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# Synchronizing socio-climatic impacts in spatio-temporal analyses of drought vulnerability: challenges and perspectives for data production[1]

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## Abstract
Records have shown that the frequency of the occurrence of extreme climatic and weather events has increased in recent years. Climate change has contributed to this increase, and models project a very likely intensification of the frequency and magnitude of these events. Brazil is home to one of the most populous semi-arid regions on the planet, which historically faces periods of drought. In the wake of this, the research efforts focused on the analysis of drought risks and hazards of water scarcity are notable, as well as on the disclosure of vulnerability factors in the face of adverse events related to climate change. However, the collection of social, economic, and demographic data depends on census surveys that are sometimes not able to express the spatiotemporal and multilevel heterogeneity of vulnerability, as well as the speed of social, political, and cultural transitions influenced by extreme events that are increasingly frequent and intense. This article seeks to discuss the challenges for data production, especially those involving the human dimension of risks and vulnerabilities to drought, and to bring perspectives on emerging techniques for data production and collection that seek practical, economic, and scientific efficiency.

## Resumo
### Sincronizando impactos socioclimáticos em análises espaço- temporais de vulnerabilidade à seca: desafios e perspectivas para a produção de dados
Os registros de ocorrência de eventos climáticos e meteorológicos extremos vêm aumentando nos últimos anos. As mudanças do clima têm contribuído para esse aumento e os modelos projetam uma muito provável intensificação da frequência e magnitude desses eventos. O Brasil abriga uma das regiões semiáridas mais populosas do planeta, que historicamente convive com períodos de seca. À reboque disso, são notáveis os esforços de pesquisa focados na análise de riscos de seca e ameaças de escassez hídrica, bem como, na evidenciação de fatores de vulnerabilidade frente a eventos adversos relacionados com as mudanças climáticas. Entretanto, a coleta de dados sociais, econômicos e demográficos fica à mercê de levantamentos censitários que, por vezes, não são capazes de expressar a heterogeneidade espaço-temporal e multinível da vulnerabilidade, bem como, a velocidade com que acontecem transições sociais, políticas e culturais influenciadas por eventos extremos cada vez mais frequentes e intensos. Esse artigo busca discutir os desafios para a produção de dados, sobretudo aqueles envoltos à dimensão humana dos riscos e vulnerabilidades à seca, e trazer perspectivas de técnicas emergentes para produção e coleta de dados que busquem eficiência prática, econômica e científica.

## Resumen
### Sincronizando impactos socioclimáticos en análisis espacio-temporales de vulnerabilidad a la sequía: desafíos y perspectivas para la producción de datos
Los registros de la ocurrencia de fenómenos climáticos y meteorológicos extremos han aumentado en los últimos años. El cambio climático ha contribuido a este incremento y los modelos proyectan una muy probable intensificación de la frecuencia y magnitud de estos eventos. Brasil es el hogar de la región semiárida más poblada del planeta, que históricamente coexiste con períodos de sequía. A raíz de esto, se destacan los esfuerzos de investigación enfocados en el análisis de riesgos de sequía y amenazas de escasez de agua, así como en la evidenciación de factores de vulnerabilidad ante eventos adversos relacionados con el cambio climático. Sin embargo, la recopilación de datos sociales, económicos y demográficos depende de encuestas censales que, por vezes, no logran expresar la heterogeneidad espacio-temporal y multinivel de la vulnerabilidad, así como la rapidez con que ocurren transiciones sociales, políticas y culturales influenciadas por eventos extremos cada vez más frecuentes y intensos. Este artículo busca discutir los desafíos para la producción de datos, especialmente aquellos que involucran la dimensión humana de los riesgos y vulnerabilidades a la sequía, y traer perspectivas sobre técnicas emergentes para la producción y recolección de datos que buscan la eficiencia práctica, económica y científica.

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## Introduction

Drought is a climatic phenomenon that can be considered an extreme event and is characterized by long periods (from months to years) in which the observed rainfall regime is below the expected average for a certain location (MARENGO; TORRES; ALVES, 2017; REBOITA *et al*., 2016). Between 2011 and 2019, all regions of Brazil, with the exception of the southern region, faced severe droughts, which produced considerable social, economic, and environmental impacts. For this period, the São Francisco River Basin - the most important in the northeast region of Brazil - at the point of the Sobradinho reservoir, between the states of Bahia and Pernambuco, presented a 44% reduction in its flow in relation to its historical average, reaching only 1% of the reservoir's capacity in 2015. The water scarcity generated by these long periods affects agricultural crops and animal husbandry since the soils no longer retain water (edaphic drought) and the water mirrors evaporate, making unfeasible food production, domestic use, and human consumption of water (CAMPOS, 1997). Between 2012 and 2017, around 6 million small farmers faced a loss of productivity, income constraints and, in some cases, worrying conditions of food insecurity (CUNHA *et al*., 2019). But it is not only the Brazilian semiarid region that experiences these extremes. In 2014, the southeast region of Brazil experienced almost 50% less rain than the expected average, which resulted in serious water and energy crises that affected around 8.8 million inhabitants of the state of São Paulo (GIULIO *et al*., 2019).

