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Vulnerability of global food production to extreme climatic events

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A B S T R A C T

It is known that the frequency, intensity or duration of the extreme climatic events have been changing substantially. The ultimate goal of this study was to identify current vulnerabilities of global primary food production against extreme climatic events, and to discuss potential entry points for adaptation planning by means of an explorative vulnerability analysis. Outcomes of this analysis were demonstrated as a composite index where 118 country performances in maintaining safety of food production were compared and ranked against climate change. In order to better interpret the results, cluster analysis technique was used as a tool to group the countries based on their vulnerability index (VI) scores. Results suggested that one sixth of the countries analyzed were subject to high level of exposure (0.45–1), one third to high to very high level of sensitivity (0.41–1) and low to moderate level of adaptive capacity (0–0.59). Proper adaptation strategies for reducing the microbial and chemical contamination of food products, soil and waters on the field were proposed. Finally, availability of data on food safety management systems and occurrence of foodborne outbreaks with global coverage were proposed as key factors for improving the robustness of future vulnerability assessments.

1. Introduction

In today's globalized world, either raw materials or final food products are produced around the globe in climatically, culturally and legally diverse places on their way to our kitchen counter. The cultural differences may lead to changes in diet preferences, and the legal differences, together with in-place institutional mechanisms, may lead to important changes in food governance strategies. Likewise, changing climatic patterns appear to be a fundamental contributor to the food-related incidents as much as the cultural, legal and economic environments in the countries of origin and destination. Impacts of climate change and climatic oscillations (such as El Niño southern oscillation and Indian ocean dipole) on food security are well documented by focusing on changing crop yields, crop (especially grains) and livestock loss on spatial scales ranging from a state and nation (Ghahramani & Moore, 2016; Hague, Braganza, & Jones, 2016; Li, Wang, Ning, & Luo, 2016; Liu, Liu, Yang, Bai, & Wang, 2015; Spencer & Polachek, 2015; Swaminathan & Rengalakshmi, 2016; Wang, Zhang, Wei, Feng, & Tao, 2016) to region and the globe (FAO, 2016c; Lassa, Lai, & Goh, 2016; Özkan et al., 2016). The aim of ensuring food security appears to be increasing access to food, eradicating hunger by increasing yields and focusing on animal and plant health, and supporting people to have more balanced diets. The other side of the coin—food safety—has emerged upon the increasing awareness on unintentional spread of food-related illnesses by addressing mainly public health and human welfare. However, it barely attracts scientific attention when it comes to global scale assessments. Major consequences of climate change for food safety have been reported as changes in temperature and precipitation patterns, ocean warming and acidification, and changes in frequency, intensity, and duration of extreme climatic events (Kirezieva, Jacxsens, Van Boekel, & Luning, 2015). Since using proxy indicators for ocean warming and acidification to compare country performances is futile on a global scale, and effects of changes in temperature and precipitation patterns on food safety show significant regional differences (Kim, Park, Chun, Choi, & Bahk, 2015; Tirado, Clarke, Jaykus, McQuatters-Gollop, & Franke, 2010); frequencies of extreme climatic events appear to be appropriate targets to assess the current levels of exposure. As reported by Intergovernmental Panel on Climate Change (IPCC), occurrence of the heat waves over most land areas has increased since the middle of the twentieth century and it is likely that the frequency and the duration will increase in the current century (IPCC, 2013). It was reported with high confidence that as the global mean surface temperatures rise, extreme precipitation events will continue to increase in frequency and intensity faster than the time's average, and remarkably, the contrast of annual mean precipitation between dry and wet regions, and between wet and dry seasons would increase over most of the globe (IPCC, 2013). Likewise, it was classified as to be likely that intensity and/or duration of drought and flood events will increase due to decreases in soil moisture (IPCC, 2013). It was also reported that there is a shift to more intense individual storms and fewer weak storms in terms of short-duration precipitation events (IPCC, 2013). Mean tropical cyclone

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maximum wind speed and rain rates have increased despite the global frequencies are likely to decrease or remain unchanged (IPCC, 2013). Apart from IPCC, several regional meteorological monitoring institutions reported on the current situation of the extreme climatic events. For example, European Drought Observatory (EDO) annually reported increased number of occurence of extreme temperature events (hot and cold), increased duration of droughts, and severe soil moisture deficits over large areas (EDO, 2015). Likewise, 2000–2016 period was the largest and most persistent drought for the West of the United States of America in the historical record (NOAA, 2017a). Moreover, U.S. Climate Extremes Index (USCEI) for 2016 was 95% above average—the third highest value on record (behind 1998 and 2012)—and mostly min. and max. temperature values contributed to this index values (NOAA, 2017b). Food production is particularly vulnerable to such large-scale changes in patterns of extreme events because the very beginning of food supply chain starts at farms by directly being exposed to climatic events (Marvin et al., 2013). The fact that food safety incidents often originate in the early stages of food supply chain not only holds true for crop production, but also for dairy and meat production (Jooste & Anelich, 2008; Norrung & Buncic, 2008; Yeni, Yavas, Alpas, & Soyer, 2016). Moreover, if contamination occurs in the primary production phase, the risk of cross contamination due to distribution of the food products will be much higher than expected (Gorny, 2006; Sofos, 2005). Therefore, the objectives of the present study were to conduct an explorative vulnerability assessment on a global scale, focusing primarily on food production stage in order to reveal current vulnerabilities and to discuss adaptation options to propose a holistic solution. To this end, it was aimed to define which extreme climatic events put pressure on food safety, which characteristics make countries more prone to exposure, and which tools can be used to facilitate climate adaptation in order to determine the levels of exposure, sensitivity and adaptive capacity (AC), respectively. Afterwards, a cluster analysis (CA) was conducted with the aim of evaluating policy implications in terms of the global North and South countries. Finally, a nonparametric correlation was carried out in order to reveal whether there is a link between availability of a national food safety authority and the vulnerability index (VI) scores.

