIAN SEA
PIZZO VUTURO
M. CUCCIO
M. CUCCITELLO
M. PETROSO
TIMPONE DELLO SCIROCCO
S. MARTINO d. SCALE
MONREALE
PUNTA GIARDINELLO
M. GIBILMESI
PIOPPO
PIZZO VALLE DEL FICO
PUNTE DELLA MOARDA
BALZO ROSSO
PIZZO FORBICE
M. GRIFONE
BELMONTE MEZZAGNO
PIZZO NEVIERA
COZZO DEL CAMPANARO
COZZO SBANDUTO
PIZZO CERVO
PIZZO MIRABELLA
N
S
A
B
Hydrostructural cross section
Monte Gallo
Cozzo di Paola
Monte Gibilforni
Pizzo del Cervo
Costa di Carpineto

Fig. 2.

• Belmonte Mezzagno - Pizzo Mirabella, divided into seven substructures, feeding some southern parts of the Piana.

Piezometric survey of the aquifers

Two semester surveys, carried out in October 1995 and June 1996, enabled us to highlight the piezometric surfaces. In the Piana dei Colli area, the whitish calcarenites lean directly onto the buried carbonatic hydrostructures, thus the piezometric level values related to the wells placed in limestones or calcarenites are comparable. In the central zone there is a powerful accumulation of sediments, from fine to extra fine grain, loose and thickening, capable of isolating hydraulically the two aquifers. In the central area of Piana di Palermo, the hydrological data available refer to the non-confined or semi-confined stratum hosted by the yellowish calcarenites. The piezometry allows identifying three aquifers, one to the north of Oreto river, a second to the south, and a third area located between Ciaculli and Acqua dei Corsari (Calvi *et al.*, 1998).

Hydrogeochemical features of the aquifers

The definition of the carbonatic hydrostructures surrounding the Piana di Palermo has also been confirmed from the geochemical point of view. The groundwater, using the classical classification procedures, is bicarbonate alkaline and chloride sulphate alkaline. Its chemical behavior is strictly related to water-rock interaction, even though processes (mixing, ionic exchange, etc.) already highlighted in previous studies (Alaimo *et al.*,1984; Cimino *et al.*, 1987; Cusimano *et al.*,1996), mask the main process. The predominance of Ca^{2+} in the water circulating in the hydrostructures to the north of the M. Cuccio overthrust, match well with the prevalence of limestone rocks. On the other hand, the greater presence of Mg^{2+} in the southern area reflects the dolomitic composition of the rocks of the hydrostructures of M. Cuccio and Belmonte Mezzagno. In the aquifers related to the Piana di Palermo, a northern zone can also be identified (Piana dei Colli) characterized by a clear prevalence of Cl^- and Na^+ with respect to the southern area where HCO_3^-, and subordinate Ca^{2+}, are prevalent (Cusimano *et al.*, 1996). There is an intermediate zone (Cruillas, Resuttana area) which, from a geochemical point of view, displays geochemical changes which are most likely related to seasonal variations (Calvi *et al.*, 1998).

The chloride ion, being a conservative element in groundwater, can be used to define the isoconcentration contours and the subsequent processes that originate them. Following the statements previously indicated it is possible to distinguish, in the Piana di Palermo, a north section with chloride concentrations above 5 meq/l, from a south section with lower values. In the north sector a process of sea intrusion has been identified which, starting from the Mt. Pellegrino hydrostructure, involves the Pizzo Vuturo and Mt. Castellaccio hydrostructures (Vallone Guggino area). Sea intrusion seems to precede, with two wedges (Figure 2), from the karst system of the Valle del Porco (Mt. Pellegrino) towards Vallone Guggino and Pizzo Vuturo hydrostructures (Cusimano *et al.*, 1996; Calvi *et al.*, 1998). Although it has also been defined as a salinisation process of the calcarenitic aquifer, caused by different factors (Cusimano *et al.*, 1996):

• Cl^- leaching and ionic exchange, between the calcarenites and the carbonatic aquifer, where clay interlayers hold Ca^{2+}, releasing Na^+, Mg^{2+} and Cl^-;

• Input of mixed water, coming from the saline wedge present in the carbonatic aquifer, when calcarenitic and carbonatic aquifers are in hydraulic continuity.