In the context of discussions and analyses on risks and vulnerabilities to drought in the Brazilian semiarid region and other regions of the globe susceptible to events characterized by water scarcity, greater emphasis is given to the explanation of the phenomenon's spatiotemporal dynamics through biophysical variables (temperature, precipitation and evapotranspiration, for example) than socioeconomic, political or cultural variables and subjective considerations inherent to those who live and sometimes suffer from drought events or other adversities (ENENKEL *et al*., 2020; ERIKSEN *et al*., 2021; MARANDOLA JUNIOR; HOGAN, 2005). This is due to the greater availability of data generated constantly (days or weeks), such as those produced by remote sensors (orbitals and radars). These tools provide information on the condition of vegetation (modified or native) from indices based on the reflectance of the targets: temperature, rainfall and evapotranspiration data, as well as data on land use change, deforestation, fire spots and expansion of agricultural area (DE OLIVEIRA--JÚNIOR *et al*., 2021; MARIANO *et al*., 2018; MUTTI *et al*., 2019; ZERI *et al*., 2018). These variables act, first, as a way of showing the occurrence of the phenomenon and, second, as direct and indirect indicators, which help to explain environmental changes, depending on the spatial level which is the focus of the analysis.

Something similar happens when the social vulnerability is analyzed. In general, it starts with variables available in government databases (country, state or municipality), which sometimes prevent a more fragmented view of heterogeneities that influence the way each individual, family nucleus or community mobilizes personal and collective assets to face adverse events that emerge in severe droughts (ALVES MENEZES *et al*., 2021; MARANDOLA JUNIOR; D'ANTONA, 2014; VIEIRA *et al*., 2020). In Brazil, demographic and agricultural censuses take place every ten years, and budget restrictions deliberated by the federal executive branch have compromised and delayed their achievements. (JORNAL DA USP, 2021). On the other hand, the National Household Sample Survey (Continuous PNAD), carried out by the Brazilian Institute of Geography and Statistics (IBGE), contributes to a general diagnosis of the population's socioeconomic conditions at the municipality level with greater frequency - monthly, quarterly and annually - but with a lower level of detail (IBGE, 2021). Added to this are the restrictions imposed by the COVID-19 pandemic, which resulted in the postponement of field data collection and any other form of research involving physical contact and imminent risk of dissemination of the coronavirus (NEDEL OLIVEIRA, 2021).

However, as highlighted by Dobkowitz *et al*. (2020), very often, the variables involved in the vulnerability analysis are risk-dependent, that is, what indicates the vulnerability (sensitivity, exposure and adaptive capacity) of an individual, family or community, depends on the risk-threat faced. The recognition that the vulnerability-risk binomial is relational and situational raises some questions. Are these risks climatic and environmental and therefore "natural"? Or are these risks constructed by the model of society in which we live?

Thus, it is an unavoidable move "to put the human back into the drought equation", as proposed by Enenkel *et al*. (2020, p. 1) so that the environmental, social, economic and demographic impacts generated by extreme events are subject to monitoring and evaluation according to local specificities and with a frequency that allows the identification of factors that influence vulnerability to drought in the short, medium and long terms.

Based on this, this article aims to discuss methodologies and data collection techniques that complement the "flyover view" (SOUZA, 2016, p. 150), commonly used in vulnerability analysis, adding an insider, inclusive and comprehensive perspective. An exploratory approach was used based on a non-systematic review of studies available on the Scopus database until July 2021. The papers found in this search which are related to alternative techniques for data generation as digital tools, citizen science and participatory research were selected for analysis.

