DIPARTIMENTO
DI SCIENZE DELLA TERRA
SAPIENZA
UNIVERSITÀ DI ROMA

DOTTORATO DI RICERCA
IN SCIENZE DELLA TERRA

Research activity

Groundwater and seismicity relationship: hydrogeological monitoring to identify "hydrosensitive sites" in central-southern Italy

General objective: Hydrogeological and hydrogeochemical characterization of the main springs in central-southern Apennines in order to identify specific sites for a potential future national monitoring network.

Specific objective: Expanding our understanding of the cause-effect relationship between groundwater and seismicity to define "hydrosensitive" sites in central-southern Italy.

State of the art: Earthquakes have a great influence on underground hydrology, such as water table changes and hydrogeochemical anomalies [1]. Changes in isotopic ratios [2], pH values and electrical conductivity [3], radon activity [4], ion concentrations in solution [5] and variation of piezometric level [6] have been documented following large earthquakes. The seismic cycle causes strain that alters hydrogeologic properties, such as permeability which controls the rate of fluid flow and involves a variation of the stress field, more and more intense till the mainshock. A conceptual model defines fluid behavior [7] and proposes that in extensional tectonic environment, the portion of crust above the brittle-ductile transition remains suspended while a dilated area forms during the interseismic period. Fluids may enter the fractured volume and water level decreases. When the portion of crust above brittle-ductile transition starts to drop, the fractures close and water level starts to rise. This increase of water level culminates in the coseismic period. This condition could explain the changes in the piezometric level before, during and after strong earthquakes. Chemical and isotopic changes in water content have been abundantly studied. For example, during the inter-pre-co-post-seismic phases of the M_w 7.2 Kobe earthquake in Japan (1995), a progressive increase in radon and chlorine concentrations has been measured in the months preceding the earthquake and a drastic decrease immediately after [8]. In central Italy as well, during the Amatrice-Norcia seismic sequence, geochemical anomalies and pH changes have been detected four months before the start of the seismic swarm [9]. In particular, a strong increase in the concentrations of As, V, Cr, Sr and Fe has been observed starting from April 2016. This amount could be linked, as supposed for a similar case recorded in Iceland [10], to the inflow into the hydrogeological system of deep hydrothermal fluids, which are characterized by these elements as primary content. These studies show that groundwater chemistry is a promising target for the predictability of earthquakes. Several considerations reported in the literature and the intense seismic activity, which affects central-southern Apennines, confirm the importance of research in this area to understand the interactions between seismicity and hydrogeology. Therefore this project has the dual purpose of identifying

potential preseismic anomalies and focusing on the hydrodynamic modifications that fractured aquifers undergo, with consequent effects on the availability and quality of water resource. The role of fluids will be analyzed in a tectonic-structural framework to develop optimally this multidisciplinary study and the dynamics related to groundwater circulation and water-gas interactions will be also defined. Following are some earthquakes occurred in the study area in recent times: Molise earthquake in 1805 (M_w 6.6), Irpinia earthquake in 1980 (M_w 7.0), Campobasso earthquake in 2002 (M_w 6.0), L'Aquila earthquake in 2009 (M_w 6.3), Sannio-Matese earthquake in 2013 (M_w 5.0).

Activity: This research is part of the PON project of the INGV hydrogeochemical monitoring and it is supported by the collaboration of the CNR-IGAG. In order to achieve the goals, a hydrogeological and hydrogeochemical survey will be carried out with a seismic and geodetic characterization of the study area. A systematic study of the hydrogeological and hydrogeochemical parameters potentially influenced by seismic activity (piezometric levels, temperature, pH, electrical conductivity, chemical and isotopic composition of groundwater and dissolved gases) is proposed and a comparative and integrated analysis of these will allow to verify existence and modalities of cause-effect relationship between the hydrogeological and hydrogeochemical signals with the seismic and geodetic ones. Moreover, the research will provide a detailed degassing investigation of mantle-derived fluids through lithospheric discontinuities [11; 12; 13] and in particular of the diffuse CO_2 degassing in tectonically active areas by groundwater. The innovation of this project is based on a multiparametric monitoring in different sites and on data cross analysis. For the first time laboratories will be carried on field and, through high frequency data, dynamics and time evolution of processes in relation to seismicity of the central-southern Apennines region will be characterized.