In the coastal plain, close to the mouth of the Oreto river, Cl^- values have been revealed higher than 10 meq/l in late autumn and less than 5 meq/l in late spring. In the calcarenitic aquifer in the Acqua dei Corsari area, Cl^- values higher than 15 meq/l. have been revealed in late spring. In the southern section of the Piana, on the northern layer of the carbonatic Belmonte Mezzagno hydrostructure, Cl^- values, lower than 0.5 meq/l, have been found in late autumn and values greater than 1 meq/l in late spring. These Cl^- seasonal variations could be due to several agricultural activities.

THE IMPACT OF URBAN FACTORS

Over the past few decades urban settlements have grown and spread in an uncontrolled way, not only along the coastal plains and the piedmont areas (the case of the expansion of Palermo city), but also in the mountainous areas (houses used prevalently during the summer). The latter has had an effect on the main recharging areas of the carbonatic aquifers. This expansion has not been accompanied by the establishment of the necessary service networks such as sewage systems, aqueducts etc. One of the consequences of the lack of such systems is the increase of wells leaking built without proper sanitary controls. The wastewater treatment plants in the towns, do not always work well in the absence of suitable testing and proper maintenance releasing contaminants into water courses. In addition, there is also the widespread presence of small MSW (disposition sites for municipal wastes) along the main roads. The unplanned urbanization has brought the construction of a large number of drinking water wells, many of which have not been authorized. The consequent exploitation of hydroresources has produced an impoverishment demonstrated by the drastic reduction of the capacity and the drying up of some springs. Such uncontrolled exploitation of groundwater, on the coastal plains, has determined deterioration on their quality, as a result of seawater intrusion, which also affects the piedmont of the carbonatic reliefs (Cusimano and Di Cara, 1995; Cimino *et al.*, 2000). The greatest, actual and potential, pollution source is the MSW site of Palermo city, situated in an extremely fractured carbonatic structure in the Bellolampo area. The waste disposal site (470 m a.s.l.) occupies a doline of approx. 8 ha and contains at least 1.2 hm^3 of MSW, distributed in three piles. One of them can not be sealed.

APPLICATION OF THE SINTACS METHOD

The intrinsic vulnerability map of the area, where the city of Palermo is situated, was done using the SINTACS R5 parametric method (Civita and De Maio, 2000). The Seven parameters of this method are represented by seven maps. The area has been divided into a regular grid of Finite Square Elements (FSE), 40 m side.

The elementary cell dimension (40 m) was chosen taking into account the DEM resolution grid (20 m), the density of the survey points per surface unit, the number of information items attainable for each point, the scale of the final map restitution. Moreover this choice is the best compromise between high resolution and real availability of detailed data.

The employment of such a method, in an urbanized area, has meant some difficulties. In particular in the evaluation of some parameters, such as those related to infiltration, difficulty arose from the fact that the area is highly urbanized. From the intrinsic vulnerability map the integrated vulnerability map was subsequently drown up considering all the potential pollution sources considered as continuous danger points including even the points with occasional dangerousness.

Analysis of SINTACS parameters

Soggiacenza (Depth to water "S"): The piezometric surface has been rebuilt through the level of the springs and the watertable of some wells. The thickness of the carbonate complex is great, hundreds of meters, and the piezometric surface could be characterized by a very low gradient $\approx 0.2\%$.

Starting with the altitude for the springs (approx. 300 m), clearly inferior to the average altitude of the carbonatic reliefs, it appears evident that the thickness of the unsaturated zone is greater than 100 m, also as a result of the fact that the topographic surface is very sloped up to its immediate proximity to the springs.

Taking into account these considerations the SINTACS score for S is equal to 1 and 2 in a large part of the carbonatic reliefs.

The reconstruction of the watertable has been performed through field measurement analysis of two piezometric surveys carried out in 1995 and 1996, and the integration of previous well data. In this part of the area, studied water depth values are quite variable, from several meters to few centimeters. In some cases even within the fine – grain cover there is well–defined hydrostatic level of perched aquifers. In fact, in some parts of the Piana, particularly in the south, near the coastal band, there have been cases of leakage, in which aquifer pressure is such that it saturates even low permeability overlaying levels; nevertheless it concerns the first aquifer of a poor production semi-permeable complex. In this case the effect of aquifer pressure has been overlooked. In fact it is opposed to further pollutant penetration, and has an intermediate watertable value between the first aquifer and the semi-confined bed (Figure 3).

