Ann Ig 2018; 30: 34-43 doi:10.7416/ai.2018.2193

The aquifer recharge: an overview of the legislative and planning aspect

O. De Giglio[1], G. Caggiano[1], F. Apollonio[1], A. Marzella[1], S. Brigida[2], E. Ranieri[3], L. Lucentini[4], V.F. Uricchio[2], M.T. Montagna[1]

Key words: Groundwater, water resource management, water scarcity, aquifer recharge
Parole chiave: Acque sotterranee, gestione della risorsa idrica, scarsità dell'acqua, ricarica acquifero

Abstract

In most regions of the world, safeguarding groundwater resources is a serious issue, particularly in coastal areas where groundwater is the main water source for drinking, irrigation and industry. Water availability depends on climate, topography and geology.
The aim of this paper is to evaluate aquifer recharge as a possible strategy to relieve water resource scarcity. Natural aquifer recharge is defined as the downward flow of water reaching the water table, increasing the groundwater reservoir. Hydro-meteorological factors (rainfall, evapotranspiration and runoff) may alter natural recharge processes. Artificial aquifer recharge is a process by which surface water is introduced with artificial systems underground to fill an aquifer.
As a consequence of global warming that has increased the frequency and severity of natural disasters like the drought, the impacts of climate change and seasonality, the artificial recharge has been considered as a viable option. Different direct and indirect techniques can be used, and the choice depends on the hydrologic characteristics of a specific area.
In Italy, Legislative Decree no. 152/06 plans artificial aquifer recharge as an additional measure in water management, and Decree no. 100/2016 establishes quantitative and qualitative conditions for recharge. Many projects examine aquifer recharge, such us WADIS-MAR in the southern Mediterranean region, WARBO in Italy and municipal wastewater treatment project in Apulia, a southern Italian region. However, aside from groundwater recharge, the community must foster a spirit of cooperation to manage groundwater as a sustainable resource.

1. Introduction

Water scarcity is usually defined as a condition in which water availability in a country or region is < 1000 m^3 per person per year. Nevertheless, several regions have < 500 m^3 per person per year, which could be considered severe water scarcity (1).

The approach to water availability, based on indicators driven by renewable water resources divided by the total population, should be considered with great care. In

[1] *Department of Biomedical Science and Human Oncology, University of Bari Aldo Moro, Bari, Italy*
[2] *Water Research Institute, National Research Council, Bari, Italy*
[3] *Dicatech, Polytechnical University of Bari, Bari, Italy*
[4] *Department of Environment and Health, National Institute of Health, Rome, Italy*

fact, this simple method may not be very meaningful in situations where countries make substantial use of desalination, non-renewable groundwater resources, and wastewater reuse to compensate for the scarcity of renewable water.

In most regions of the world, safeguarding groundwater resources is a serious issue, particularly in coastal areas where groundwater is the main water source for drinking, irrigation, and industry (2) and the proximity to the sea may put such resource at risk. For example, in a coastal area, such as the Apulia Region (in Italy), the problem represents an important environmental criticality (3).

Actually, in Italy, 85% of water used by the population is of underground origin (4).

The water availability of a region depends primarily on its climate and secondarily on its topography and geology. Its sufficiency depends on the demand placed upon it.

Global climate change, mainly involving inadequate rain and an altered annual rainfall distribution, is causing substantial reductions in the flow of water for aquifer recharge and irrigation (5-7). Other climatic factors, dependent on the location of a region such us humidity, temperature and wind, affect the rate of evaporation and plant transpiration.

Topography is important because it controls the way rainfall is distributed, in terms of both quantity and rate, as well as the development of lakes, marshlands and opportunity for surface water to infiltrate and recharge aquifers.

Geology affects the topography and controls the availability of suitable underlying rocks that form aquifers into which water can infiltrate and become available for exploitation (1).

