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# Geothermal favourability mapping by advanced geospatial overlay analysis: Tuscany case study (Italy)

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ABSTRACT

The geothermal resource exploration generally requires a combined analysis of various geo-information datasets. In this framework the geospatial analysis as the weighted overlay, performed under GIS (Geographic Information Systems) environment, represent a strong tool to solve problems such as the site selection. This technique is applied on not homogeneous input data to perform an integrated analysis and producing favourability maps.

This work is based on the development of a new weighted overlay scheme, that combines favourable geological factors, which allow the identification of hydrothermal geothermal resources, and geological hazards (seismicity and volcanism), which can potentially limit the exploitation of a geothermal resource.

The technique was tested on Tuscany Region (Italy), where two geothermal fields, Larderello-Travale/Radicondoli and Monte Amiata, are in operation.

Results show that the most promising areas mostly coincide with the exploited geothermal fields. Moreover, new areas with a high geothermal favourability are identified.

Low-cost and rapid resource evaluation approaches like this could play a key role during the early stages of a geothermal exploration plan. Moreover, this methodology could be extensively used in other geothermal areas not only by the scientific community but also by stakeholders, as first concrete tool to explore a potential resource suitable for exploitation.



## 1. Introduction

Geothermal energy is considered one of the most promising option for a sustainable energy supply. Commonly the main question to which scientists, stakeholders and decision-makers are asked to respond is: where are the best potential areas suitable for geothermal exploitation? In order to properly answer, a reliable geothermal favourability map represents a strong decision-making tool to locate the exploration on the territory.

Usually, a conventional geothermal exploration programme is carried out through a step-by-step analysis, starting from regional to sub-regional surveys before proceed to more detailed studies [1]. These different exploration phases can be reassume in: *reconnaissance*, *pre-feasibility* and *feasibility*. During each phases the less interesting areas are gradually discarded to concentrate further efforts on the remaining, more promising ones [2]. The exploration methods became progressively more detailed passing from a regional to a local and more detailed scale. In the first-reconnaissance stage a combined analysis of various geo-information datasets as surface and underground geology by direct geophysical investigations (boreholes, seismic profiles, potential field methods), underground temperature distribution and geochemical manifestations, is required.

In this framework, GIS (Geographic Information Systems) can improve and facilitate the entire process since they represent a useful tool that permits a multidisciplinary and multi-scale spatial interpretation of different data.

Several authors applied this methodological approach as a decision-making scheme for energy supply planning [3,4] and geothermal resources exploration [5–12]. It has been generally demonstrated that the potential resources defined by GIS-based methods strongly correlate with the same areas defined by conventional methods [6]. Similarly to Noorollahi et al. [6,13], this work propose a new GIS-based technique useful during the early stages of a regional-scale geothermal exploration programme and capable to recognize potential exploitable geothermal resources. The innovation with respect to previous works lies on the consideration of such geological factors which help to identify the geothermal resources as well as those that might limit or hamper the exploitation.

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In this framework, the proposed analysis is based on two main groups of data:

- GPF (*GeoPredisposing Factors*): favourable geological factors to identify geothermal resources (e.g., geochemical manifestation, high temperature of the resource, depth of the reservoir minor than 3000 m);
- GHF (*GeoHazard Factors*): geological hazards (mostly seismicity and volcanism) that can potentially limit the exploitation of a geothermal field.

Therefore, the aim of the study was to define a technique to create a geothermal favourability map meant as potential resources suitable for geothermal exploitation.

This study represents an update and improvement of the contribution presented at the EGC2013 [14]. New data on tectonics and fluid geochemical manifestations ITHACA (ITaly HAzard from CApable faults and GOOGAS database (database of Italian gas emissions) [15,16]) were included to identify hydrothermal geothermal resources.

The technique was validated in Tuscany Region (Italy) where two geothermal field, Larderello-Travale/Radicondoli and Monte Amiata, are in operation; also allowing the identification of new favourable areas to consider for further geothermal exploration perspectives.

## 2. The case study area

The main Italian geothermal areas are located along the peri-Tyrrhenian coast, where anomalous thermal gradients and a high heat flux (120 mW/m$^2$ on average) were identified [17]. Geothermal anomalies in those areas are generally related to crustal thinning and sub-crustal anatectic intusions, as wells as volcanism [18]. Despite the huge geothermal potential of several Italian regions, only two geothermal fields of Larderello-Travale/Radicondoli and Monte Amiata (southern Tuscany) are currently exploited. Their gross electricity generation is approximately 5.5 TWh [19] (Fig. 1).