Infiltrazione efficace (Infiltration "I"): the presence in some parts of the Piana of thick soils, while there is an almost entire absence of soil on the carbonatic reliefs, has influenced two different types of approach for estimating this parameter. In fact, in the case of thick soils the whole value of average annual precipitations P was used for the χ_s index (the actual type of soil texture) $Ie = P \cdot \chi_s$. While in the case of bare or poorly covered rocks the value of effective average annual precipitations (P – Er) is multiplied by the actual index of the type of rock present χ_r.

$Ie = (P - Er) \cdot \chi_s$, where P represents the yearly average rainfall, Er the evapotranspiration and χ_r the potential recharge coefficient relevant to the different considered rocks (Figure 3).

Non saturo (Vadose zone "N"): for assessing the effect of autodepurification of the unsaturated zone in the study area, 2000 stratigraphic investigation points were examined and interpreted; geological surveys, lithostratigraphy of wells, excavations and trenches. Given the mixed nature of these sources it was necessary to establish a first stage to interpret and to compare data.

The entire thickness of the unsaturated zone is often constituted by different lithological types, from which it is necessary to calculate an average weighted of it. This is possible considering the relationship between the sum of the score (p) of every single lithotype for its thickness (h) and the total strength of the unsaturated zone (Figure 3).

Tipologia della Copertura (The overburden typology "T"): for the evaluation of this parameter, pedological profiles car-

