Forested Infiltration Area (FIA) design in the Arborea Nitrate Vulnerable Zone (Sardinia, Italy)

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Abstract. This research aims to test a Managed Aquifer Recharge (MAR) technique based on Forested Infiltration Areas (FIA) to reduce the groundwater nitrate contamination of a sandy phreatic aquifer in the Arborea NVZ (Sardinia, Italy). The FIA system in Arborea will be supplied with drainage water having an average NO_3 concentration of 70 mg L^{-1} , pumped from a dewatering pumping station. The water will be treated before infiltration through an innovative Passive Treatment System, consisting of a mixture of inert and organic materials, to attenuate organic and inorganic contamination and to prevent clogging processes at the infiltrating surface. The experiment will be conducted for a duration of two years. A monthly monitoring will define, *ante operam,* the quality baseline of drainage water and groundwater and will assess, *post operam,* the efficiency of the FIA system. An estimation of the infiltration rate in the sandy soils based on preliminary surveys showed a potential recharge rate of around 0.7 hm^3 $year^{-1}$ per 0.4 ha of FIA system.

Keywords: Groundwater nitrate contamination, Managed Aquifer Recharge, Forested Infiltration Area, Non-conventional water reuse, Mediterranean region.

1 Introduction

Among nonpoint sources, synthetic and organic fertilizer application represents the most important input of nitrate in groundwater. After almost three decades, despite the measures implemented since 1991 to minimize agricultural nitrate pollution (Directive 91/676/CEE), there is no significant reduction in groundwater nitrate contamination which still frequently exceed the threshold value of 50 mg L^{-1} [1].

Managed Aquifer Recharge (MAR), which is the intentional recharge of water to aquifers for subsequent recovery or environmental benefits, represents an effective solution to improve water quality in aquifers [2]. In many aquifers, dilution has been one of the major processes that have diminished nitrate concentration [3]. Several FIA systems have been implemented in Veneto (Northern Italy) which consist of the distribution of surface water in areas equipped with a network of trenches and forested with various trees and/or shrubs species. The forest maximizes the infiltration rate and the denitrifying bacteria, living in symbiosis with the tree roots, have a very effective action to promote NO_3 attenuation (up to 80-90%) [4].

The paper presents the preliminary results of the FIA system implementation to contribute to mitigate groundwater contamination in the Nitrate Vulnerable Zone (NVZ) of Arborea, within the MENAWARA project, funded by EU under the 2014-2020 ENI CBC MED Programme.

2 Settings, materials and methods

2.1 Study area

The study area is located in the farming district of Arborea (about 60 km^2), central-western Sardinia (Italy) (Figure 1a). The climate is typically Mediterranean. The Arborea plain was a swamp which was reclaimed in the 1920–1930ies. Nowadays it represents one of the most productive agricultural sites in Italy where more than 200 farms, associated in a strong farmers' cooperative, manage some 30,000 dairy cattle on a 6,000 ha [5]. This intensive dairy cattle system caused nitrate groundwater pollution originated from the intensive input of effluents. Consequently, the Arborea area was identified as NVZ in 2005 [6].

In the plain two Hydrogeological Units (HU) have been identified [6]: the Sandy Hydrogeological Unit (SHU) and the Alluvial Hydrogeological Unit (AHU). SHU is represented by a phreatic aquifer hosted in the Holocene littoral sands. It is separated by a clay layer from the underlying multi-layer aquifer hosted in the Pleistocene continental deposits (AHU). In the southern part of the plain, the clay layer is missing and the two aquifers are in hydraulic communication with each other [6]. Previous studies carried out in the Arborea plain [6, 7, 8] showed nitrate concentrations in both aquifers exceeding the 50 mg L^{-1} threshold value, up to exceed 250 mg L^{-1}, especially in the southern part of the plain. The nitrate isotopic composition ($\delta^{15}N$-NO_3, $\delta^{18}O$-NO_3) confirmed the occurrence of denitrification processes whereas the integration of $\delta^{11}B$ data with $\delta^{15}N$ values showed that organic fertilizers were the main source of nitrates in groundwater.