2. Research methodology

2.1. Study design

Until the fifth assessment report, vulnerability was defined by IPCC as a systematic approach comprised of three elements (exposure, sensitivity and adaptive capacity) which, as a whole, was used as a tool to analyze the propensity of the overall system to be adversely effected by a factor (IPCC, 2007). Although the last report focuses on the notion of social vulnerability by phasing out the exposure component, the classical notion of vulnerability is still considered as a highly effective way of identifying and prioritising adaptation interventions (Fritzsche et al., 2014). To this end, both biophysical (exposure) and socio-economic (sensitivity and AC) dimensions were integrated into vulnerability analysis (VA) in order to provide an underpinning for discussion. In this study, outcomes of the VA were demonstrated as a composite vulnerability index (VI) because composite indices (CIs) are recognized as useful tools in identifying trends and providing simple comparison of countries in highly complex issues (Munda & Nardo, 2009; Nardo, Saltelli, Tarantola, Hoffmann, & Giovannini, 2008). However, in literature, there is an ongoing debate on constructing CIs and on taking the outputs of CIs as the sole base for policy making. In a recent study (Santeramo, 2015a, 2016), by comparing different food security CIs based on the same data, it was concluded that choosing relevant data and the right methods for data imputation and aggregation are crucial while the choice of normalization and weighting methods are less of a concern. Reaching the relevant data to construct the index is the first issue which has to be addressed by the researchers. For instance, for food safety related indices with global coverage, lack of the data on foodborne outbreaks, prevalence of in-place food safety management schemes, or choice of traceability systems, level of adaptation efforts made by each country creates the main shortcomings of an index. After the data collection stage, imputating the missing data is a critical step because imputation may lead to biased estimates depending on the method used and the percentage of missing values in the dataset (Nardo et al., 2008). For normalization, there are various methods and each of them having its limitation. But the most widely used ones are standardisation and min-max normalization, both of which are affected by the outliers in the data (Nardo et al., 2008). For weighting indicators, there are a whole range of statistical and participatory methods. Researchers may choose factor analysis or Principle Component Analysis (PCA) if variables are correlated, or equal weighting method can be chosen if there is a prior information that the indicators have equal contributions to the index (Santeramo, 2015b). For the last stage, aggregation, linear or nonlinear aggregation methods can be used by the researcher depending on the compensability of the components of an index (Munda & Nardo, 2009). In total, considering the complexity of the realm of climate vulnerability and safety of food production, and the limited nature of available indicators in terms of relevance, discussions on outputs of composite indices need to be considered as hypotheses rather than definitive conclusions (Barré, 2001; Hoskins, Saisana, & Villalba, 2015). In this sense, a statistically sound and conceptually coherent index was aimed to be built by ensuring the transparency of method selection. In this study, in the first step, extreme climatic events were associated with microbial or chemical contamination of food (crops, feed and livestock) and production environment through impact chains (Fritzsche et al., 2014). In the second step, the most relevant and available indicators with global coverage, and up to date records were chosen and collected from open-access sources for the index to be repeatable and transparent (FAO, 2016a, 2016b; Guha-Sapir, Hoyois, & Below, 2016; WB, 2016). Analysis was performed with no missing data. Instead of missing data imputation, the countries lacking data were excluded from the analysis, and, for this reason, number of countries were downsized from 193 to 118. In the third step, the direction of indicators was adjusted where necessary, in order to demonstrate the trend, where lower values reflect decrease in vulnerability. As the fourth step, weights were assigned to each indicator of each vulnerability component after running a PCA as was proposed by Gomez-Limon & Riesgo in order to avoid subjective results (Gomez-Limon & Riesgo, 2009). In the fifth step, Monte Carlo simulation was performed after PCA in order to determine the number of principal components to be extracted from the analysis (O'Connor, 2000). In the sixth step, normalized exposure and sensitivity scores were linearly aggregated into potential impact, and afterwards normalized potential impact and AC were linearly aggregated into CI in order not to underestimate their equal importance (Fritzsche et al., 2014). In the seventh step, a hierarchical CA was performed using Ward's method to group the countries based on vulnerability index (VI) scores (Ward, 1963). Finally, a nonparametric correlation (Spearman's rank correlation) was run to determine the relationship between availability of legislation to establish an independent food safety authority, and AC and VI scores, respectively (Spearman, 1904).

2.2. Developing impact chains

The aim of developing impact chains was to set cause-effect relationships between extreme climatic events and potential food safety threats. For this purpose, case studies in the voluminous literature on the subject were used. In these studies, extreme climatic events were found to manifest themselves as eight main pressures on food safety through direct and indirect effects (Fig. 1). These pressures can be grouped into two as microbial (bacterial, viral, fungal and parasitic) and chemical contamination.