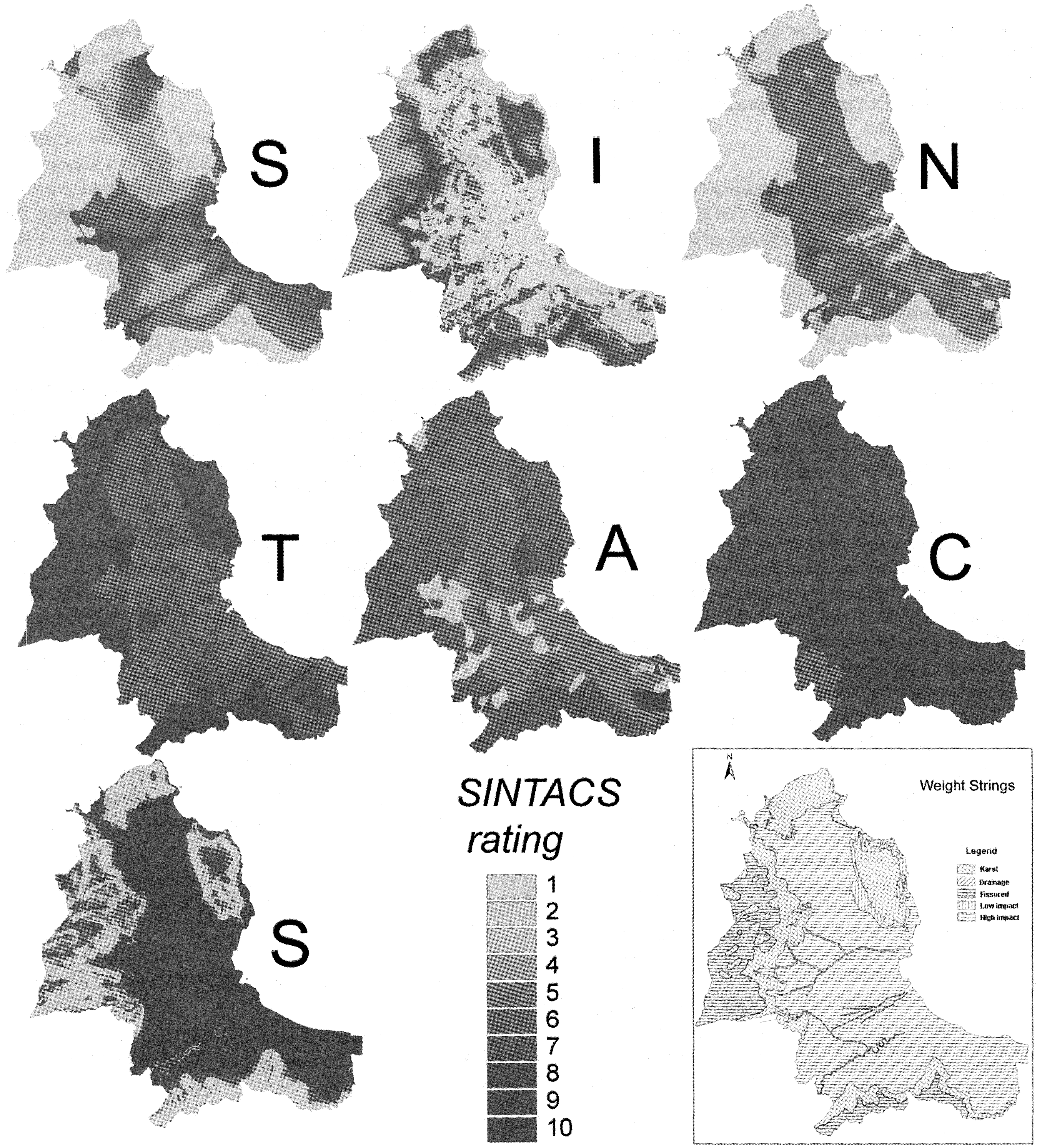

Fig. 3.

ried out in the study area provided by researchers of the Faculty of Agriculture, Palermo University, were examined. In addition the map of sicilian soils, scale 1:250000 was used and the Land use map (Cobello *et al.*, 1990). Ten different types of soil have been identified to which the relative SINTACS scores have been added (Figure 3). Moreover, the soil is generally thin or absent in the karst area, in this case it was attributed the maximum rating (10) for the T parameter.

Acquifero (Hydrogeologic characteristics of the aquifer "A"): the same lithographic control points employed for the unsaturated zone have been used for aquifer evaluation. As in the case of the unsaturated zone, given the presence of more lithological units, the score indicated by the parameter "A" is the result of the average weighted by the scores of every single layer characterizing the saturated area regarding its thickness (Figure 3).

Conducibilità idraulica dell'acquifero (Hydraulic conductivity "C"): for the estimation of this parameter different sources have been used: well test data of the Piana aquifers, pumping test, tests of drinking water wells and interpretations of exhaustion curves of significant springs. For the most important aquifers the hydraulic conductivity value results to be: recent alluviums 10^{-4}–10^{-6} m/s, calcarenites 10^{-2}–10^{-3} m/s, carbonates 10^{-5}–10^{-8} m/s.

Since the studied aquifer is constituted by several layers, characterized by types and/or different permeability grades, a weighted mean was also considered (Figure 3).

Superficie topografica (Slope of the topographic surface "S"): this parameter is particularly significant, in so far as it depends on the flow speed of the meteoric waters. For this evaluation a DTM (digital terrain model) was used with points given every 20 meters, and through the use of ArcView functions the slope map was drown up (Figure 3). Five different weight strings have been applied for the whole area in order to consider different scenarios and to describe, as well as possible, the different hydrogeological situations. Figure 3 shows the weight strings map.

RESULTS AND CONCLUSIONS

The intrinsic vulnerability map highlights the fact that about 80% of the study area can be classified as of high to very high vulnerability (Figure 4). In particular, the highest vulnerability areas are those very close to the river bed of the Oreto river which represents the main superficial water body in the Piana di Palermo whose waters for some time have shown a marked decline in quality. Other areas are related to sectors of the Piana where there is still agricultural activity, the karst zones destined for the waste disposal (Bellolampo) and those related to ex wetlands such as Mondello. High average values can also be found in the S-E area of the Piana, characterized by low water depth or, in some cases, with a sub outcropping hydro stratum.

Areas where seawater intrusion has been evidenced (Figure 2) are comprised in high vulnerability sectors. It is important to point out that this may be considered as a coincidence because the SINTACS method does not take into account, among its parameters, the horizontal input of seawater contamination.

The grid square cell structure of the SINTACS input data has been designed to use several weight strings (multipliers), both in serial and parallel way (Figure 3). The weight strings obtained emphasize, to lower or greater extent, single parameter rating in order to describe satisfactorily the effective hydrogeologic and impact situation (Civita and De Maio, 2000). In this study the urban area was discretized with the maximum value of impact.

Average weighted values for the unsaturated zone and for the aquifer were considered due to the geological environment and the presence of different lithologies. This strategy produced acceptable results in the SINTACS rating.

In order to observe the impact of urban activity, there have been highlighted the areas where the main carriers and contamination intakes (underground caves, subterranean caves, qanat, drainage tunnels, tunnels from where the long standing water courses derive, etc.). Such a map is an essential tool for people involved in water management and to the identification of monitoring centers points.

Finally, the use of SINTACS method is revealed useful tool to define the aquifer vulnerability even in an area strongly urbanized.