During the last 10 years, many goals have been reached concerning water resource management and quality in Europe. In particular, groundwater is widely recognized as a precious public resource, above all in the arid and semiarid parts of the continent. However, overexploitation, salinization, and direct and non-direct pollution, make it increasingly unavailable, not only for drinking but also for uses such as agriculture and industry (8).

The overexploitation of groundwater, especially for irrigation, may affect the quality of groundwater, especially in areas of high evapotranspiration, owing to the accumulation of salts at the surface and their subsequent leaching into the aquifer. Fertilizers and pesticides used in agriculture also affect local groundwater quality when proper crop management and effective agricultural practices are not used. Similarly, pollutants from industrial and urban areas, including heavy metals and organic substances, can produce point-source contamination of aquifers when raw wastewater percolates into groundwater (1).

The primary goals of groundwater management are to manage aquifer development according to a designated plan that treats aquifers as either renewable ("safe-yield" management) or exhaustible (planned-depletion management) resources and to protect groundwater property rights of.

The aim of this paper is to evaluate acquifers recharging as a possible strategy to relieve water resource scarcity also by demonstrating the technical feasibility, the economic advantage and the environmental sustainability of municipal wastewater technology treatment suitable to supply a managed recharge of the aquifer.

2. Aquifer recharge

2.1 Natural aquifer recharge

Aquifer recharge is generally defined as the downward flow of water reaching the water table, so increasing the groundwater reservoir (9).

Quantifying groundwater recharge is important to determine sustainable yields when groundwater is extracted for public, industrial or agricultural purposes (10, 11). Hydro-meteorological factors such as climate change, rainfall, evapotranspiration and runoff, as well as changes in land and water use such as agriculture and drainage, may alter the natural groundwater recharge processes (12-15).

The groundwater storage and exploitation potential of an aquifer depends on its hydrogeological features and stratigraphic distribution of permeable layers, its vertical or lateral extent, and the effective porosity.

Groundwater recharge may occur slowly via the soil matrix or preferential flow through macropores (16). Soil macropores, similar to fractures, may rapidly transmit nearly unaltered precipitation to the water table, but are very difficult to characterize because of strong spatial heterogeneity and a three-dimensional structure (17).

The exploitation of aquifers must be planned on the basis of their safe yield or "perennial yield". Safe yield is a widely used concept in groundwater management. It refers to an average rate of groundwater extraction that is calculated over a period climatically representative of the region encompassing the groundwater basin. The safe yield also serves as a baseline for assessing whether a basin has been subjected to long-term groundwater extraction that exceeds aquifer recharge, thereby causing basin "overdraft" (i.e., protracted decline of groundwater levels) (18).

Rainwater plays a key role in the hydrologic cycle and represents the major source for aquifers to be recharged through the soil. The method of infiltration also has benefits such as groundwater recharge and consequent increase of the minimum flow capacity of rivers. Moreover, the percolation of water into the soil may remove pollutants. Particulate substances are trapped by the ground, where microorganisms contribute to the removal of organic substances. The practice of infiltration, however, has some disadvantages. It is not usable if rainwater originates in commercial or industrial areas, which may be filled with pollutants such as microbiological substances, heavy metals, or organic compounds. Moreover, this practice cannot be used in soils with low permeability.

There are several technical possibilities to develop infiltration systems for rainwater, among which two systems can be distinguished, surface and groundwater (19).

Surface infiltration occurs by entry of rainwater into flat surfaces, in ditches or ponds. In these cases, infiltration occurs as a rule through a revived surface layer of organic soil that ensures effective purification of rainwater.

In underground infiltration systems, rainwater is introduced into infiltration trenches or *losers wells*. Despite the advantage of having less need for filtering surface area, however, almost the purifying effect of these systems is lost because the rainwater do not cross the superficial soil layer. For this reason, these systems should be used only for slightly polluted rainwaters; otherwise, they should be pre-treated. Combined infiltration systems can be made by linking surface and underground systems.

