Land Use Policy 68 (2017) 97–106

Contents lists available at ScienceDirect

Land Use Policy

journal homepage: www.elsevier.com/locate/landusepol

Spatial analysis of grey water in Italian cereal crops production

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ARTICLE INFO

Keywords:
Water management
Water pollution
Spatial dependence and heterogeneity
Italian regions
Grey water

ABSTRACT

Explorative spatial data analysis (ESDA) is a set of tools to emphasise spatial structure in case of localised data and widely used for testing effects in the case of environmental data. Grey water indicator is considered as a reliable water pollution indicator able to show the quality of water, useful in agriculture and crops production. In this paper, an analysis on the presence of spatial effects in the grey water indicator for crops production is proposed. This analysis is carried out on four cereal crops (i.e., corn, barley, durum wheat and soft wheat) in Italian regions for the period 2011–2015. The output reveals the presence of spatial effects especially for corn which shows a high level of polarisation between South and North regions. ESDA analysis indicates that grey water descending from cereal crops production is characterised by a persistent presence of positive spatial dependence and spatial heterogeneity. Policy makers should take into account those effects to improve the bundle of policies in the field of water management.

1. Introduction

Agriculture is actually the main user of freshwater in the world (Rodriguez et al., 2015) and accounts for about 70% of water withdrawals (Chen and Chen, 2013). Our knowledge relating to water contamination has increased in recent years and there have been many studies focusing on effluent from sewage plants or combined sewer overflows (Schreiber et al., 2015). Agricultural water pollution is a major concern both in European than in developing countries. Many research papers have focused on the relationships between crop yields and water resources (e.g. Wang et al., 2008; Piao et al., 2010; Peng, 2011), water use efficiency (e.g. Deng et al., 2006; Fan et al., 2011), and agricultural management (e.g. Hu et al., 2006). Agricultural practices determine the level of food production but also the state of the global environment (Tilman et al., 2002). The theme of water regards not only the scarcity but also the quality and the environmental consequence in agriculture. The problems of water scarcity and water pollution have become increasingly severe (Zhou et al., 2016). Water resources are widely used for food production and, consequently, its demand is expected to increase in the future due to population growth (Bocchiola et al., 2013; Curmi et al., 2013). A failure to optimally manage many water systems represents an environmental damage; this is more evident in case where activities may cause the degradation of hydrological habitats (Chapagain and Orr, 2009). Ertug Ercin and Hoekstra (2014) support the idea that freshwater scarcity and pollution will be aggravated in the future and will decrease its quality. However, through changing in water management is possible to remain at sustainable levels even with increasing populations (Ertug Ercin and Hoekstra, 2014).

Water footprint (WF) of a product is defined as the volume of freshwater used to produce it and should be measured over the full supply chain (Hoekstra et al., 2011). To monitor the unsustainable use of global freshwater resources, indicators which make water used patterns transparent are needed (Ridoutt and Pfister, 2010). WF is one of the most common tools used to analyze water management.

Hoekstra et al. (2011) defines the concept of blue, grey, and green water footprint. Blue water footprint measures the amount of water available used in a certain period and so, not immediately returned within the same catchment. Grey water footprint of a process step is an indicator of the degree of freshwater pollution associated with the process step, defined as the volume of freshwater that is required to assimilate the load of pollutants. Green water footprint is an indicator of the human use and refers to the precipitation on land that does not run off or recharge the groundwater, but is stored in the soil or temporarily stays on top of the soil or vegetation. The sum of those three components constitutes WF. In the context of social responsibility, WF has been widely used as an indicator that contributes to a safe and sustainable use of water (Marano and Filippi, 2015). WF is a global tool that could be referred on spatially located data. In this sense, it could be affected by spatial relationships according to "the first law of geography" (Tobler, 1970) that states "everything is related to everything else, but near things are more related than distant things". Performing spatial analysis on these geographically distributed data let us to investigate the spatial patterns of water usage and add more information

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http://dx.doi.org/10.1016/j.landusepol.2017.06.024
Received 24 March 2017; Received in revised form 8 June 2017; Accepted 26 June 2017

to the aim of developing better strategies for water management.

In agricultural field, many studies about the WF of different crops have been published. In particular, some contributions have been produced for agricultural products like tea and coffee (e.g. Chapagain and Hoekstra, 2007), tomato (e.g. Chapagain and Orr, 2009), wine (e.g. Herath et al., 2014), rice (e.g. Chapagain and Hoekstra, 2011), and grain production (e.g. Liu et al., 2014). In this work, we decide to focus particularly on grey water footprint because of the special importance of this indicator relatively to the agriculture. Grey water footprint from production refers to the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards (Cazcarro et al., 2016). The volumes obtained for grey water are a measure of the pressure imposed, mostly through economic activities, on water resources in a region that, especially compared to the water availability in the region, results in a significant environmental indicator. Microbiological and chemical constituents (nitrates, fertilizers etc.) of grey water can pose hazards to human health and to the environment (Nicholson et al., 2003; Rusan et al., 2007; Rodda et al., 2010). Grey water usually contains high numbers of micro-organisms, some of which can cause disease for those who encounters the plants and irrigated crops, and also contains substances that can reduce plant growth or crop yield if present at sufficiently high concentration. Furthermore, grey water can change soil properties so that it becomes progressively less fertile (Rodda et al., 2010). Specifically, nitrate influences grey water level so that this effect is part of the Directive 91/676/EEC included in the Water Framework Directive (Wall et al., 2011).