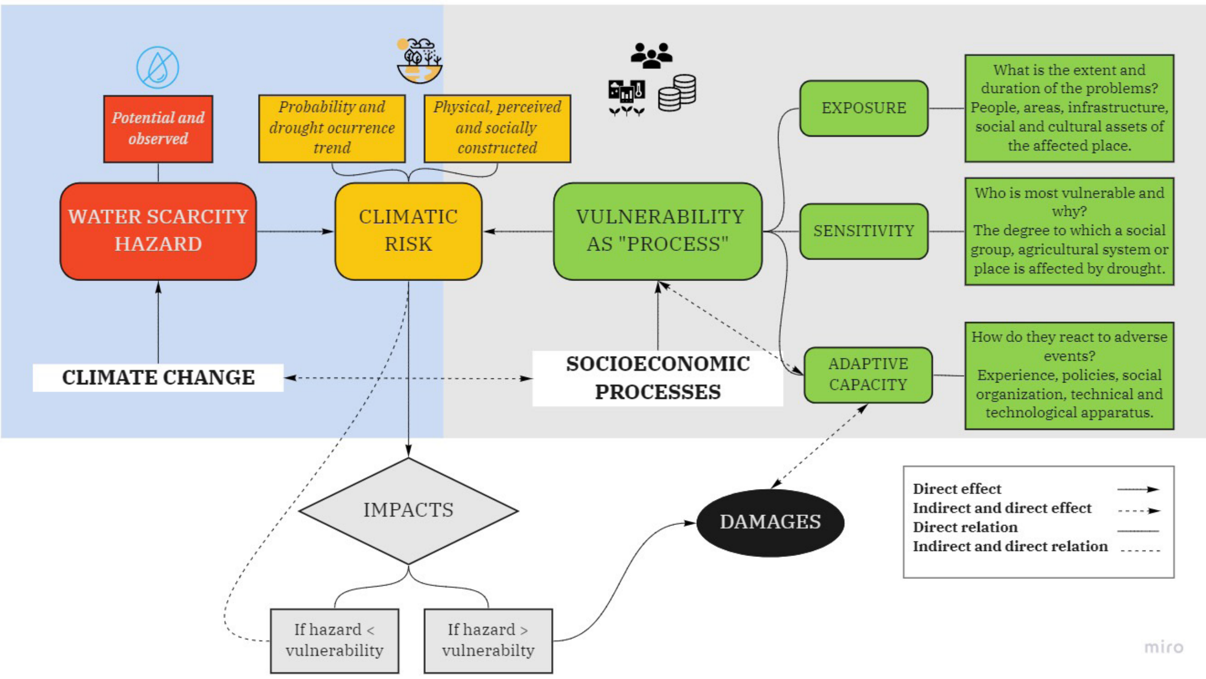
In addition to this introductory section (1), the theoretical overview, concepts and challenges inherent in spatiotemporal and multilevel analyses of vulnerability to drought are described (2); then, research techniques and methodologies that aim to resolve the challenges imposed on the production and collection of data are presented (3); these research results are discussed (4); and considered in the last section (5).

## Drought vulnerability: concepts in space and time

The concept of vulnerability is polysemic and operationalized in a multi and interdisciplinary way. The evolution of the epistemological, ontological and methodological debate, as well as the political implications around vulnerability analyses in the socio-environmental scope is very well documented in previous works (ADGER, 2006; JURGILEVICH *et al.*, 2017; MARANDOLA JUNIOR.; HOGAN, 2005; MILLER *et al.*, 2010). Thus, in this section, the definitions considered in this article for risk, hazard, vulnerability and their determinants (exposure, sensitivity and adaptive capacity) will be presented. Furthermore, some theoretical models for the operationalization of vulnerability analyses that aim to contemplate the multidimensional, multiscale and multilevel aspects are explored.

By taking an analytical approach that proposes to be flexible and heuristic, something quite reasonable in times of "reflexive modernity" (BECK, 2010), to explain hybrid and multifaceted risks, it starts from the assumption of the inextricable interrelationship between environment and society. There is, therefore, an attempt to apprehend structural processes that accentuate inequalities and conditions of access to resources that would potentially reduce conditions of vulnerability. From this intertwining of interactions of biophysical, socioeconomic and experiential factors derives the recognition that the same drought event can cause different impacts depending on the degree of vulnerability of an individual, group or population over months, harvests or years.

**Figure 1**- Proposition of a drought vulnerability analytical framework.




**Source:** Prepared by authors based on IPCC (2014), Iwama et al. (2016), Marandola Jr. & Hogan (2009).

### Climatic risk

Risk is considered here as a hybrid concept embedded in uncertainty. First, as the probability of occurrence of a climatic phenomenon that can be observed, evidenced in time series according to its variability, that has its known physical process and potential damage to the production of agricultural crops, for example, foreseen and measurable, as it is the case of drought events (IWAMA *et al*., 2016; UN-ISDR, 2009).