2.2 Artificial aquifer recharge

Artificial recharge of aquifers has been used worldwide since the 1960s and 1970s, in which surface water was introduced underground to fill the aquifer. This involves the movement of water by artificial systems from the surface to underground aquifers, where it can be stored and used in the future. The vital purpose of an artificial aquifer is to preserve superfluous water to meet human needs through a wide range of direct and indirect methods of recharging groundwater. The choice among different techniques depends on the hydrologic character of a specific area (20). The application of these methods has been recently indicated by the acronym MAR (Managed Aquifer Recharge). The power source for recharging groundwater is surplus water from the earth surface (21), which is the excess quantity with respect to volumes (or flow rates) that form on the surface as part of the natural hydrologic cycle. For example, surplus water from full rivers, runoff from rainwater on artificial soils (with reduced permeability), or downstream discharge from anthropogenic uses (heat exchange, civil use, condensation) can be considered water resources. Also, as long as it can be demonstrated that its use for recharging does not have unsustainable impacts, surface water in dry weather (deterioration of the ecological status of a surface water body) can be considered a water resource.

The artificial recharge of aquifers is often used because of the following advantages:

- it improves the performance of an aquifer and increases the availability of water throughout the year, especially during periods of shortage
- it reduces water loss through evapotranspiration and surface runoff in arid and semiarid regions or under water scarcity conditions
- it improves the chemical characteristics of seeped water through natural processes occurring during infiltration and percolation. Aquifer characteristics can also be improved using high-quality water for recharging
- it balances previous, current or future groundwater sagging (caused by natural or anthropogenic activities.

Charging methods are ecologically interesting, particularly in arid regions, and easy to use and manage. The appropriate technology is easy to understand for technicians and the public. The need for special tools is very limited. In some regions, the control of surface water flow reduces problems of erosion and sedimentation. Artificial recharge is also possible through the reuse of treated sewage, although direct recharge with such sewage requires constant vigilance. Reclaimed water contains pollutants such as nitrate, heavy metals, and new-type contaminants. Thus, there is a definite environmental risk in reclaimed water recharge. Surface recharge increases salt and nitrate contents in groundwater but reduces heavy metal risk. Well recharge can induce arsenic release from sedimentary aquifers. On the contrary, pathogen microorganisms pose less pollution risk to groundwater, although there some virus risk remains (22). However, most pathogenic bacteria can tolerate anaerobic conditions for a limited period. Other bacteria, such as those in the genus *Clostridium*, require anaerobic environments for growth. In contrast, many viruses are very resistant to environmental stress and will remain viable in both aerobic and anaerobic conditions. Therefore, the need for high-quality effluent for use in groundwater recharge must be stressed. Although the reuse of wastewater should be encouraged and groundwater recharge is a sound method for doing so, careful consideration should be given to the siting of recharge schemes, and viral and bacterial contents of groundwater should be regularly monitored (23).

An understanding of risks posed by microbial pathogens is essential for the ongoing management of MAR schemes, particularly those that use lower-quality water such as treated wastewater or urban stormwater. Assessment of potential survival times of enteric pathogens in groundwater should influence the design of MAR schemes, including determination of the need for additional treatment steps, either prior to groundwater recharge or at the time of extraction of recharged water (24, 25).

3. Legislation

The Water Framework Directive (WFD) (26) establishes a framework for community action in water management. It provides that

"Member States shall protect, enhance and restore all groundwater bodies and ensure a balance between abstraction and recharge of groundwater in order to achieve good groundwater status [...] within 15 years after entry into force of this Directive" (art. 4, paragraph 1, lett. b ii), subject to exceptions and extensions specifically provided by the same act.

To achieve these objectives for each river basin district, each member state shall prepare a program of measures that counts as a minimum requirement, i.e., so-called "basic measures". These also specify that "…the water used can be any surface water or groundwater, provided that the use of the source does not compromise the achievement of the environmental objectives established for the source or to the groundwater body subject to recharge or growth," and that "such control measures are regularly reviewed and updated when necessary". Finally, in a non-exhaustive list of supplementary measures that member states may decide to take within each river basin district under the program of measures (Annex. VI, Part B), there is "artificial recharge of aquifers" (Annex. VI, Part B, letter. xiv) (26).