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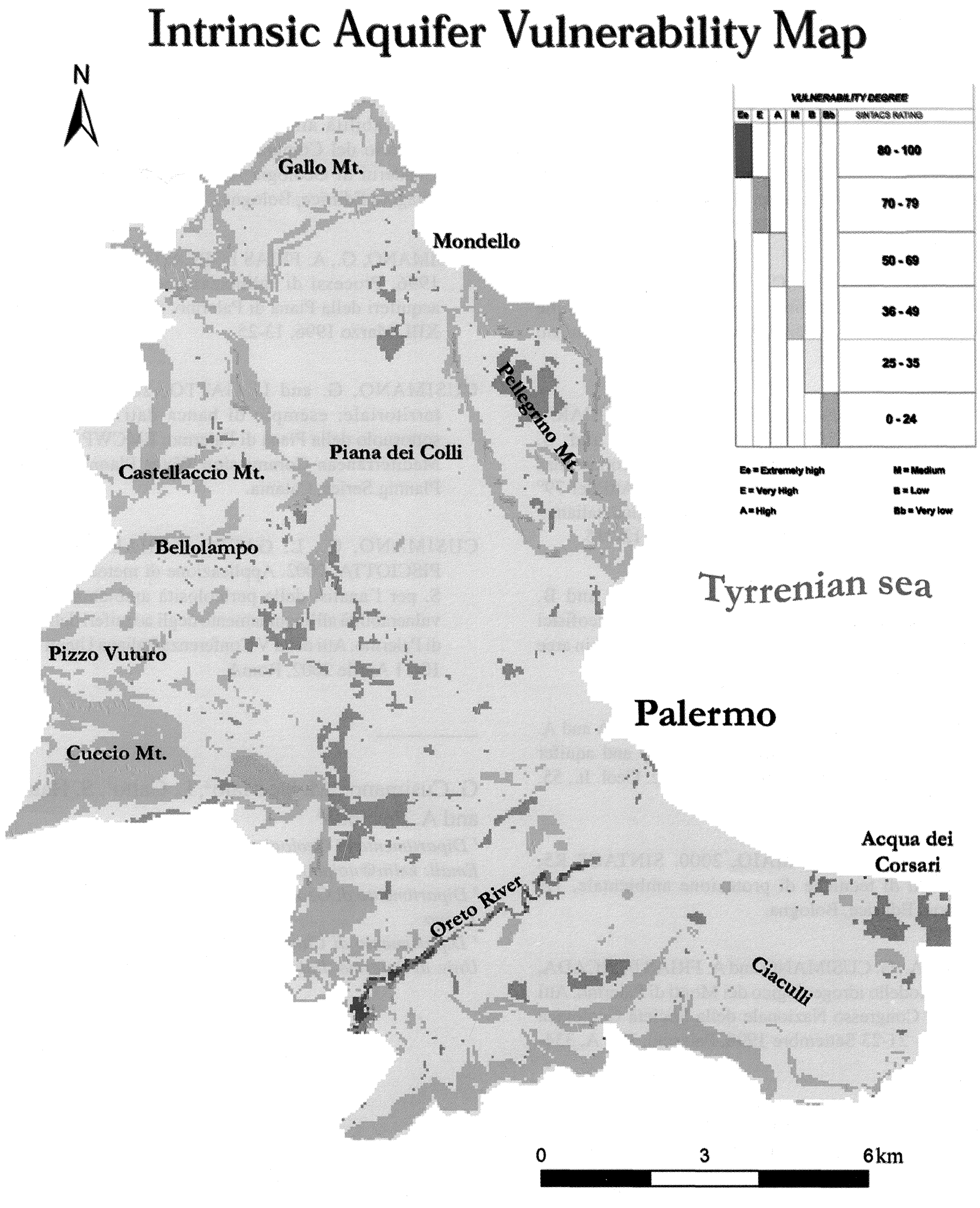

Intrinsic Aquifer Vulnerability Map
N
VULNERABILITY DEGREE
Ee
E
A
M
B
Bb
SINTACS RATING
80 - 100
70 - 79
50 - 69
36 - 49
25 - 35
0 - 24
Ee = Extremely high
E = Very High
A = High
M = Medium
B = Low
Bb = Very low
Gallo Mt.
Mondello
Pellegrino Mt.
Piana dei Colli
Castellaccio Mt.
Bellolampo
Pizzo Vuturo
Cuccio Mt.
Tyrrenian sea
Palermo
Acqua dei Corsari
Oreto River
Ciaculli
0
3
6km

Fig. 4.

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