However, in a socio-environmental context, especially in agricultural systems, the biotic and abiotic properties of the place are overlapped by social, economic and demographic dynamics, permeated by intentions, conflicts of interest and different world views. Thus, it can be considered that risk can also be produced, as a reflection of modernity and technical-scientific advances (BECK, 2010). An example of a contextual adaptation strategy is the irrigation projects in the Brazilian semiarid region, which, while reducing socio-climatic vulnerability to drought periods, accentuate the unequal distribution of risks, reinforcing asymmetries between irrigators and those who are private of the same conditions of access to water resources (ORTEGA; SOBEL, 2010). In this way, risk can be understood as the product of the interaction between the extreme weather event and the conditions of vulnerability (MARANDOLA JUNIOR., 2014).

### Water scarcity hazard

The hazard can be considered the materialization of the risk. Hazard is defined as the potential occurrence, as well as the physical impact of a natural or man-made event capable of causing damage to human lives, ecosystems, cultivation areas and the physical infrastructure of a certain place (IPCC, 2014). In the case of extreme drought events – resulting from the absence of rain for long periods, the physical impact is caused by water scarcity, which can lead to the unfeasibility of agricultural crops and food production, the deterioration of the quality of water for human consumption, as well as its rationing, the drop in individual and family income, and the induction of population migration to regions that offer minimal conditions for human welfare restricted in their place of origin by adverse climatic events and an unfavorable social context (BOURONCLE *et al*., 2017; CORREIA; BARBIERI, 2019; HARVEY *et al*., 2014; MEZE-HAUSKEN, 2000). When the hazard is greater than the vulnerability, damage is generated, and socio-environmental assets necessary for the reaction, adaptation and transformation of a system are mobilized in order to repair them and, in an optimal situation, create mechanisms to prevent potential new damage. On the other hand, when the hazard is less than the vulnerability (which is a function of sensitivity, exposure and adaptive capacity), the damage is null or reduced; however, the risk is not eliminated.

### Socioclimatic vulnerability as a "process"

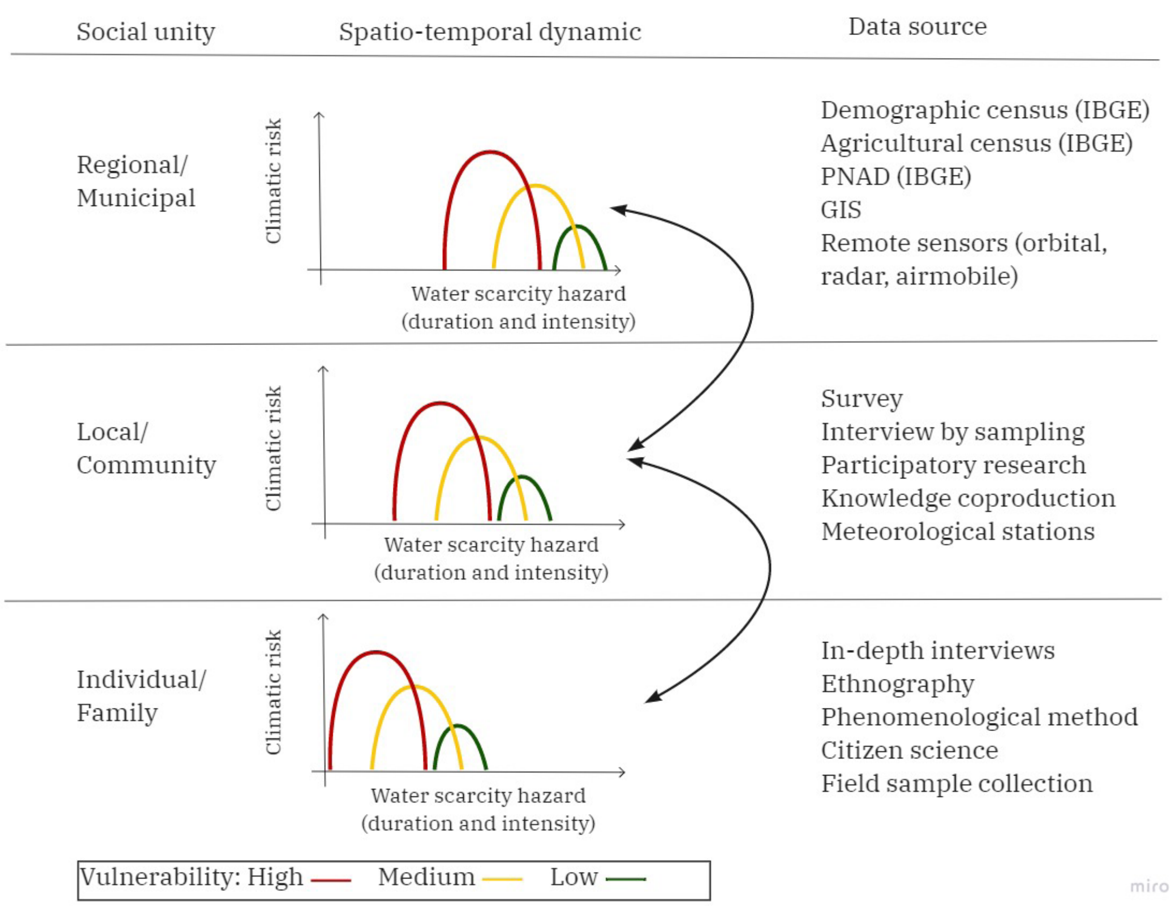
Socioclimatic vulnerability is defined as the set of attributes and resources intrinsic to an individual, location, system or population that can be triggered in situations of materialization or potential occurrence of risks and hazards of a climatic and meteorological nature - droughts, floods, storms (AQUINO *et al*., 2017; CUTTER, 2003; MARANDOLA JUNIOR., 2014). Vulnerability can be operationalized as a function of the magnitude and rate of climate change to which a system is exposed, its sensitivity, and its adaptive capacity (MCCARTHY *et al*., 2001). The distribution of vulnerability over space and over time depends on social and climatic processes that manifest themselves in a heterogeneous and interdependent manner. Therefore, vulnerability is not only the result of the occurrence of a natural phenomenon or the product of a context induced by human action but also a spatiotemporal process imbricated in the feedback dynamic of natural and anthropic effects that can be beneficial or adverse (IWAMA *et al*., 2016).