Through the WFD, the European Union (EU) advances new principles and guidelines in water resource policies. This document points to ''the need to establish procedures for the regulation of abstraction of freshwater and for the monitoring of freshwater quality and quantity". The WFD established a framework for the protection of groundwater, which promotes ''sustainable water use based on a long-term protection of available water resources".

The European Groundwater Directive (27), which was recognized only by Italy in early 2009 (28), requires that such resources be characterized under a qualitative standpoint, and the risk of pollution by individual or groups of pollutants be evaluated.

The Italian legislation, in line with the WFD provisions, plans artificial recharge of aquifers as an additional measure to be considered in water management for the achievement of quality targets set by the guidelines (29). The latter legislative decree, which established rules for classifying the environmental status of national water, was also approved at the regional level to regulate the discharge of wastewater by the industries.

Very recently, a decree of the Italian Ministry of the Environment has been issued, Decree no. 100/2016, establishing quantitative and qualitative conditions for recharge of groundwater bodies, including both recharging and receiving aquifers (30). In particular, actions of "artificial recharge or augmentation of groundwater bodies" are considered permissible, in accordance with the criteria established by the Ministry for the Environment, Land and Sea. The Decree no. 100/2016 has introduced an innovative approach that includes a risk analysis based on the evaluation of chemical and microbiological hazards associated with the use of the aquifer as drinking water. For this aim, an adequate monitoring system should also be planned, both for water quality and for the piezometric level in the aquifer.

4. Projects

Many current projects consider aquifer recharge.

Water harvesting and agricultural techniques in dry lands: an integrated and sustainable model in the Maghreb regions (WADIS-MAR) is a demonstration project funded by the European Commission through the Sustainable Water Integrated Management (SWIM) program.

SWIM aims to contribute to the effective implementation and extensive dissemination of sustainable water management policies and practices in the southern Mediterranean region.

WADIS-MAR actions deal with the realization of integrated water harvesting and aquifer recharge techniques in two watersheds of the Maghreb region, *Oued Biskra* in Algeria and *Oum Zessar* in Tunisia. These watersheds are characterized by water scarcity, overexploitation of groundwater resources, and strong vulnerability due to climatic change risk.

Arras et al. (31) reported on a project developed in the framework of WADIS-MAR. The areas studied suffer from a dry climate, where erratic behavior of brief rainfall events often produces short and intense floods that converge on ephemeral streams. In this research, geo-electrical methods, integrating geologic field survey and boreholes information, were extensively used in hydrogeologic study (32), particularly to identify geologic bodies in which aquifers could be hosted.

Electrical resistivity tomography surveys were carried out at six selected sites in the Jeffara Plain (Tunisia) during April 2014. The aims were to recognize and characterize *wadi* alluvium thickness above the Lower Triassic formation to better design MAR systems.

Another important project is WARBO (WAter Re-BOrn) (33). Its aim is to simplify aquifer recharge regulation in Italy by testing its application to mitigate groundwater level in areas where unused surplus surface water, usually lost during winter–spring, can be used. A multidisciplinary approach, involving geophysical, hydrogeological and geochemical methods to characterize aquifer structure and surface/underground water, was necessary to improve numerical models and process understanding. WARBO considers artificial recharge the only effective method in the short and long term to attack water scarcity and drought. Another aim of the project is to reduce the gap between water demand and resources available for domestic use, agriculture, and other industrial and craft activities in need of freshwater.

