Using Radon in the ground and stream water interaction analysis at reach scale in the Upper Tusciano river (Southern Italy)

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Abstract: In this paper, the results of the experimental investigations on the spatial-temporal variations in Radon activity concentration along a reference segment and reaches of the Upper Tusciano river, are illustrated and discussed. The research aims to perform integrate and interdisciplinary hydro-geomorphological approaches in the framework of the best improvement and site adaptation of the EU Water Directive in Mediterranean, complex river basins. The study area is located inside the M.nt Picentini Regional Park (Campania region, southern Italy). Along the river segment, complex interactions and exchanges between surface and groundwater exist. One of the main problem is to detecting river reaches functioning as gaining by spring flows and losing by stream bed infiltration, respectively. As a support to assess these interaction processes, monthly monitoring campaigns in discharge, electrical conductivity and Radon activity concentration measurements have been and are currently carried out. Results show a general, downstream increase in stream flow discharge along the step-and-pool and bedrock river reaches and a local decrease in the alluvial reaches of the river segment. Both electrical conductivity and Radon space-time distribution provide detailed information about a typical behavior of the stream flow in alternating gaining-losing reaches, where the only discharge measurements are not able to detect this functioning.

Key-Words: Radon, Groundwater, Hydro-geomorphology, River Drainage Basin, Electrical conductivity, discharge

1 Introduction

In order to assess and manage water resources, the EU Water Framework Directive 2000/60/EC [1] suggests an integrated approach taking hydro-geological, hydro-geomorphological, hydrological, hydro-geochemical, physical and biological contributions into account [2]. Recently, a great efforts have been made in the groundwater-stream flow interaction assessment and monitoring [3], especially in the small, mountainous, karst Mediterranean landscapes the inter-disciplinary approaches are fundamental [4, 5, 6]. In fact, in this landscapes very complex recharge processes and groundwater circulation mechanisms exist [7, 8, 9], controlled by climate, lithology and geomorphology. Generally, the Mediterranean landscapes are characterized by a climate alternating intense...
rainfall events, generating very rapid floods in ephemeral river stream beds of small and step catchments and long dry periods. In the Tyrrhenian Mediterranean Climate Province, mountainous, headwater functioning is controlled by abundant orographic-induced rainfalls in springtime and fall and prolonged snow cover in winter. These precipitations are able to recharging many, karst, mountainous aquifers [10] many springs by suspended karst aquifers feeding stream flow of the headwater river segments, producing a permanent yearly discharge, inducing best condition for riverine habitats and providing many eco-services to communities. Due to this great importance, many karst, headwaters are recognized as protected areas, as Regional and National Parks and natural Reserves, where the water regulation has to be integrated by ecological considerations and requires water assessment based on environmentally-sustainable methods and materials.

In the last decades, an useful help in answering to the questions of interest in water resources management have been the integration by karst hydro-geomorphology and isotope hydrology by the use of isotopes (stable and unstable), as natural tracers, both in field investigations as in laboratory analysis [11, 12, 13, 14, 15, 16].

One of the most interesting and promising approach to assess quantitatively the groundwater contributions to stream waters consists in measuring Radon-in-water activity concentrations [17, 18, 19]. Therefore, it has been proved that Radon-222 can be an useful natural tracer, because its activity concentrations in groundwater is typically one order of magnitude or bigger than those ones occurring in surface waters [20].

In this paper are used combined data of EC and Rn as tracers, in detecting groundwater contributions, also along the reaches where only the discharge measurement result in stream flow decrease.

2 Study Area

The drainage river basin (Fig. 1a) is located in the Picentini Regional Park (province of Salerno, Campania region, Southern Italy, Fig. 1b).

Fig.1a) Tusciano River Basin; Fig.1b). Campania Region

Orographically, the highest peaks of the Picentini Mountain System is Mt. Polveracchio (1.790m asl) from which originates the Tusciano river. The Tusciano river basin (Fig.1a) extends to the sea for an area of about 260 km² and the main stream is about 41 km long.