2.2 Materials and methods

The FIA system has been designed according to the following steps: i) the identification of the most suitable area on the basis of the 3D hydrogeological model, the previous hydrogeochemical study, in particular concerning the nitrate groundwater contamination [6, 7, 8], the drainage water availability; ii) the set-up of a monthly *ante operam* and *post operam* monitoring plan, iii) the design of the FIA system and the Passive Treatment System (PTS).

Anaerobic batch and flow-through experiments will be carried out in the coming months to (i) evaluate the intrinsic potential and effectiveness to promote NO_3 attenuation of two different organic materials (rice straw and eucalyptus wood chips), to be used in the PTS and (ii) assess the generation of undesirable compounds.

3 Results

3.1 Pilot site identification

The FIA system designed for the pilot site of Arborea will be located in the southern part of the plain, in an area of around 0.4 ha close to the dewatering pumping station of Luri, which ensures the supply of an adequate volume of drainage water (Figure 1b). Drainage water will be pumped from the station, treated and reused to supply the FIA system and recharge the SHU aquifer to contribute to mitigate nitrate contamination in groundwater, especially through dilution processes.

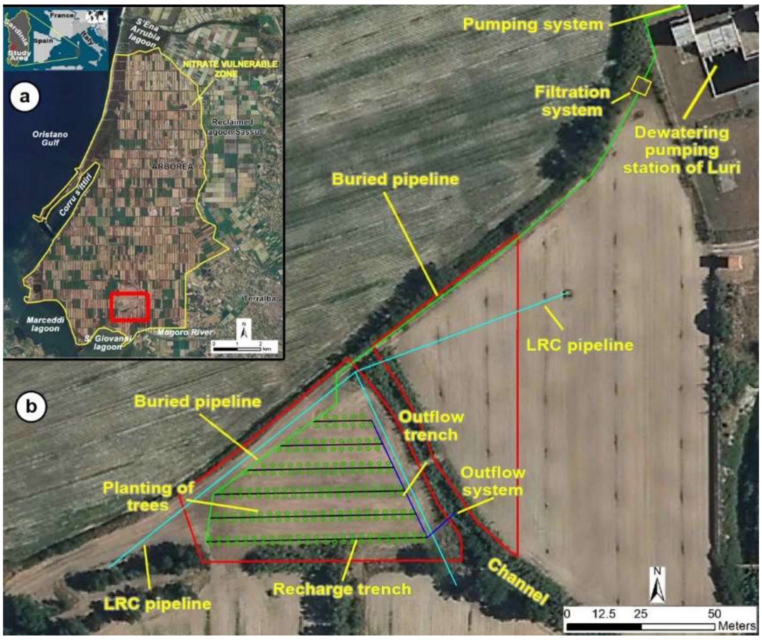

Fig. 1. (a) Pilot site location; (b) FIA system

3.2 Monitoring plan

The experiment will be conducted for a duration of two years. A monthly monitoring plan is developed, both *ante operam* and *post operam*. The former (October 2020 - October 2021) aims to define the quality baseline both for drainage water and groundwater in an area of around 9 km^2 surrounding the pilot site. The second (March 2022 - February 2024) will aim to assess the efficiency of the implemented FIA system. The *ante operam* monitoring foresees monthly samplings from 12 wells and from the pool of the Luri station for chemical analyses. Only for drainage water samples, ethyl and methyl Clorpyrifos and Linuron, the most used phytosanitary and biocide products by the farmers in Arborea, will be also detected. During the *post operam* monitoring phase, on a subset of groundwater and soil solution samples, isotopic analyses ($\delta^{15}N\text{-}NO_3$ and $\delta^{18}O\text{-}NO_3$, $\delta^{15}N\text{-}NH_4$) will be performed to assess the occurrence of natural nitrate attenuation process (e.g. denitrification) in the recharge water and groundwater.

