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Assessing the magnitude of potential environmental impacts related to water and toxicity in the Peruvian hyper-arid coast: A case study for the cultivation of grapes for *pisco* production

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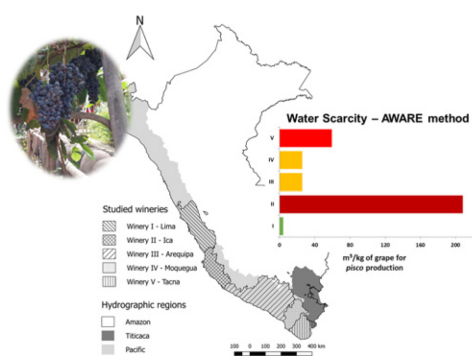
HIGHLIGHTS

- The cultivation of grapes for *pisco* production was analyzed using LCA.
- Water footprint, including toxic emissions, was assessed using a life-cycle approach.
- Results show substantial differences in water scarcity depending on location.
- Regionalized characterization factors were used based on the AWARE method.
- The PestLCI model was adapted to model pesticide emissions in coastal Peru.

GRAPHICAL ABSTRACT



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ABSTRACT

The environmental sustainability of the cultivation of grapes for the production of alcoholic beverages has been extensively analyzed in the literature from a Life Cycle Assessment perspective, although certain impact categories have been repeatedly neglected despite their importance, such as toxic emissions or the depletion of freshwater resources. Hence, the current study provides a detailed assessment of water footprint-related impact categories, including toxicity, for the cultivation of grapes for *pisco* production, an alcoholic beverage produced in coastal Peru in hyper-arid areas that suffer high levels of water scarcity. Characterization factors at a sub-watershed level were used to calculate water consumption impact assessment of grape production using the AWARE method. Site-specific toxic emissions were modelled using the PestLCI model, considering primary climate and soil data. The USEtox assessment method was then used to compute freshwater eco-toxicity with these data. Results demonstrate the high water footprint of irrigating vineyards in coastal Peru, especially considering the inefficient flooding irrigation process. In terms of water consumption, despite the high variability shown between sub-watersheds, the shift to other irrigation technologies must be analyzed with care due to the high competition for water existing in the area. Eutrophication potential showed particularly high values compared to the literature, whereas freshwater eco-toxicity impacts were relatively low due to the high volatilization of pesticides to air. Nevertheless, the lack of an adequate wastewater management system implies that the estimated potential toxic and eutrophying emissions may constitute a further environmental threat to water bodies.

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1. Introduction

Peru is a country that presents a variety of climates (Vidal, 2014). These can be grouped into three main natural areas: the hyper-arid coast, the highlands of the Andes and the Amazon basin. This differentiation is visible in terms of water availability, but also water demand, in the three bioregions (Webb and Baca, 2016; Boulay et al., 2015). Therefore, it is evident that the withdrawal of water from natural water bodies in each of these regions will have a different impact on the environment. Recent studies, such as one conducted by SENAMHI, the Peruvian meteorological agency, suggest that by 2030 rainfall could be down by up to 20% in the Andes (SENAMHI, 2009). Moreover, there is strong evidence that global warming is melting the main glaciers in the nation (Baraer et al., 2012), which are the only source of water trickling down the Pacific during great part of the year (Vuille et al., 2008).

In this context, coastal Peru, one of the most arid areas in the world, reports average annual rainfalls in most weather stations below 10 mm (SENAMHI, 2015; Yzarra et al., 2015). Despite this lack of precipitation, which is only (sparsely) disrupted whenever the ENSO event hits the Peruvian coast, agricultural production has experienced an expansive surge in past decades through the exploitation of aquifers and surface water arriving from the Andes (Oré et al., 2012; Schwarz and Mathijs, 2017). In fact, throughout most of the Peruvian coast, but especially in the agricultural hub around the city of Ica (14°03′55″S; 75°43′51″W), the main crops that have developed are intensive in their thirst for water. This is the case of green asparagus, cotton, and to a lesser extent grapes (table grapes and for *pisco* production), citrus fruits, artichoke or avocado (DRAI, 2014). However, an expected reduced and less reliable water supply will cause unprecedented problems in the ever-growing agricultural sector along the hyper-arid Peruvian coast due to increased competition between downstream users along the Pacific watersheds (Bury et al., 2013; Lynch, 2012).

In this context, the concept named water stress arises, which according to the European Environmental Agency "occurs when the demand for water exceeds the available amount during a certain period or when poor quality restricts its use" (EEA, 2016). On the one hand, there is evidence of overexploitation in most aquifers along the Peruvian coast (Oré et al., 2012). On the other hand, Peru has serious technological limitations in terms of treating wastewater of all types, which leads to minimal and inefficient water recovery methods, both in terms of quantity and quality (Jhansi and Mishra, 2013). In fact, the lack of these technologies implies that water quality of most rivers along the Peruvian coast has been jeopardized by decades of overexploitation and lack of planning (UNESCO-IHE, 2011), generating additional impact, such as eutrophication, saline intrusion, toxicity, among other impacts (Yakirevich et al., 2013; Kuroiwa et al., 2014).