WARBO has been tested in three Italian areas to determine rates of rainfall that flows into major rivers and its transfer underground. The three selected areas are 1) the Po Delta (in the province of Ferrara), 2) High Friuli Plain (province of Udine), and 3) springs of the Friuli-Venezia Giulia (province of Pordenone), where various artificial recharge methods have been applied. The project assessed the role that artificial recharge may have in reducing pollution by nitrates (Friuli Plain) and salinity intrusion (Po Valley). It was also verified that recharging integrates with flood management plans, defining phytoremediation and water treatment strategies focused on integration with guaranteed quality of water channels (34-36).

WARBO analyzed how to connect flooded quarries with river networks, and thereby the reinforcement of the fluvial axis ecological corridor. Finally, the project introduced innovative methods for the characterization of sites, in order to facilitate essential knowledge for proper management plans. The problems faced are common to many climatically sensitive areas bordering the Mediterranean. Plant operators (Consortium of Leda and Tagliamento Copparo) have become involved in recharge activities through their operational plans, which will give continuity to the project.

The results of the afore mentioned activities have enabled the preparation of multidisciplinary analysis protocols in support of procedures and recharge methods. The WARBO project proposed these protocols based on the EU regulatory framework, via methods, experiences, and operational implementation and coordination between the instruments Floods Directive 2007/60/EC (37) and the Water Framework Directive 2000/60 /EC (38).

In Southern Italy, particularly in Apulia region, the use of treated municipal wastewater represents a crucial point for the environmental sustainability of this region, because many areas are seriously affected by the increase of salinity, a problem due

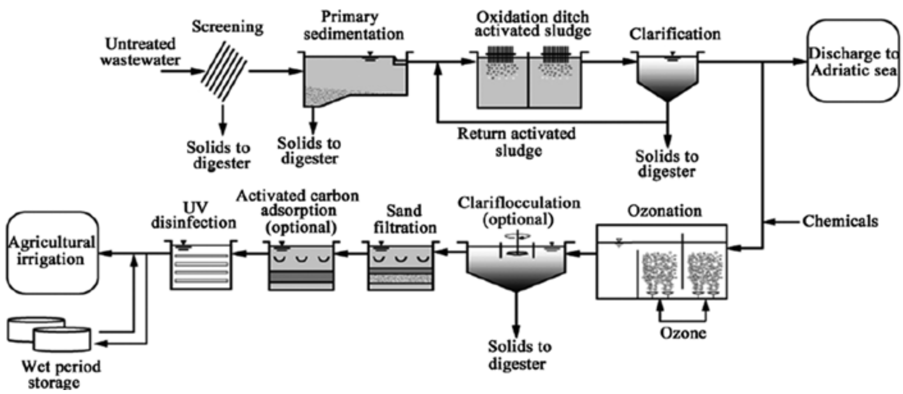

Figure 1 - Process flow diagram for the wastewater reclamation facility for production of water for unrestricted irrigation reuse and managed artificial aquifer recharge (Foggia province, Apulia region, Italy).

to the excessive use of groundwater and to the higher level of the sea-water interface. However, the standards established for the reclaimed water may be considered overly restrictive for the water reuse application; in fact, the surface water supplies currently used would not be able to meet the standards. The artificial recharge of groundwater basins with treated wastewater should be recommended when the water is not used for agricultural purposes, particularly where the joint use of surface water and groundwater resources is considered in the context of integrated water resources management (39).

Figure 1 illustrates the diagram flow of municipal wastewater treatment project (39) in Foggia, a northern province of Apulia region, with the representation of a full equipped mechanical-biological wastewater treatment plant (WWTP) that ensure an effluent quality suitable for the aquifer recharge.

5. Conclusions

This paper gives an overview of various techniques used in the world to address the issue of aquifer recharge. These can be used to improve the natural yield and capacity of aquifers, ensuring a consistent and continuous supply of safe and fresh water, even during dry periods.