The analytical framework proposed in Figure 1 lists the three determinants of socioclimatic vulnerability: (i) exposure; (ii) sensitivity; and (iii) adaptive capacity. Exposure to drought corresponds to the extent and probability of a site's infrastructure, areas for agricultural crops and sociocultural assets being affected by this extreme event. (IPCC, 2014; MALLARI; EZRA, 2016). This determinant takes into account technical, socio-economic, land use and physical infrastructure (natural and man-made) variables. Sensitivity, on the other hand, seeks to capture the degree to which an agro-ecosystem or population is affected by the occurrence of droughts (O'BRIEN *et al*., 2004). In the case of climatic risk of drought to agricultural crops, edaphoclimatic (soil and climate), agrometeorological and hydrological variables can operate as sensitivity indicators. Finally, adaptive capacity refers to the factors that determine the ability of a system to adapt to negative externalities, disruptions and adversities (SMIT; WANDEL, 2006). In general, for this determinant, the aim is to assess the socioeconomic level of the region, the local sociopolitical and institutional organization, and the technical (cultivation practices and adoption of technologies) and economic infrastructure (access to agricultural insurance and investment credit) (HARVEY *et al*., 2014; PARKER *et al*., 2019).

### Scales and levels

Vulnerability as a concept and analytical lens is dynamic in its spatial distribution and its variability over time. Actions aimed at reducing vulnerability can vary and be transmitted along different spatial scales and cause short, medium and long-term effects (MENONI *et al*., 2012). Likewise, the types of variables and direct and indirect indicators of vulnerability conditions are different depending on the spatial level analyzed and may even overlap in many moments (DOBKOWITZ *et al*., 2020). However, the driving issue discussed in this article is the "spatial and temporal mismatch" between the climate dynamics over a certain space and for a time inherent to that phenomenon - with increasing potential for damage in a context of climate change - and strategies of risk management adopted by public managers, social groups and individuals in the face of these adverse events (CASH *et al*., 2006).

**Figure 2** - Theoretical models of the spatiotemporal dynamics of climatic risk to drought.




**Source:** Prepared by authors based on Luers et al. (2003), Menoni et al. (2012).

Figure 2 illustrates theoretical models that can help design research that considers the spatiotemporal dynamics of climate risks and their possible impacts. In some cases, extreme events affect a very specific area with a small territorial extension. This is the case of the occasional occurrence of strong winds and storms, for example. This does not mean that the impacts caused are irrelevant; on the contrary, it demonstrates that the lens that analyzes vulnerability as a process facing climate risks needs to be multifocal.

Let's hypothetically think of two regions with similar degrees of vulnerability (institutional and physical infrastructure, social organization and cultural aspects), but one of them tends to be more affected by the hazard of water scarcity. Drought events affect the hydrological cycle at regional and river basin levels; therefore, a large territorial extension is understood. If we apply a "flyover view", the variables analyzed at a higher spatial level may indicate that the impact may not have been significant: at first, rainfall below average did not influence the Gross Domestic Product of that municipality or region and the population migration rate was unchanged, indicating that, on average, the disturbance apparently did not harm the region. At the same time, if we consider that this drought lasted for months, some communities located within the affected region may have taken on water rationing strategies or food exchange counters (MESQUITA; WITTMAN; MOTA, 2016). At an individual level and within the household, the rationing of meals, the search of one of the members of the household for income from non-agricultural activities, attempts to obtain special credit for investment in water collection and storage systems, as well as emergency aid, can be some of the short and medium-term strategies that are generally adopted in these situations (HARVEY *et al*., 2014).