An increasingly used method to evaluate water stress and scarcity is Water Footprint (WF), which can be considered, according to ISO 14046, as any assessment method that quantifies the potential environmental impacts linked to water (ISO14046, 2014; CADIS, 2016). Although several different methods have been developed throughout the beginning of the century (Brown and Mattlock, 2011; Chenoweth et al., 2014), the recently published ISO standard for WF is based on a life cycle thinking perspective, and considers quantitative and qualitative water-related impact categories (ISO 14046, 2014), or as described by Ridoutt and Pfister (2013), consumptive and degradative water use.

WF has gained importance in several productive sectors, including industry and services, but it is in the agricultural sector where it has become an important reference method for policy makers and stakeholders (Bazilian et al., 2011; Roelich et al., 2014). This importance is linked to the high amounts of water needed for the production of agricultural products, which, according to Hoesktra and Mekonnen (2012) represent 92% of the total WF worldwide. Hence, water use has important consequences in global food policy, human development, or poverty (Jeswani and Azapagic, 2011).

For the particular case of agricultural production in coastal Peru, research linked to WF has been limited to a small amount of case studies (Hepworth et al., 2010; Schwarz and Mathijs, 2017). However, we argue that this type of studies is of utter importance, not only to evaluate the stress of agricultural processes on water availability, but also due to the scarce mechanisms (e.g., wastewater treatment plants) to guarantee that water pollution is treated correctly once effluents return to natural water bodies (Malik et al., 2015).

The case study selected in this research paper is the production of grapes for *pisco* elaboration, a local brandy produced in central and southern coastal Peru (Huertas Vallejos, 2004). The rationale behind this choice is linked to the following factors: i) despite the fact that other crops in the area, such as asparagus or cotton, have higher irrigation rates than grape, most of the production of grapes for *pisco* in coastal Peru do not use irrigation methods other than flooding (Yzarra et al., 2015), making the process highly inefficient; ii) *pisco* is becoming an increasingly relevant commodity in international markets, with exports rising abruptly in recent years (PRODUCE, 2014); and, iii) grape production is highly intensive in the use of plant protection agents due to the high sensitivity of vines (Renaud-Gentié et al., 2015); therefore, the analysis of water quality impacts, such as freshwater toxicity, is included within the WF assessment. Approximately 70% of the vineyards in the valley of Ica (300 km South of Lima) use flood irrigation from the Ica river, whereas 30% use dripping from groundwater sources, according to Yzarra et al. (2015). In other *pisco* producing areas in Lima, Moquegua, Tacna and Arequipa we hypothesize that reliance on groundwater resources is more limited given the lower expansion of the agricultural frontier beyond the main riverbeds.

There are several research studies in the literature that have analyzed the WF of grape-related products [mainly wine] in different geographical areas, although most have concentrated in Southern Europe (Comandaru et al., 2012; Ene et al., 2013; Lamastra et al., 2014; Rinaldi et al., 2016), whereas no studies in South America have been identified in Scopus (Scopus, 2016). However, certain companies do report that they have contracted consultancy services to perform the WF of their winery products (Concha y Toro, 2016). Despite this timid proliferation, other life-cycle methods have delved deeper into other environmental impacts (Rugani et al., 2013). For instance, greenhouse gas emissions (Bosco et al., 2011; Pattara et al., 2012; Point et al. 2012; Vázquez-Rowe et al., 2013), ozone depletion (Vázquez-Rowe et al., 2012a) or land use (Villanueva-Rey et al., 2015) are some of the repeatedly assessed impact categories, whereas impact categories related to toxicity (Renaud-Gentié et al., 2015) or water quality have been analyzed in less detail.

Therefore, the main objective of this study is to analyze the environmental impact that the production of *pisco* grapes has on impact categories linked to water footprint, which tend to be generally under-represented impact categories in the literature, and are considered critical in the agri-food industry in coastal Peru. These categories include water depletion and scarcity, eutrophication potential and freshwater eco-toxicity impacts. In addition, the results presented are expected to contribute to a better understanding of the effects of intensive agriculture along the arid Peruvian coast in terms of environmental impacts, which have been mostly understudied in the past decades.

2. Materials and methods

2.1. Methodological framework

The ISO 14046 standard was used as the main framework to assess water availability and degradation environmental impacts (ISO 14046, 2014). Similarly, the ISO 14040 and 14,044 standards were followed to analyze the toxic emissions of grape production (ISO, 2006a, 2006b). The function of the production system is the harvest of a certain amount of grapes for the production of *pisco*. Hence, the functional unit (FU) considered was 1 kg of grapes ready for transportation to the wineries for the *pisco* production process. Table 1 presents the yield of