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Original Articles

Environmental impact of cattle grazing on a karst aquifer in the southern Apennines (Italy): Quantification through the grey water footprint

V. Allocca[a,*], E. Marzano[b,c], M. Tramontano[b], F. Celico[d]

[a] Department of Earth, Environmental and Resource Sciences, University of Naples Federico II, Italy
[b] Department of Economic and Legal Studies, University of Naples Parthenope, Italy
[c] CESifo Fellow, CESifo Research Network, Munich, Germany
[d] Department of Chemistry, Life Sciences and Environmental Sustainability, University of Parma, Italy

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ABSTRACT

In this paper we draw on a unique dataset of hydrological and microbiological time series to apply water footprint (WF) methodology to quantify the environmental impact of cattle grazing on karst area in a regional park of the southern Apennines (Italy). The use of WF methodology in the same specific environment where relevant data are monitored, and the hydrogeological and microbiological characterisation of the study area, validate the results of our WF assessment, that can be summarised as follows. First, we show that an ecological indicator such as the grey water footprint (GWF) may be of particular relevance to the park authority to implement policies to preserve groundwater quality. Second, we introduce a new metric, referred to as the environment-related grey water footprint (GWF_{env}), to estimate the virtual water needed to absorb the microbial pollution of a cattle grazing process.

1. Introduction

In many countries, karst aquifers are primary freshwater resources (Ford and Williams, 2007; Hartmann et al., 2014; Chen et al., 2017). Recurrent in-stream uses of karst groundwater comprise drinking water for livestock and recreational uses. Further, karst environments contain many natural resources, are bio- and geodiversity-rich and deliver valuable natural ecosystem services (Goldscheider, 2012), also needed for agriculture and animal husbandry. Furthermore, the prominent potential of karst landscapes in terms of agricultural, pastoral, recreational, cultural and historical value, is widely recognized (Sauro, 1993; Goldscheider, 2012). Several karst areas worldwide have been declared UNESCO World Heritage sites, and are considered strategic resources for socio-economic development at local, national and international levels.

The existence of alternative and possibly competing uses of groundwater resources requires the adoption of suitable tools to evaluate their efficient allocation and preserve their quality characteristics. To this end, water footprint (hereinafter WF) methodology may provide appropriate support since it deals with the use of freshwater resources in the light of limited supplies. Freshwater availability is a matter of concern not only in terms of quantity, but also as regards quality. Indeed, WF is an indicator of freshwater use that considers both consumptive water use and water pollution (Hoekstra et al., 2011). In the version proposed by the Water Footprint Network (WFN), total WF at national or production level splits into three subcategories, each of which has different environmental impacts and opportunity costs. One concerns the use of ground and surface water (blue water footprint), the second takes into account the amount of rainwater, stored in the soil as soil moisture, used by plants (green water footprint) and the third subcategory considers polluted water (grey water footprint). In this article we are mostly concerned with the latter category, the grey water footprint (referred to as GWF hereinafter), since our interest is evaluating water quality degradation, with specific regard to the degradative use of groundwater originating from cattle grazing.

In the hydro-microbiological literature, the impact of livestock grazing on chemical and bacteriological water quality has been documented in several works (Gary et al., 1983; Agouridis et al., 2005; Farnleitner et al., 2005; Celico et al., 2004ab; Goldscheider et al., 2006; Allocca et al., 2008; Naclerio et al., 2008, 2009; Pronk et al., 2009; Bucci et al., 2015b; De Giglio et al., 2016). It has been suggested that a primary factor is due to the removal of protective vegetation (Wood et al., 1989), although the microbial contaminant rate is affected by cold shocks, freezing-thawing cycles and prolonged exposure to subzero thermal conditions (Mazur, 1966; Mackey, 1984; Allocca et al., 2008; Naclerio et al., 2008, 2009; Bucci et al., 2015a, 2017).

* Corresponding author.
E-mail address: vincenzo.allocca@unina.it (V. Allocca).

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Despite the above evidence documenting contamination related to cattle grazing, in the recent literature on livestock water footprint (Mekonnen and Hoekstra, 2010, 2012) the grey component of the water footprint has been largely overlooked. To date, it has been pointed out that grazing can have a large impact on livestock WF, especially due to the green component of WF (Mekonnen and Hoekstra, 2012; de Miguel et al., 2015), with the grey component making a relatively negligible contribution.

With regard to the GWF of dairy farming, most contributions calculate nitrate and phosphorus concentrations (Zonderland-Thomassen and Ledgard, 2012; Zonderland-Thomassen et al., 2014; Palhares and Pezzopane, 2015), and to a lesser extent the GWF originating from feed crops and "dairy processing water" (Owusu-Sekyere et al., 2017). None of the existing studies consider the risks of pollution due to microbial contamination from animal faecal matter.

In this paper we intend to fill this gap in the WF literature, introducing a new indicator to estimate the GWF due to microbial contamination from animal faecal matter, which we refer to as the environment-related grey water footprint (GWF_{env}). To this end, we measure the impact on bacteriological quality of groundwater originating from cattle grazing in a test site within a regional park in the southern Apennines (Italy).

In Italy, several karst environments in the Alps and Apennines are included within the boundaries of regional and national parks. Despite stringent environmental regulations protecting such karst areas, there remains the impact of human activity, especially agricultural land use and cattle grazing. This is the situation occurring in our study area, an upland karst environment in the Regional Park of the Picentini Mountains in Campania, one of Italy's largest regional parks. Microbial pollution originating from cattle pasturage, a degradative use of groundwater, lies at the origin of the new metric we introduce to estimate GWF due to microbial contamination, namely GWF_{env}.