The investigated drainage area study concerns the Upper Tusciano river basin (circa 80 km²) whose main stream is about 15 km long (Fig.1a).

The study area is characterized by a typical Mediterranean climatic regime, tending to temperate
from the coast to the mountain reliefs. In the Table 1
are shown average monthly temperature and rainfall
recorded to the Acerno meteorological station [21].
The drainage pattern on the basin is weakly trellised
and ramified. Table 2 contains the main catchment
morphometric parameters.
The Upper Tusciano river stream flow originates by
junction of two headwater torrents. On the left, it
receives a lot of waters through the Bardiglia torrent
feeding by the Bardiglia and Savuco springs, both
coming from the NE hillside of the M.nt Polveracchio (Fig.2).
On the right valley side, the river segment receives
the stream waters from the Pinzarrino catchment
and the Ausino spring group. This latter is located
upper stream the Isca della Serra valley, while on
the left side it circumvents the Acerno village until
arriving at Acqua Buona segment, where it swells
for the water coming from the Molari valley (Fig.2).

Table 1. Average 50-year, monthly temperature and
rainfall in Acerno.

<table>
<thead>
<tr>
<th>Months</th>
<th>[mm]</th>
<th>[°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>152</td>
<td>4,7</td>
</tr>
<tr>
<td>February</td>
<td>112</td>
<td>4,9</td>
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<td>March</td>
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<td>6,9</td>
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<td>April</td>
<td>81</td>
<td>9,8</td>
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<td>May</td>
<td>52</td>
<td>14,3</td>
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<td>38</td>
<td>18,2</td>
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<td>August</td>
<td>35</td>
<td>21,3</td>
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<td>September</td>
<td>84</td>
<td>18,1</td>
</tr>
<tr>
<td>October</td>
<td>127</td>
<td>13,5</td>
</tr>
<tr>
<td>November</td>
<td>152</td>
<td>9,4</td>
</tr>
<tr>
<td>December</td>
<td>155</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 2. Main catchment morphometric parameters

<table>
<thead>
<tr>
<th>Code</th>
<th>Rc</th>
<th>Ru</th>
<th>Rf</th>
<th>Ra</th>
<th>D</th>
<th>n1</th>
<th>F1</th>
<th>ga</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isc</td>
<td>0.59</td>
<td>1.30</td>
<td>0.32</td>
<td>0.64</td>
<td>4.47</td>
<td>147</td>
<td>6.46E-06</td>
<td>2.90</td>
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<tr>
<td>_04</td>
<td>0.46</td>
<td>1.47</td>
<td>0.33</td>
<td>0.65</td>
<td>3.60</td>
<td>231</td>
<td>5.40E-06</td>
<td>10.33</td>
</tr>
<tr>
<td>_03</td>
<td>0.53</td>
<td>1.37</td>
<td>0.39</td>
<td>0.70</td>
<td>3.93</td>
<td>392</td>
<td>5.92E-06</td>
<td>8.26</td>
</tr>
<tr>
<td>_02</td>
<td>0.50</td>
<td>1.41</td>
<td>0.34</td>
<td>0.66</td>
<td>3.96</td>
<td>416</td>
<td>6.06E-06</td>
<td>8.13</td>
</tr>
<tr>
<td>_01</td>
<td>0.45</td>
<td>1.48</td>
<td>0.33</td>
<td>0.65</td>
<td>3.93</td>
<td>434</td>
<td>6.05E-06</td>
<td>8.17</td>
</tr>
<tr>
<td>_00</td>
<td>0.49</td>
<td>1.43</td>
<td>0.35</td>
<td>0.67</td>
<td>3.95</td>
<td>488</td>
<td>6.16E-06</td>
<td>7.65</td>
</tr>
</tbody>
</table>

Code: Rc: circularity ratio; Ru: uniformity coefficient; Rf: form
factor; Ra: length ratio; D: drainage density; n1: number of first
order fluvial branches; F1: frequency of first order fluvial
branches; ga: density of hierarchical anomaly.

Fig. 2. Upper Tusciano river basin and monitoring
system stations.