Therefore, from the moment when there is no water in the tap of a house, which can happen in a few weeks, until the worsening of macroeconomic indicators, which can take months, there is a cascade of effects that can be observed quickly and slowly and that feedback. This implies the need to adopt research, monitoring and evaluation methodologies fed by multiple data sources. And, also, data collection techniques that enable the protagonism of localized perspectives, starting from the bottom-up, not only explain what makes them vulnerable but also make it possible to know who is made vulnerable (ERIKSEN *et al*., 2021; HARAWAY, 1995).

## Alternatives for data collection and production

The year 2020 was marked by the unleashing of a global COVID-19 pandemic with devastating effects on thousands of lives. This catastrophic event, given its magnitude and duration, caused scheduled field data collections to be suspended indefinitely (NEDEL OLIVEIRA, 2021). As if that were not enough, the Demographic Census scheduled to take place in 2020 was cancelled. This act will inevitably cause a vacuum of data regarding the evolution of living conditions of the Brazilian population since 2010 - the year of the last census - and, consequently, will make it difficult to carry out analyses and evaluations of public policies and other adopted strategies in the meantime (JORNAL DA USP, 2021).

From an academic point of view, many research designs that prevised interviews and observations of individuals and groups needed to be remodeled, considering the strict sanitary protocols established to prevent the dissemination of the coronavirus. Focus group executions: structured, semi-structured and open interviews as well as the observation of social dynamics in specific groups have been canceled or adapted to a virtual environment through the use of digital tools. Some tools that had already been used were elevated to the position of the main and only means to ensure the progress of research. Interviews started to be conducted through videoconferencing platforms (Zoom, Google Meet, Skype, etc.). Questionnaires were turned into forms that allow sharing and filling out online (Google Forms, SurveyMonkey, LimeSurvey, among others) (HORST; MILLER, 2012), even ethnographic research could be adapted and carried out with certain groups that interact on widely used social networks (Facebook, WhatsApp, Twitter, etc.) (MALINI, 2016; SEGATA; RIFIOTIS, 2016). Alternatives, therefore, exist. However, scientific rigor and attention to ethical implications must be redoubled in their executions (FRANZKE *et al*., 2019).

Nevertheless, some methodological and technical limitations need to be considered. The propensity to generate bias with the use of digital tools to collect data from individuals and populations should not be neglected. The conditions of access to a certain model of mobile device, as well as the degree of familiarity of the respondent with the handling of smartphones, computers and specific applications, and even having access to the internet or not, may restrict the representativeness of the data generated through these techniques.

Although limitations and restrictions exist, the amount of variables that can be explored, as well as the frequency with which they can be generated, constitute an enormous potential for scientific work in the human sciences, especially in spatiotemporal analyses of climate risks, the production of these data can help both in identifying vulnerability factors and immediate socio-climatic impacts, as well as in evaluating climate change adaptation strategies at a local level.

Table 1 presents some studies published in the last seven years (2014-2021) in the thematic areas of risks, vulnerabilities and climate change that used methodologies to collect data that were alternative to the usual field surveys, in which the presence of the researcher as an observer or inductor of questions in loco is essential.

Some studies reported here are not directly linked to drought, climate change or other climate-related risks. However, their methodologies can be adapted to research in these areas and inspire the design of others.

Examples of the application of citizen science, an approach that summons the general public to not only participate but also produce scientific practice, can be seen in Daum, Capezzone, Birner (2021); Salvati *et al.* (2021); and Snik *et al.* (2014). In the first two, apps were developed and made available to researchers, assistants and volunteers who started to record, in an autonomous way, data inherent in the respective research problems of the studies. As reported by Salvati *et al.* (2021), the efforts put into the construction of digital forms and apps are large and time-consuming; however, they are rewarded by the quick way in which data is collected, updated and stored. The spread of geographic data collection points is also highlighted as an advantage, as presented by Snik *et al.* (2014), who share authorship of the study with “3187 citizen scientists” who collected data on aerosols using iSPEX spectropolarimeters attached to their smartphones. The territorial coverage opportunity offered by mobile devices is also taken advantage of in a study on heat islands in the city of Seville, Spain. In this study, a temperature sensor and a GPS were installed on a bicycle, which was able to take temperature measurements along a predetermined path (transect) (ROMERO RODRÍGUEZ *et al.*, 2020). Not only temperature measurements can be collected but also qualitative impressions (landscape description) and observation of pedestrian movement under extreme heat, for example.

