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Using geographical information system to generate a drought risk map for rice cultivation: Case study in Babahoyo canton (Ecuador)

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Extreme weather events are occurring more frequently, and they affect people, infrastructure and crops. Drought is one of the most important hazards that threaten agriculture and livestock. Such adverse events can result in yield losses over large cropping areas. It is difficult for farmers to cope with prolonged periods of drought. In the absence of government support, rainfed farmers have very limited adaptation capabilities.

In this study, we used geographical information system (GIS) tools to generate a drought risk map (DRM) for rice cropping in Babahoyo Canton, Ecuador. This map represents production risks incurred through the onset of a drought event based on the interaction between vulnerability and threat. The vulnerability of rice cropping is determined through a soil land evaluation for rice cropping and the availability of water during the crop cycle rather than approaching the issue based on drought indices, such as the standard precipitation index (SPI). Threat is the likelihood of the occurrence of a drought event that affects rice crops. The DRM was compared to another drought risk map that was generated based only on climatic variables as risk factors (DRcM). We adjusted the DRM and DRcM by adding a layer of operational irrigation projects and by removing drought hazards from areas that are currently irrigated.

Based on Normalized difference vegetation index (NDVI) temporal series and drought claims insurance data, the obtained DRM and DRcM were validated. Both maps show a significant relationship between zone classification and NDVI values. However, the DRM adjusted better to insurance data than the DRcM, which does not consider soil variables. The DRM is an effective tool for agricultural risk management decision-making and it serves as an important source of information that could be used for index-based insurance implementation.

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1. Introduction

Climate change, which has a significant influence on local and regional climatic regimes (Holman, Rivas-Casado, Bloomfield, & Gurdak, 2011), produces extreme weather events with increasing intensity and frequency; furthermore, climate change affects hydrological and water resource systems (Arnell & Reynard, 1996; Pachauri et al., 2014). Most of the world's annual crop losses are due to weather events (e.g., drought, flooding, frost, hail, etc. (Fraisse et al., 2006)), constituting one of the main production risks and uncertainty factors that impact the performance and management of agricultural systems (Sivakumar & Motha, 2008).

Consequently, this pressure has increased risks related to agricultural and livestock production (Kgakatsi & Rautenbach, 2014). To reduce hazards and economic losses that could jeopardise farmers' incomes and threaten their business continuity, it is very important to implement agricultural risk management plans through governmental and research institutions.

Currently, agricultural insurance schemes are widely used to transfer farmers' yield risks (Trærup, 2012). As Berg, Quirion, and Sultan (2009) and Barnett (2004) stated, one efficient form of agricultural insurance is that of index-based insurance, which is based on a comparison of index values with a defined threshold to trigger payments in lieu of yield losses. Vegetation indices are widely used, with the normalized difference vegetation index (NDVI) being the most frequently used (Gu, Brown, Verdin, & Wardlow, 2007).

However, in functional risk management plans, index-based agricultural insurance must be integrated with a detailed monitoring system that relates many sources of information and tools (Valverde-Arias, Garrido, Villeta, & Tarquis, 2017) (e.g., index influence areas, crop production risk maps, crop yields, claim statistics, etc.; Valverde-Arias, et al., 2017) to avoid asymmetric information, adverse selection and systemic risk (Kalogirou, 2002; Stoppa & Hess, 2003).

According to Iglesias, Garrote, Cancelliere, Cubillo, and Wilhite (2009) and Hoag (2009), drought is one of the most important extreme weather events that threatens agricultural production and affects mostly at regional levels. However, it is not only extreme drought events that can affect crops; even a short delay of the beginning of the rainy season date or a water scarcity in a critical crop stage could produce a significant yield loss (Habiba, Shaw, & Takeuchi, 2012).

Hayes, Svoboda, Wall, and Widhalm (2011) identified different categories of drought: meteorological, climatic, atmospheric, hydrological and agricultural drought. The last of these is a shortage of soil water available for crops, which depends not only on precipitation but also on soil water retention capability, crop type and phenological stage (McKee, Doesken, & Kleist, 1993). Therefore, soil water availability at any given time is determined not only by precipitation, but also by evapotranspiration, infiltration, runoff, soil texture, effective depth and slope (Lascano et al., 2007).

Optimal crop production conditions are based on numerous factors that encourage proper crop development; these factors are rooted in topographic, physical and chemical soil characteristics and climate, some of which can be modified or managed by farmers at different levels to achieve optimum crop requirements. Higher levels of divergence from optimal conditions can be compensated for through larger investments.

Drought risk models have been assessed through different approaches mainly based on drought indices. For example, many authors have obtained drought risk categories from values of different vegetation indices (Dalezios, Blanta, Spyropoulos, & Tarquis, 2014). Another group of researchers have preferred to use climatic indices based on precipitation (Shahid & Behrawan, 2008; Strzepek, Yohe, Neumann, & Boehlert, 2010) or combined with temperature (Wu & Wilhite, 2004). Finally, a combination of both can also be found (Chopra, 2006).

Our goal is to generate a drought risk map (DRM) based on a specific water availability analysis and on soil conditions for the crop selected. This model applies a new approach that replaces drought indices commonly used in risk models, such that the DRM can be adjusted to consider irrigation projects in drought risk analyses.

This case study focuses on rice crops in Babahoyo Canton, Ecuador. To reveal soil effects on risk levels, we compare our adjusted DRM with another that does not consider soil characteristics (DRcM). An NDVI imagery set and spatially referenced drought insurance claims are used to validate and compare the DRM to the DRcM. A novel statistical analysis based on insurance data is presented.

2. Materials and methods

2.1. Location of the study area

The study area is located in Babahoyo canton, Ecuador (see Fig. 1); its area is 109,391 ha from which 102,517 ha correspond to agricultural lands and 6874 ha are urban, protected and non-agricultural lands (miscellaneous lands, water bodies, etc.). Babahoyo canton is administratively divided in five rural districts which are: Babahoyo, Caracol, Fébres Cordero, La Unión and Pimocha.

The agricultural land of the Babahoyo canton is mainly cultivated with rice, banana and soybean which reach 70,152 ha of the total Babahoyo canton's area (IEE, 2009a,b). Rice is the most important crop with 46,556 ha, representing 45% of the total cultivated area in the Canton (MAGAP, 2014a,b).

2.2. Drought risk framework

There have been many studies assessing drought risk for specific crops, even in real-time (e.g. Wu, Hubbard, & Wilhite, 2004; Zhang, 2004). However, these are mainly focused on maize and located in Asia and United States. There is a need to develop studies in this field adapted to Ecuador's conditions using the available information.

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