The Picentini Mountains hydrogeological unit
includes calcareous-dolomitic structures that
represent one of the most important aquifers in
southern Italy, thanks to the abundant orographic
rainfalls produced by very wet frontal systems from
Tyrhenian sea.
The groundwater flow is very high (85-90%)
compared to surface runoff, due to the intense
infiltration phenomena and to the presence of
widespread carbonate bedrock discontinuities. The
basin is mainly composed of limestone and
dolomite, secondarily of lacustrian and epiclastic
deposits complex, as shown in Fig.3.
It has been chosen as the most significant reaches
the one included between Casa Isca location and
Acqua Buona (Fig.2) because it is representative of
the geomorphical stream behavior for its mountain
section and in a situation not overly influenced by
anthropogenic interventions.

3 Materials and Methods

The direct discharge measurements were carried out
using the Swoffer 3000 current meters. The protocol
used was DISCH and the collected data of water
depth, velocity and discharge were processing and
implemented in a specific database. Fig.4 contains
river discharge measurements along the cited
reference reach in the years 2010-2014.
In order to gain useful and effective insights derived from Radon activity concentration measurements and elaborations, monthly measurement campaigns have been performed in the Tusciano river basin. Discharge measurements are gauged about a week after rain events, in order to estimate as much as possible base flow component of the total hydrograph.

Simultaneously with the discharge measurements were performed electrical conductivity and Radon activity concentration measurements. For the experimental implementation of the Radon measurements and in compliance with the boundary conditions of the area where to operate, the most suitable experimental setup turned out to be the portable Radon-in-air analyzer, RAD7 by Durridge Company, Inc. (Bedford, MA, U.S.A.). We chose this instrument because of the following characteristics: (1) very low intrinsic background < 0.004 cpm in channel A, 218Po; (2) relatively high sensitivity in “sniff mode” (218Po counts) at ~0.4 cpm/pCi/L for 222Rn in air; and (3) energy discrimination for the different radon daughters [22]. It is also capable to perform Radon short-lived progenies’ alpha spectrometry, in the laboratory, on water sample vials collected during the campaigns [23].

Besides Radon activity concentrations, chemical and physical parameters (pH, water temperature, dissolved oxygen, TDS, water conductivity (EC), water resistivity, etc.) have been collected. The instrument used was the multi-parametric HI 9828 (HANNA Instruments S.r.l.).

The stations, whose coordinate locations have been measured by means of GPS GS20 Professional Data Mapper Leica Geosystems, have been chosen according to their relevance for the study of the interactions between groundwater and surface waters.

Each monitoring station has been labeled with an alphanumeric code, beginning with the three letters TSC (TSC stands for Tusciano) followed by a string of bits, containing the station ID number plus a code for distinguishing between spring and river stations (Fig. 2 and Fig. 4).

The following data acquisition procedure and measurement protocol, consisting of the following steps, have been adopted: sample collection protocol, experimental measurements of the Radon-in-water activity concentrations, evaluation of the effective Radon-in-water activity concentration at the collection time.

Above them, background and blank count rates in each of the appropriate channels are subtracted from all the obtained standard and sample values, and are also used for calculation of the MDA of the system.

We first purge the RAD7 with dry air and use a charcoal trap to adsorb radon if the background count rates caused by air entering the system are higher than 0.6 cpm in the A channel.

The water samples have been stored in two different types of glass vials: W250 (calibrated volume of 250 ml) and W40 vials (calibrated volume of 40 ml), depending on the value of the Radon activity concentration presumably expected for that location. More specifically, W40 vials have been used for stations with expected high values (about the order of tens of Bq/l), like those characterizing the springs in the Tusciano basin, and W250 vials for much lower values (from few Bq/l down to tenth or hundredth of them), like the ones typically occurring in the waters along the streamflow.