A close look can also be given to social media. In two studies referenced in Table 1, the researchers used content analysis and semantic information extraction from publications made on Twitter shortly after the occurrence of disasters – a storm and an earthquake – in order to investigate which regions received more attention in the communication of damage by users of the social network and whether, in any way, this information can be used to qualify the magnitude of such extreme events (RESCH; USLÄNDER; HAVAS, 2018; ZHANG; YANG; MOSTAFAVI, 2021). In two other studies carried out in the South Pacific Islands region, the recruitment of respondents and data collection via text messages (SMS – Short Message Service and USSD – Unstructured Supplementary Service Data) were carried out to investigate the perception of specific groups about natural risks and effects of these risks on population migration (WALSHE *et al.*, 2018; ZANDER; GARNETT, 2020).

In studies with a global and regional focus, the use of GIS (Geographic Information System) technologies, as well as data obtained by remote orbital sensors (satellite) and socioeconomic data available in secondary databases, can be combined to investigate poverty and vulnerability of agricultural crops, for example (JEAN *et al.*, 2016; PARKER *et al.*, 2019).

Finally, an alternative to conducting focus groups can be the gathering of research participants in interactive workshops held on video conferencing platforms. This is the case of Dallo and Marti (2021), who carried out a series of workshops via the Zoom platform with volunteer participants, to evaluate applications developed for smartphones that communicate various natural risks (climate, geological, hydrological).

**Table 1** - Examples of studies that used alternative tools to collect data on risks and vulnerabilities.

| Reference | Risk | Vulnerability of who or what | Tools for data collection | Spatial level / Social Unit | Possible frequency | Data type |
|---|---|---|---|---|---|---|
| **SALVATI et al., 2021** | Geo-hydrological | Buildings and population present in areas prone to flooding and landslides | Smartphones, Open Data Kit, GISCloud, digital survey, volunteer participation | Local | High | Qualitative, quantitative, images |
| **WALSHE et al., 2018** | Climate change | Teachers, media and communities in Pacific | Mobile phones (SMS and USSD), voluntary participation, use of incentives (phone credits) | Local/ Community | Medium | Qualitative, quantitative |
| **ROMERO RODRÍGUEZ et al., 2020** | Heat island | Urban areas | Transect carried out with bicycle with attached sensors, GIS (geographical information system), smartphone | Local/ Community | High | Quantitative |
| **PARKER et al., 2019** | Climate change | Agricultural crops | GIS, secondary socioeconomic data | Global/ Regional | Medium | Quantitative |
| **DALLO; MARTI, 2021** | Natural, multiples | User ratings on apps that report multiple-natural risks | Interactive virtual workshops (Zoom), participant research, knowledge co-production and design thinking | Group | Medium | Qualitative |
| **ZANDER; GARNETT, 2020** | Natural, multiples | Filipino citizens residing in the country and those who have emigrated to Australia | Survey online, MicroWorker (the platform that identifies potential respondents who fit a sample profile) | Regional | Medium | Qualitative, quantitative |
| **DAUM; CAPEZZONE; BIRNER, 2021** | Health | Relationship between agricultural mechanization and farmer welfare in Zambia | Smartphone, App TimeTracker (used to measure an individual's time allocation), participant survey | Individual/ Family | High | Qualitative, quantitative |
| **SNIK et al., 2014** | Climate and health | Air quality monitoring via participatory aerosol mapping | iSPEX spectropolarimeter attached to a smartphone, whose camera acts as a sensor. Volunteers received the tool and generated the data | Regional | High | Quantitative |
| **RESCH; USLÄNDER; HAVAS, 2018** | Earthquake | Population and physical Infrastructure in California, USA | Machine learning (LDA) techniques for extracting semantic information from Twitter combined with GIS | Community/ Regional | High | Qualitative, quantitative |
| **JEAN et al., 2016** | Poverty | Economic situation at sub-national scales of 5 African countries | Combination of GIS with machine learning through neural networks to identify expenses and average wealth of neighborhoods or communities using the intensity of night light as a proxy for economic activity | Community/ Neighborhood | High | Quantitative |
| **ZHANG; YANG; MOSTAFAVI, 2021** | Storms | Neighborhoods and urban districts in the USA | Quantitative and qualitative analysis of the content published by influencers of the social network Twitter after the passage of a hurricane and subsequent correlation of the places mentioned with those most affected | Local/ Regional | High | Qualitative, quantitative |

**Note:** A complete list of tools for collecting and producing data related to drought and climate change can be found in Enenkel et al. 2020.