Work plan: PON project has already pre-selected 24 springs in Abruzzo, Molise and Campania regions which could be monitored. In the first year of the PhD, considering some elements including the hydrogeological characteristics of sites and the logistical conditions, I will select a smaller group of springs suitable to achieve the objectives (from a minimum of 5 to a maximum of 10). I will take samples for each spring in periodic campaigns for major and minor elements measurement, for the chemical composition of dissolved gases and isotopic analysis (^{2}H, ^{18}O, SO_4,^{13}C, Sr, B, He, Ne, Ar), useful for characterization of deep water flowpaths and processes that can modify water chemistry during seismic cycle. I will conduct all samples analysis at the Sapienza geochemistry laboratories and at the INGV laboratories in Palermo. The first year of work will allow to outline a baseline, providing a representative framework for the elaborations and interpretations of following years.

Once the hydrogeological will be acquired, a preliminary model of groundwater flowpath will be developed and between the first and second year of the PhD, I will identify some specific sites among those previously selected, for which the installation of automatic stations for multi-parameter monitoring is planned. The stations will be equipped with sensors to measure the main chemical-physical water parameters, electrodes for the measurement of specific ions and probes for monitoring the concentrations of free and dissolved gases such as radon and CO_2, which have shown greater sensitivity to the seismic activity [4; 14]. Dissolved and free gases will be monitored for the isotopic study of ^{13}C in CO_2, as well as helium, for the evaluation of the potential depth of gasses origin. Besides, in collaboration with the INGV, I will contribute to the elaboration of specific data sequences related to short time intervals for the study of correlations between transient signals

of potential significant earthquakes and possibly recorded hydrogeological anomalies. I will consider earthquakes recorded by the National Seismic Network for seismic investigation. Moreover, I will acquire data of solid earth tide to identify the periodic crustal deformations induced by the gravitational luni-solar forces [15].

I will make all the time series suitable for comparison to point out correlations and/or interactions between the parameters by processing techniques implemented in software. The processing will allow to identify periodicity, trends and relations with local, seasonal and anthropic conditions and potential characteristic trends that occur in relation to crustal strain. Moreover, the sensitivity of each parameter can be defined with this multi-parameter filtering and the connection to the seismic cycle of some metals and metalloids in solution, dissolved and free gases, can be confirmed or not. During the last year, I will focus on the processing, comparison and interpretation of data acquired from the monitoring networks. On the basis of obtained results, the influence of seismic cycle on water chemical-physical characteristics will be verified and the potential variations in the time series will be detected. In the last months of the third year I will write the PhD thesis.

In the three years of PhD, the bibliographic study will be continuously updated in order to better develop the research project. In addition, publications in scientific journals and didactic activities are planned through the attendance of master university courses, conferences and seminars.

PhD activity	First year		Second year		Third year	
	First semester	Second semester	First semester	Second semester	First semester	Second semester
University courses	X	X	X	X		
Bibliographic study	X	X	X	X	X	X
Monitoring and processing	X	X	X	X	X	X
Screening of the main springs (PON)	X	X				
Sites selection and station installation		X	X			
Training period abroad				X		
Analysis and comparison of processed data				X	X	
Data interpretation					X	X
Publications		X		X		X
Seminars and conference	X		X		X	
Thesis						X

References:

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[3] Malakootian & Nouri (2010) *Int. J. Environ. Res.* 4, 443-454
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[7] Doglioni et al. (2014) *Geosci. Front.* 5, 767-780
[8] Ingebritsen & Manga (2014) *Nat. Geosci.* 7, 697-698
[9] Barberio et al. (2017) *Sci. Rep.* 7, 11735
[10] Skelton et al. (2014) *Nat. Geosci.* 7, 752
[11] Italiano et al. (2000) *J. Geophys. Res.* 106, 13569-13578
[12] Caracausi et al. (2013) *J. Volcanol. Geoth. Res.* 253, 65-74

[13] Caracausi & Paternoster (2015) *J. Geophys. Res. Solid Earth* 120, 2200-2211
[14] Chiodini et al. (2004) *Geophys. Res. Lett.* 31
[15] Igarashi & Wakita (1991) *J. Geophys. Res. Solid Earth* 96, 4269-427

1. Research products

a) Publications (ISI journals)

Barberio, M.D., **Gori, F.**, Barbieri, M., Billi, A., Devoti, R., Doglioni, C., Petitta, M., Riguzzi, F., Rusi, S. (2018) - Diurnal and Semidiurnal Cyclicity of Radon (222Rn) in Groundwater, Giardino Spring, Central Apennines, Italy. Water, 10, 1276.

b) Publications (NON ISI journals)
c) Manuscripts (submitted, in press)
d) Abstracts

Barberio, M.D., Barbieri, M., Billi, A., Doglioni, C., **Gori, F.**, Franchini, S., Lacchini, A., Petitta, M., Rusi, S. (2018) - Monitoring groundwater and earthquake relationships: “hydrosensitive zone” concept and experiences from Central Italy