The global imbalance in the consumption of fertilizers and pesticides inevitably has had great impacts on cereal production around the world, particularly in developed countries, such as those in Europe and including Italy, where the amount of fertilizers and pesticides used has also been high (Liu et al., 2014).

More than others economic activities, agriculture is strictly associated to the location characteristics so that is meaningful to understand its spatial distribution also in terms of water use and water management. Various elements connected to the location may influence water management in agriculture. Some of that are intrinsically morphological as for soil structure and climatic conditions (Chapagain and Hoekstra, 2007; Chapagain and Orr, 2009; Casolani et al., 2016), others are considered geographically located due to their connection to specific locations, including either common practices and area infrastructure. While dealing with spatially located phenomena (as water resource exploitation and use of fertilizers), discard of spatial effects is considerably affecting the informative potential of any statistical technique (Cliff and Ord, 1973). Ready and available information about location, area extension, and distances can usually convey additional insight and lead to the reconstruction of spatial dependence patterns (Anselin, 1993). Therefore, exploring more the underlying structure of spatial connections in water use practices can enlighten about the spread effects of local environmental policies, help to validate local effects of global regulation, and point out more accurately reasons under why some basin-control policies are ineffective. However, final consumers and all sorts of businesses active along the supply chains of final consumer goods remain out of the scope of governmental policies regarding mitigation of water scarcity and pollution (Aldaya and Hoekstra, 2010).

An important toolkit to study the significant effects of spatial characteristics is the Explorative Spatial Data Analysis (ESDA) (Anselin and Getis, 1992). ESDA is set to analyze the spatial distribution of a certain phenomenon, to highlight the presence of spatial dependence, and to indicate the presence of spatial heterogeneity. In terms of grey water indicator, this means either testing for the presence of a global pattern of spatial correlation, such that close neighbours are expected to be similar, or verify the presence of different regimes due to spatial non-stationarity.

As spatial characteristics are entitled to play a considerable role while studying the level of grey water, the aim of this paper is to perform an application of the ESDA to the grey water indicator, especially for four cereal crops (i.e., corn, barley, soft wheat, and durum wheat), to evaluate the presence of spatial effects in crops production in Italy. Here, the main purpose is to add to the existing literature a new approach to interpret information included in grey water indicator necessary to assess the quality of water management process at a regional level. This information can be used by stakeholders to define appropriate policies. In fact, different tools can be used to achieve the safe management of waste water. Some countries provide incentives for the increased use of available natural resources (including water resources) towards local food production; others may provide subsidies to farmers to maintain a critical human resource base for local agricultural production. Policy makers should create a broader strategic local plan, considering behavioral change and cultural factors, environmental aspects, economic and financial considerations and health protection measures, according to the suggestion of World Health Organization (2006). However, all those aspects are not expected to influence the phenomenon of water pollution at the same way in all context due to presence of climate, cultural, and economic differences in the country (i.e., spatial heterogeneity). Spatial analysis could facilitate to explain spatial variation and to disentangle the presence of contextual influences (Haining, 2003) to the aim of helping stakeholders to improve water management policies at regional level in the case of Italian cereal crops production.

The paper is organised as follows. Section 2 is devoted to the description of data and methodology adopted to define the indicator and perform the ESDA. Section 3 contains the results of the spatial explorative analysis. In Section 4 some implications on policy frames of spatial effects detected in the analysis are discussed. Finally, Section 5 concludes.

2. Methodology

2.1. Grey water calculation

In this paper, grey water for different cereal crops has been calculated following the methodology introduced by Casolani et al. (2016) and Rodriguez et al. (2015). In the computation of our indicator, the values of grey virtual water content for each region were taken from Mekonnen and Hoekstra (2010). Grey virtual water represents the volume (m^3) of water required to dilute pollutants produced for each unit of cereal production (t) to achieve water quality standards. Grey water regional impact on area (GW_{RIA}) is calculated as:

$$GW_{RIA} = \text{Grey Water regional impact on area } (m^3/Km^2) = [VWC_{Grey\ \mathit{Region\ i}}\ (m^3/t) \times T.P._{\mathit{Region\ i}}\ (t)]\ /\ TRA_{\mathit{Region\ i}}\ (Km^2)$$

where:

$VWC_{Grey\ Region\ i}$ = Grey Virtual Water content in *Region i* .

$TRA_{Region\ i}$ = *Total Area* of *Region i*(Km^2).

$T.P._{Region\ i}$ = Total production of *Region i* (t).

Then, grey water impact on agricultural area (GW_{AA}) is computed as:

$$GW_{AA} = \text{Grey Water impact on agricultural area } (m^3/ha) = VWC_{Grey\ \mathit{Region\ i}}\ (m^3/t) \times Y_{p\ \mathit{Region\ i}}\ (t/ha).$$

where:

$VWC_{Grey\ Region\ i}$ (m^3/t) = Virtual Grey Water content in *Region i* .

$Y_{p\ Region\ i}$ = productivity of cereal per hectare (t/ ha) of Region *i* .

GW_{RIA} expresses a value of grey water emerging from the total amount of cereal crop cultivated in the region on the regional area. GW_{AA}, instead, indicates a potential value of grey water for hectare of crop and it is a potential value linked to cereal productivity. We consider the GW_{AA} indicator as the best choice to perform a spatial analysis of grey water in Italy as it is a value of grey water normalized on the