## Discussion

The methodologies and techniques for data collection explored by the studies reviewed in this article do not announce totally disruptive approaches. However, they sought to creatively integrate mixed tools into their research designs, overcoming limitations imposed for various reasons. The only study that reported having adapted their research to the virtual environment due to the COVID-19 pandemic was that by Dallo and Marti (2021), who chose to conduct their design thinking workshops with focus groups through videoconferencing. All other studies were conducted prior to the pandemic period, yet they resorted to alternative techniques for data collection as they envision saving time, money and personnel - notable aspects, especially if we consider the pauperization of funding for research and investments in science and technology in Brazil. Furthermore, the possibility of extensive geographic coverage, combined with a higher frequency of data updating, also favored the researchers' methodological choices. As an example, the United Nations World Food Program surveys conducted using mobile devices were cheaper (3-9 US$/point researched) than surveys that were, until then, applied in a conventional way (20- 40 US$/point researched) (ENENKEL *et al.*, 2020). Likewise, the opportunity generated by the fact that each citizen carries with them an instrument capable of collecting different data, whether using smartphones or driving a vehicle with embedded technology for the transmission of information, can improve climate models and weather forecasting systems existing (BAUER; THORPE; BRUNET, 2015; MAHONEY; O'SULLIVAN, 2013). It is true that many times, these data are of low accuracy, but a large amount of data forms networks with high information density, which can be exploited by appropriate techniques of machine learning and artificial intelligence.

In addition to quantitative variables such as temperature, humidity, date and time, and geographic coordinates, the possibility of textual and audiovisual recordings can complement and enrich the analytical approaches commonly used in drought vulnerability studies, allowing the collection of qualitative data produced by participants on weather conditions on a particular day or crucial agricultural period (rainy, cloudy or dry at the time of planting, growing or harvesting). Likewise, the fluctuation of food purchase and sale prices can be monitored in a more frequent and localized way. Nevertheless, the dynamics of interpersonal relationships in times of crisis and the mobilization of individual and collective assets in the face of adverse events can be better understood through data informed by the participant, guided by guidelines suggested by the researcher.

As noted in the previous section, despite the potential of digital tools to generate a large amount of data, there is a tendency for analytical bias if the limitations and restrictions imposed by the use of these research technologies are not considered. In the study on the perception of natural risks conducted by Walshe *et al.* (2018), the authors emphasize the positional aspect between researcher and participant that also exists in data collection via mobile phones. The fact that the data correspond to a sample involved in a specific context and with particular conditions of access and ability to use digital research tools indicates that the results generated cannot be extrapolated to a population. However, they provide an almost immediate record of the on-site observation of trends relating to a phenomenon. And this can be taken as a favorable point in spatiotemporal analyzes of vulnerability to drought, acting in a complementary and comprehensive way to analyses based on data corresponding to a regional and even global level.

PNAD data from 2019 reveal that 55.6% of households located in rural areas in Brazil are connected to the internet; in the urban area, 86.7% of households are connected to the internet. The mobile phone is the main tool used for connection, being present in 99.5% of households with internet access (MCOM, 2021). Therefore, there is considerable potential for the production and collection of data obtained by remote tools, both those aimed at the observation of biophysical variables and those focused on the human dimension of drought and climate change.

## Final considerations

This article aimed to explore methodologies and techniques for the production and collection of socio-environmental data related to three (among many) current challenges: (i) the synchronization of socio-climatic impacts in spatiotemporal analyses of vulnerability to drought; (ii) the absence of open and updated data due to the budgetary tightening for carrying out census surveys and financing for science; and (iii) the impediment and postponement of conducting field research caused by the COVID-19 global pandemic.

Although the methodologies applied in the reviewed studies have limitations in relation to the sample representativeness of the results and a large amount of time spent in research design and construction of forms, applications and databases. Overall, the authors report that these constrictors are offset by the speed and high frequency with which data can be collected, updated, and organized into databases that allow for near real-time preliminary analysis. This point is essential and promising for analysis at the local level on observed and perceived impacts, and also for monitoring the trend of occurrence of drought events and evaluating strategies to adapt to these events.

Nevertheless, the inclusion of the participant in the co-production of knowledge and scientific practice allows for a constant reassessment of the theoretical-methodological framework used, integrating a comprehensive perspective of the phenomenon with analytical models commonly explained by biotic and abiotic variables. In any case, the ethical implications must also be considered in research that opts for data collection techniques based on digital tools.

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