Larderello and Travale/Radicondoli are two nearby parts of the same deep field, covering an area of approximately 400 km$^2$. They produce super-heated steam at a pressure of 2 MPa, with temperature in the range between 150 and 270 °C [18]. The Larderello side covers 250 km$^2$, with 22 units for an installed capacity of 594 MW, whereas the Southeast side of Travale/Radicondoli covers an area of 50 km$^2$, with an installed capacity of 160 MW (6 units). Four additional units were installed here between 2005 and 2009, with a total capacity of 100 MW [19].

The Mount Amiata area includes two water-dominated geothermal fields, Piancastagnaio and Bagnore. Their exploitation started in 1960. In both fields, a deeper water dominated resource has been discovered under the shallowest resource, with a pressure of 20 MPa and a temperature near 300 °C. Public acceptance problems with local communities are hindering the full exploitation of such a high potential deep reservoir. Presently, this area contains 5 units with 88 MW of installed capacity: one in Bagnore and four in Piancastagnaio [19].

Since Tuscany has been interested by geothermal exploration activity, a huge amount of geological datasets useful to map the geothermal favourability of the Region, is available.

## 3. Methodology

The analysis were performed under the ESRI ArcGIS Desktop environment, using the *MB* (*ModelBuilder*) and the *WO* (*Weighted Overlay*) tools.

Several authors applied this approach as a decision-making scheme for and geothermal resources exploration [5–12]. The innovation with respect to previous works lies on the consideration of such geological factors which help to identify the geothermal resources as well as those that might limit or hamper the exploitation as the *GHF* (Fig. 2).

### 3.1. The ModelBuilder & the weighted overlay

The *MB* (*ModelBuilder*) is an internal application of ESRI ArcGIS Desktop that can be used to create, edit, manage and run spatial analysis models.

The *WO* (*Weighted Overlay*) functions are commonly applied as one of the most powerful technique to perform multi-criteria spatial analysis as the evaluation of natural resources as well as the site selection and suitability models.

Running an overlay model basically consists in performing a series of sequential operations among spatial information. In particular it is necessary to apply a common scale of values to dissimilar input data to create an integrated analysis. In order to perform an overlay analysis for a specific purpose, like the construction of a favourability map, it is useful to organise the model into sub-models and processes.

The necessary steps to allow the *WO* analysis are: i) identification of input data (significant layers with different influences); ii) transformation of the input data into grid datasets and reclassification of them with common reference scale (processing); iii) definition of weights and influence for each reclassified grid (modelling) (Fig. 2).

Then every cell value (weight) of each reclassified grid [*r_grid*] is multiplied by the *data-type* influence that define the importance (%) of the layer-information in the model. The resulting cell values are added to produce the final output grid $[m\_grid]_{WO}$ following the equation n.1, where $n$ represents the total amount of input data considered for the analysis.

$$[m\_grid]_{WO} = \sum_{i=1}^{n} \left( cell\ value_{[r\_grid]i} \cdot influence_{[data-type]i} \right) \tag{1}$$

In detail, the analysis were based on a sequence of chained procedures (Fig. 2), which produced three main overlay models: a basic overlay model for the GPF (*GPF-Model*: identification and areal distribution of potential geothermal resources) and the GHF (*GHF-Model*: identification and areal distribution of geo-hazard), respectively; and a final overlay between *GPF* and *GHF-Model*, producing the spatial distribution of the "reliably exploitable" geothermal macro-areas. This final grid represents the geothermal favourability map of the study area in terms of potential geothermal exploitation (*GF-Model*).

## 4. Data-processing

The data processing is a necessary step to allow the *WO* analysis. It consists in a series of functions to organise, convert, homogenise and reclassify the input data. The input data type and the performed operations are described below.

### 4.1. Geodatabase

The input data were organised into a dedicated ESRI *Geodatabase*, which contains of three main Feature Datasets relative to the *input*, *processed* and *model data*. Each Feature Dataset contained several Feature Classes on which the overlay procedures were based on.