With the introduction of GWF_{env}, in this paper we pursue a twofold goal. On the one hand, we intend to fill a gap in the literature related to livestock WF, documenting how a hitherto unexplored dimension within this literature may undermine the estimates of the WF of animal products. On the other, beyond this methodological contribution, GWF_{env} may be a useful tool for groundwater management when in-stream water uses are involved.

The paper is structured as follows. Section 2 describes the study area, with specific attention to hydrological characteristics and detailing the mechanisms underlying the contamination process, whose evidence is briefly commented upon in Section 3. In Section 4 the methodology adopted to calculate the GWF_{env} indicator is described, whereas in Section 5 the results and management implications for the study area are discussed. Section 6 concludes the article.

2. Description of the test site

2.1. Hydrogeological and climatic characteristics

The Acqua della Madonna test site (Campania, southern Italy) lies at an altitude of about 1200 m a.s.l. in the central sector of the Mt. Terminio karst aquifer and the Picentini Regional Park (Fig. 1a and b). The site holds a compartmentalised karst groundwater body (Fig. 1c), covered by sand-size alkali-potassic ash-fall pyroclastic deposits (Allocca et al., 2008, 2015), originating from the Somma-Vesuvius volcano. The karst aquifer is unconfined and is bounded by direct faults (Fig. 1a), which locally produce low hydraulic conductivity cataclastic zones, resulting in a basin-in-series aquifer system (Fig. 1), according to experimental findings in different carbonate aquifers in southern Italy (Celico et al., 2006; Petrella et al., 2009, 2015; Bucci et al., 2014; Aquino et al., 2015; De Vita et al., 2018).

The water table of the groundwater body feeds several high-altitude springs (Fig. 1b and c): S1 (altitude 1182 m a.s.l. and mean annual discharge of 0.01 m^3/s), S2 (altitude 1168 m a.s.l. and mean annual discharge of 0.025 m^3/s) and S3 (altitude 1151 m a.s.l. and mean annual discharge of 0.040 m^3/s). The groundwater flow is oriented from NW to SE (Fig. 1b and c) within a well-connected fracture network.

The sub-basin of spring S2 (Fig. 1c and e) is of prime interest for this study, since it contains a small endorheic karst plain where grazing occurs. Grassland is the predominant land cover in this karst plain, whereas deciduous forest (*Fagus sylvatica* L.) is the main land cover along the hillslopes. The boreholes in the plain (Fig. 1b) show that the water table is on average less than 10.0 m deep (Fig. 1c and d). This causes a rapid response-time of the water table and spring S2 to rainfall, with a time lag of a few days (Allocca et al., 2008, 2015).

Recharge of the karst aquifer mostly occurs from September to May. After major precipitation events, mostly between December and April, recharge is primarily autogenic, from net infiltration and percolation through the vadose zone.

The climate of the Acqua della Madonna test site is a Mediterranean-mild (CSb) type (Geiger, 1954). The mean annual air temperature is 8.4 °C and mean annual rainfall is about 1730 mm, whereas the average annual groundwater recharge is 1280 mm, about 74% of mean annual precipitation (Allocca et al., 2014). From December to March there is intermittent and uneven snow cover within the pasture area and on the carbonate slopes, since snowfall alternates with rain.

2.2. Grazing system and microbial contamination

The Acqua della Madonna site, like other upland regions in Italy, is used by local communities for extensive livestock farming. This is a small-scale free-grazing system (Caballero et al., 2009): the herd of cattle (Podolica breed, about 300 head, Fig. 1e) arrives under the transhumance system in the small plain between springs S1 and S2 (Fig. 1b and c), and stays continuously from June to November. Cattle grazing in this karst area is supported by the use of local environmental resources, namely natural upland pastureland and high-altitude springs, and it is aimed at the organic production of meat, milk and cheese. This herding pattern, as in other Mediterranean countries, is a strategic resource for local rural development, because it provides high quality organic production (meat, cheese and milk), and is the main source of income for rural communities.

Nevertheless, for the Acqua della Madonna site grazing is also an anthropogenic source of groundwater microbial contamination (Allocca et al., 2008; Bucci et al., 2015a), as it results in the release of bacteria-rich faecal matter on the soil surface which persists year-round, and are transported into the groundwater body by infiltration. The source-pathway-receptor conceptual model for the mechanism of microbial contamination of the groundwater body and spring S2 is shown in Fig. 1c–e. Given the flat morphology of the pasturage area (Fig. 1c and d) and the absence of runoff processes, all the microbial contaminants are transported into the groundwater body by infiltration, and then flow into spring S2 (Fig. 1e). Therefore, measuring the microbial groundwater quality at spring S2 provides a complete and reliable picture of the degree of pollutant loading due to grazing.

Furthermore, given the short pathway and rapid travel time of microbial contaminants from the soil surface to spring S2, the microbial quality of the spring water mirrors that of the groundwater body, since infiltration and transport processes occur through sand-size pyroclastic deposits and wide and well-connected fractures of the carbonate bedrock, with a limited capacity of retention of the microbial pollutant load (Allocca et al., 2008; Bucci et al., 2015a).

3. Datasets

An overview of data inputs, sources and duration is reported in Table 1.

Daily precipitation and minimum and maximum daily air temperatures were recorded by a meteorological station (Fig. 1b) for the period 2001–2006. For the same period, the discharge of spring S2