3.3 Passive Treatment System design

A technical innovation in the FIA implementation is represented by the PTS to be installed within each recharge trench to improve the recharge water quality and reduce the clogging processes at the infiltrating surface. The PTS design, which is based on previous experiences in Tunisia and Algeria [9], foresees 2 main components: a Reactive Layer (RL) and a layer of inert materials (gravel and sand). The RL is a mixture which includes (a) inert materials (gravel and sand, 50% in volume) to provide structural integrity and ensure hydraulic conductivity; (b) vegetable autochthonous compost (49% in volume) which provides a source of DOC, easily degradable, to improve the degradation capacity of microbial communities, to generate different redox environments, triggering processes as denitrification and degrading organic micropollutants (e.g. pesticides); (c) minor clays (<= 1% in volume) and (d) iron oxides (<= 0.1% in volume) for sorption of cationic and anionic organic contaminants. The RL is then covered by a layer of gravel and sand to ensure the mechanical filtering of suspended particulate matter and to prevent the subjacent material from erosion. Preliminary results of batch and flow-through experiments conducted in laboratory by using drainage water showed that the RL is effective in promote a complete denitrification in 24 hours, in line with other researches (Grau-Martinez 2017). During the *post operam* monitoring, the effectiveness of the PTS in field condition will be evaluated.

3.4 FIA system design

The design of the FIA system consists of different components: a pumping system, a filtration system, buried pipelines, recharge trenches, an outflow trench and an outflow system (Figure 1b).

The *pumping system*, with a power of around 8 kW, will be installed in the pool of the dewatering pumping station. The *filtration system* will consist of calibrated sands and/or disc filters to reduce the Total Suspended Solids (TSS) content in the drainage water and prevent clogging processes in the recharge trenches. High-density polyethylene PN10 *buried pipelines* (diameter of 180 mm) will connect the pumping system to the filtration system and after to the head of each recharge trench. Each pipeline will be placed in a trench with a depth of 0.50 m. Six *recharge trenches* will be arranged parallel, with a total length of 240 m. They will have a trapezoidal reversed section with a depth of 1.00 m. Each recharge trench will be filled with the PTS. The section of the trees species for the planting is still ongoing. A preliminary infiltration test on the field showed an infiltration rate at pseudo-stationary conditions of $1.394 \cdot 10^{-4}$ m^3 s^{-1} per meter of trench. Based on this preliminary result, we estimated that the FIA system will have to be supplied with around 120 m^3 h^{-1} of recharge water. The *outflow trench* will collect the excess water flowing out from the recharge trenches and will be filled with the PTS. At the end, it will merge into an *outflow system* consisting of a triangular weir to measure the discharge flow.

4 Discussion and conclusion

The MENAWARA pilot action in the Arborea plain presents some innovative aspects. Non-conventional water such as drainage water will be used to supply the designed FIA system, according to the typical approach of the Integrated Water Resources Management. These waters that usually flow to wetlands, causing a high input of nutrients (in particular N and P), will be treated through the innovative PTS, installed at each recharge trench, and reused to recharge the sandy phreatic aquifer (SHU). PTS will ensure the improvement of the drainage water quality before the recharge, especially in the first phase of functioning of the FIA system, when the planting of trees will be in the initial phase of growth and will contribute minimally to the depurative action. The batch and flow-through experiments will allow to identify the organic material characterized by the highest denitrification rate to be used in the RL. Preliminary surveys to estimate the infiltration rate in the sandy soils showed a potential recharge rate of 0.7 hm^3 $year^{-1}$ per 0.4 ha of FIA system. However, the expected impact of this pilot system on the SHU aquifer will be very localized and it will obviously not solve the issue of the groundwater nitrate contamination for this aquifer. On the basis of the results that will be achieved by the pilot action, it will possible to estimate the number of ha of FIA systems to be implemented and identify the most suitable sites in the whole Arborea plain to improve significantly the groundwater quality of the SHU aquifer.

As the aim is to test the FIA technique as best practice, since the beginning relevant stakeholders (e.g. Farmers' Cooperative and the Land Reclamation Consortium) have been involved to create the prerequisites for the sustainability and replicability of the action in the Arborea NVZ. Even if this intervention is conceived as a pilot project on a small surface which will have a limited impact on the aquifer, the Land reclamation consortium has already showed its interest for a large scale FIA system implementation over the Arborea plain. This up-scaling could produce relevant positive impacts on the quality of the whole sandy aquifer. FIA systems could be integrated into the Sardinia Basin Management Plan as possible tool to mitigate the quantitative-qualitative degradation of groundwater not only in the Arborea plain but also in similar hydrogeological context, and through the international network of the MENAWARA project this MAR technique could be disseminated in all Mediterranean region.

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