Many techniques are easy, cost-effective and sustainable in the long term and can be used by individuals, rural and urban communities with locally available materials and manpower. These methods can reduce the lowering of piezometric level in groundwater, concentrate runoff underground, make groundwater available for various purposes (especially in summer), and improve groundwater quality. Microbiological contamination of groundwater has severe implications for public health, particularly in small communities and developing countries where groundwater is often the preferred source of drinking water. Although groundwater is usually of good quality, it can deteriorate quickly because of inadequate source protection and lack of water management. Contaminated groundwater can contribute to high morbidity and mortality rates from diarrheal diseases, and sometimes cause epidemics.

It is suggested, in controlled procedures, the improvement of the artificial groundwater recharge because this is becoming increasingly important in groundwater management and particularly where the joint use of surface water and groundwater resources is planned.

In conclusion, the development of artificial recharge model structures yields encouraging results. However, if these are treated as an open-access resource and extraction is continuous, over-extraction ultimately results. Although groundwater recharge schemes, either natural or artificial, may not be the final answer, the community must create a spirit of cooperation to effectively manage groundwater as a sustainable resource.

Riassunto

La ricarica artificiale delle falde idriche: una panoramica degli aspetti legislativi e progettuali

Nella maggior parte delle regioni del mondo, la salvaguardia delle risorse idriche sotterranee è un problema serio, soprattutto nelle zone costiere dove le acque sotterranee costituiscono la fonte principale di acqua potabile, per l'irrigazione e l'industria. La disponibilità di acqua dipende dal clima, dalla topografia e dalla geologia. Lo scopo di questo lavoro è quello di considerare la ricarica degli acquiferi come una possibile strategia per alleviare la scarsità delle risorse idriche.

La ricarica naturale delle falde è definita come il flusso discendente dell'acqua che raggiunge la falda, aumentando il serbatoio delle acque sotterranee. Fattori idro-meteorologici (pioggia, evapotraspirazione e ruscellamento) possono alterare i processi di ricarica naturale. La ricarica artificiale degli acquiferi è un processo attraverso il quale l'acqua di superficie viene introdotta con sistemi artificiali nel sottosuolo per riempire una falda acquifera. Come conseguenza del riscaldamento globale che ha aumentato la frequenza e la gravità dei disastri naturali come la siccità, gli impatti dei cambiamenti climatici e la stagionalità, la ricarica artificiale è stata considerata come una valida opzione.

Diverse tecniche dirette ed indirette possono essere utilizzate, e la scelta dipende dalle caratteristiche idrologiche di una determinata area.

In Italia, il decreto legislativo n. 152/06 indica la ricarica artificiale degli acquiferi come una misura aggiuntiva nella gestione delle acque, ed il decreto n. 100/2016 stabilisce le condizioni quantitative e qualitative per la ricarica.

Molti progetti studiano la ricarica degli acquiferi, come WADIS-MAR nella regione del Mediterraneo meridionale, WARBO, in Italia e un progetto sul trattamento delle acque reflue in Puglia, regione italiana.

Nonostante i processi di ricarica degli acquiferi, la comunità deve promuovere sempre uno spirito di cooperazione per la gestione delle acque sotterranee come risorsa sostenibile.