In order to be sure that Radon cannot escape from the sample (degassing phenomenon) during the sampling procedure, transportation and offline analysis in the laboratory, vials have been capped with TEFILON lined caps, as quickly as possible after filling them up.
Measurements were carried out in the laboratory for Environmental Radioactivity (AMBRA), (UNI EN ISO 9001-2008 (ISO 9001-2008), N. 297uSGQ00). For these measurements the RAD7 has been equipped with the accessory kit for sampling measurements in water, RADH20, enabling it to measure radon-in-water over a wide activity concentration range, from less than about 1 Bq/l up to much greater (orders of magnitude) values than 3 kBq/l \[24, 25\] with an accurate reading achieved in 30 minutes acquisition data runs. The RAD7 device, used together with this accessory, contains two built-in measurement protocols for Radon-in-water measurements, for the two types of vials: W250 and W40 protocols. Each run, 30’ long, consists of 6 cycles, each one 5’ long. During the first cycle, the water sample is aerated with air pumped from the internal pump of RAD7. In this way 95% of Radon contained in the water is extracted to air. In the next one, the system waits for the formation and decay of Polonium-218, while the effective counting of the alpha particles emitted by $^{218}$Po starts only in the third cycle and goes on until to the end of the run, when Polonium-218 reaches the secular equilibrium with Radon; thus, enabling the device to compute the Radon activity concentration value. The instrumental output represents the final value of the Radon activity concentration value in water and not the one occurring in the air.

4 Results and discussion
The results of the measurement campaigns highlight, as shown in Fig.5, clear and gradual increase in discharge along the reach between the closure section TSCS_00 and the ones upstream (junction between TSC_ISC and TSCS_04) \[26\]. Nevertheless was recorded an anomalous decrease in streamflow discharge in the months of March, June, July, November 2011, March, May, June 2012, January, July 2013 and finally in March 2014 from TSCS_03 to TSCS_02, identified as the most representative reaches.

Analyzing the average monthly discharge data, reported in Tab. 3, was confirmed the anomaly of the decrease in streamflow discharge between the two above mentioned stations; conversely the number of spring should increase progressively and significantly the river discharge. Simultaneously with the flow measurements and in order to establish the role of the groundwater on the streamflow, it was considered appropriate to conduct joint radon-discharge-EC analysis measurements. They were carried out from August 2010 to June 2012. Figures 6 and 7 contain all the Radon activity concentration data and EC data from these selected stations. These results show, as expected, that most of all Radon concentrations and EC values measured at the group of 2 stations TSCS_03 to TSCS_02 increase because of the inflow of the lateral resurgence springs, whose water is richer in Radon and contribute to the increase in conductivity.

Tab.3 Average of discharge at the main stream stations [m$^3$/s]

<table>
<thead>
<tr>
<th>IS0 +04</th>
<th>03</th>
<th>02</th>
<th>01</th>
<th>00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean [m$^3$/s]</td>
<td>1.40</td>
<td>1.60</td>
<td>1.59</td>
<td>1.93</td>
</tr>
</tbody>
</table>

In the months following the campaign of June 15, 2012 was continued to perform only discharge and EC measurements that confirm as referred above.

Fig. 4 – Tusciano stylized main stream.

5 Conclusions
The implementation of the Radon measurement techniques has confirmed the prospective of using these methodologies in a karst Mediterranean
Fig. 5 Discharge at the Tusciano main stream stations \([\text{m}^3/\text{s}]\). The dashed lines refer to the campaigns carried out during the recharging period (from October to May) while the continuous lines to streamflow recession period (from May to October).

Fig. 6 EC values.

Fig. 7 Radon concentration \([\text{Bq/l}]\)
environment to investigate the complex interactions and exchanges between streamflow and groundwater. Experimental data about Radon concentrations, in addition to physical-chemical data and streamflow rate, have been acquired during monthly measurement campaigns. The future aim of this research program is to continue and improve these studies using Radon as a naturally occurring tracer in the Tusciano river basin, and to extend this investigation to other karst Mediterranean environments in the Campania Region and in the whole Southern Italy. In addition to shedding light on the frequency of decrease in streamflow discharge in the significant reaches of the stream, it would be necessary a future installation of piezometers.

References:


[21] Historical data from SIMN.


[24] DURRIDGE, RAD7 RADON DETECTOR. Owner’s Manual (Bedford, MA.), 2012, USA.