References

1. Pereira LS, Cordery I, Iacovides I. Coping with water scarcity: UNESCO, International Hydrological Programme, IHP-VI, Technical Documents in Hydrology No. 58 2002.
2. Güler C, Kurt MA, Alpaslan M, Akbulut C. Assessment of the impact of anthropogenic activities on the groundwater hydrology and chemistry in Tarsus coastal plain (Mersin, SE Turkey) using fuzzy clustering, multivariate statistics and GIS techniques. J Hydrol 2012; **414-415**: 435-51.
3. De Giglio O, Barbuti G, Trerotoli P, et al. Microbiological and hydrogeological assessment of groundwater in southern Italy. Environ Monit Assess 2016; **188:** 638.
4. Ministry of Health. The Water Safety Plans. Available from: http://www.salute.gov.it/portale/temi/p2_6.jsp?lingua=italiano&id=4529&area=acque_potabili&menu=controlli [Last accessed 2017, May 3].
5. Idoko OM. Seasonal variation in iron in rural groundwater of Benue State, Middle Belt Nigeria. Pak J Nutr 2010; **9**(9): 892-5.
6. Sun W, Wang J, Li Z, Yao X, Yu J. Influences of climate change on water resources availability in Jinjiang Basin, China. Scientific World Journal 2014 http://dx.doi.org/10.1155/2014/908349
7. De Giglio O, Quaranta A, Barbuti G, Napoli C, Caggiano G, Montagna MT. Factors influencing groundwater quality: towards an integrated management approach. Ann Ig 2015**; 27**: 52-7.
8. Masciale R, Barca E, Passarella GA. Methodology for rapid assessment of the environmental status of the shallow aquifer of "Tavoliere di Puglia" (Southern Italy). Environ Monit Assess 2010; **177**: 245–61.
9. de Vries JJ, Simmers I. Groundwater recharge: an overview of processes and challenges. Hydrogeol J 2002**; 10**: 5-17.
10. Herrmann F, Baghdadi N, Blaschek M, et al. Simulation of future groundwater recharge using a climate model ensemble and SAR-image based soil parameter distributions—a case study in an intensively used Mediterranean catchment. Sci Total Environ 2016; **543**(Part B): 889-905.
11. Hornero J, Manzano M, Ortega L, Custodio

E. Integrating soil water and tracer balances, numerical modelling and GIS tools to estimate regional groundwater recharge: application to the Alcadozo Aquifer System (SE Spain). Sci Total Environ 2016; **568**: 415-32.

12. Crosbie R, Jolly I, Leaney F, Petheram C, Wohling D. Review of Australian Groundwater Recharge Studies. In: CSIRO*:* Water for a Healthy Country National Research Flagship, 2010.
13. Awan UK, Ismaeel A. A new technique to map groundwater recharge in irrigated areas using a SWAT model under changing climate. J Hydrol 2014; **519**(Part B): 1368-82.
14. Ehlers L, Herrmann F, Blaschek M, Duttmann R, Wendland F. Sensitivity of mGROWA-simulated groundwater recharge to changes in soil and land use parameters in a Mediterranean environment and conclusions in view of ensemble-based climate impact simulations. Sci Total Environ 2016**; 543**(Part B): 937-51.
15. Webb JR, Santos IR, Tait DR, et al. Divergent drivers of carbon dioxide and methane dynamics in an agricultural coastal floodplain: post-flood hydrological and biological drivers. Chem Geol 2016**; 440**: 313-25.
16. Meixner T, Manning AH, Stonestrom DA, et al. Implications of projected climate change for groundwater recharge in the western United States. J Hydrol 2016; **534**: 124-38.
17. Johnston S, Hirst P, Slavich P, Bush RT, Aaso T. Saturated hydraulic conductivity of sulfuric horizons in coastal floodplain acid sulfate soils: variability and implications. Geoderma 2009**; 151**: 387-94.
18. Loáiciga HA. The Safe Yield and Climatic Variability: Implications for Groundwater Management. Groundwater 2016. doi: 10.1111/gwat.12481
19. Kompatscher P. Guidelines for the sustainable management of rainwater. Agenzia provinciale per l'ambiente (Bolzano), Ufficio tutela acque, 2008. Available from: http://docplayer.it/13670709-Linee-guida-per-la-gestione-sostenibile-delle-acque meteoriche.html [Last accessed 2017, May 3].
20. Kavuri M, Boddu M, Annamdas VGM. New Methods of Artificial Recharge of Aquifers: A Review. Poster presented at the 4th International Perspective on Water Resources & the Environment (IPWE), National University of Singapore (NUS), Singapore January 4-6, 2011.
21. ISO 18091:2014: Quality management systems — Guidelines for the application of ISO 9001:2008 in local government. 2014.
22. Chen WP, Lü SD, Wang ME, Jiao WT. Effects of reclaimed water recharge on groundwater quality: a review. Ying Yong Sheng Tai Xue Bao 2013; **24**: 1253-62.
23. De Giglio O, Caggiano G, Bagordo F, et al. Enteric Viruses and Fecal Bacteria Indicators to Assess Groundwater Quality and Suitability for Irrigation. Int J Environ Res Public Health 2017;**14**(6). pii: E558.
24. Sidhu JPS, Toze S. Assessment of pathogen survival potential during managed aquifer recharge with diffusion chambers. J Appl Microbiol 2012**; 113**(**3**): 693-700.
25. Agostinetto L, Dalla Venezia F, Gusmaroli G. La ricarica delle falde in condizioni controllate- Linee guida tecnico-operative. Veneto Agricoltura, 2015**.**
26. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Official Journal L 327, 22/12/2000, 1-73.
27. Directive 2006/118/EC of the European Parliament and of the Council of 12 December, 2006 on the protection of groundwater against pollution and deterioration. Available from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:372:0019:0031:EN:PDF [Last accessed 2017, May 3].
28. Legislative Decree of 16 March 2009, n. 30. Implementation of Directive 2006/118 / EC on the groundwater protection against pollution and deterioration. (OJ 79 of April 4, 2009).
29. Legislative Decree of 3 April 2006, n. 152 Environmental Regulations. (OJ General Series 88 of April 14, 2006 - Ordinary Supplement n. 96).
30. Decree May 2, 2016, n. 100. Ministry of Environment and Protection of land and sea. Regulation containing criteria for the granting of the artificial recharge or to the growth of groundwater bodies in order to achieve the objective of quality, according to Article 104, paragraph 4-bis of Legislative Decree 3 April 2006 , n. 152. (16G00111) (OJ General Series 136 of June 13, 2016).
31. Arras C, Longo V, Testone V, et al. Electrical Resistivity Tomography for the identification of the alluvium-Triassic boundary in Medenine Region (SE Tunisia). Rend Online Soc Geol It 2015; **35**: 10-12.

32. Christensen NB, Sorensen KI. Surface and Borehole Electric and Electromagnetic Methods for Hydrogeological Investigations. European Journal of Environmental and Engineerig Geophysics 1998; **3**: 75-90. Available from: http://www.hgg.geo.au.dk/ref_manager/christensen1998a.pdf [Last accessed 2017, May 3].
33. Martelli G, Granatia C, Paieroa G, et al. Artificial Recharge of Phreatic Aquifer in the Mereto Di Tomba Area (Upper Friuli Plain). 16th Conference on Water Distribution System Analysis, WDSA 2014.
34. Van Lienden C, Shan L, Rao S, Ranieri E, Young TM. Metals removal from stormwater by commercial and non-commercial granular activated carbons. Water Environ Res 2010; **82(**4): 351-6.
35. Gikas P, Ranieri E. Effects of plants for reduction and removal of hexavalent chromium from a contaminated soil. Water Air Soil Poll 2014; **225(**6): 1-9.
36. Ranieri E, Fratino U, Petruzzelli D, Borges AC. A comparison between Phragmites australis and Helianthus annuus in chromium phytoextraction, Water Air Soil Poll 2013; **224**(3): 1-9.
37. Directive 2007/60/EC of the European Parliament and of the Council of 23 October, 2007 on the assessment and management of flood risks. Available from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:288:0027:0034:IT:PDF [Last accessed 2017, Feb 28].
38. Nieto DY. WARBO - Ricarica artificiale: tecnologie innovative per la gestione sostenibile delle risorse idriche. OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale), 2010.
39. Ranieri E, Leverenz H, Tchobanoglous G. An Examination of the factors involved in agricultural reuse: technologies, regulatory and social Aspects. J Water Resource Prot 2011; **3**: 300-10.

Corresponding author: Dr. Osvalda De Giglio, Department of Biomedical Science and Human Oncology, University of Bari Aldo Moro, Piazza G. Cesare 11, 70124 Policlinico Bari, Italy
e-mail: osvalda.degiglio@uniba.it