Integration of constraints linked to water availability, accessibility and demand in spatial foodshed models. Existing methodological approaches. A systematic literature review

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Short abstract (200 words):

Numerous foodshed models were developed to estimate and map the agricultural areas needed to supply cities with food. They generally allocate crops as a function of distance from built-up areas, land use derived from geo-interpretation and estimates of food requirements based on average diets. We hypothesize however that, in areas with limited water resources, water is another factor influencing the spatial distribution of crops, food production levels and therefore the spatial characteristics of foodsheds. In view of developing a foodshed model integrating constraints linked to water availability and accessibility, we first performed a systematic literature review to explore the state of the art of the existing methodological approaches to model foodsheds. The first results of our review highlight that articles explicitly referring to water as a factor of the model are rare, and that completeness and spatial accuracy of the implemented data do not allow realistic descriptions or simulations of the effects of climate change and water deficit on the characteristics of local foodsheds. Despite these shortcomings, the review highlights modelling strategies allowing the integration of the water factor and thus enabling a better adaptation of agriculture to biophysical conditions at territorial level in the future.

[1] Please rename the file with the last name of first author, a keyword and conference topic

Extended Abstract for the 15th IFSA conference

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1. Purpose

Nowadays arable lands cover one third of the earth's surface in order to answer food demand. The development of technology has resulted in an increase in production, but at the same time has caused some harmful effects on the environment, such as the increase in the concentration of greenhouse gases in the atmosphere (Fitton et al., 2019). Closing crop yield gaps has been proposed as a means of relieving pressure on food production systems, but the actual benefits of these strategies depend on environments with non-resource-limited resources, especially in regards to water availability (Fitton et al., 2019). Among the possible options to cope with the climate and environmental crisis, the prospect of regional and local food systems has gained popularity (Kaufmann et al., 2022). The foodshed approach is also progressively utilised to examine the spatial localisation of urban food supply and especially to depict the linkages between producting and consuming regions (Schreiber et al, 2021). Closed nutrient flows, closer relationships between consumers and producers, healthier diets, and a small carbon footprint due to shorter transport distances are all valuable attributes of regional food systems.

Globally, cropland irrigation accounts for 70% of water withdrawals, making agriculture the largest water consumer. Cropland and pasture productivity can be negatively impacted by declining water availability and increasing water scarcity, even though 95% of agricultural land is primarily irrigated with rainwater. Africa and the Middle East, China, Europe and Asia are at a higher risk (Fitton et al., 2019). In Europe, one of the main effects of climate change will be a decrease in the amount of water available for irrigation in all areas. Future precipitation patterns and their temporal allocation, as well as the frequency of extreme weather events, are two factors that are very important for agriculture (Iglesias and Garrote, 2015). Primary effects of altered water resources on agricultural output are as follows: (i) higher water demand in all areas throughout the year due to rising temperatures and consequential higher crop evapotranspiration; (ii) more frequent water shortages, especially during the spring and summer, raising the amount of water needed for irrigation, especially in areas already experiencing water stress; (iii) lower water quality as a result of rising water temperatures and decreased runoff in some areas, especially during the summer, adding stress on irrigated areas; (iv) the expected concentration of winter rainfall will increase the risk of flooding. (v) unless measures are taken to protect vulnerable land, projected increases in sea levels will have an impact on agricultural production in low-lying coastal areas (Iglesias and Garrote, 2015).

Worldwide, the demand for food will probably double by 2050 (Dinar et al., 2019). This will be due to the increase in world population and incomes, raising the question of whether the resources currently available will be able to meet this demand for food. In particular, the question concerns how land and water resources will be managed, as well as whether agricultural practices, technological advances and trade agreements will be adequate (Dinar et al., 2019). In this context, understanding the relationship between local food production and water is crucial. The purpose of this communication is to present the state of the art of existing methodological approaches that could be used (under some conditions and with some modifications) to address the constraints linked to water availability and accessibility into the spatial modelling of foodsheds.

2. Design/Methodology/Approach

We have designed a systematic literature review to analyse papers examining foodshed modelling, both those who already explicitly integrate water as a factor of the model, and those who do not consider it. The research question wants to find out the existing methodological approaches that could be used, under some conditions and with some modifications, to address the constraints linked to water availability and accessibility into the modelling of foodsheds (Table 1).

Table 1

DETAIL OF THE RESEARCH QUESTION AND THE ELIGIBILITY CRITERIA AS FUNCTION OF THE PICOS COMPONENTS	
Population	• Foodsheds modelled worldwide are considered • All foodshed and local food system models with a territorial, regional and landscape spatial extent • Models with a national or global spatial extent are considered only if they are developed on support units at territorial level • Only studies focused on food production will be considered ;
Intervention	Water considered as a factor of the models Foodshed models, both those that address the issue of water and those that do not: • Spatial allocation models for agricultural land use ; • Flows and environmental impact models (e.g. water and carbon footprint); • Hybrid models
Comparison	Foodshed models that do not explicitly implement water
Outcome	All types of results are considered
Study type	Primary and peer reviewed articles
	(From Methley et al., 2014)

The PICOS protocol (Methley et al., 2014) guided the literature query we developed. It relied on the combination of foodsheds and models keywords. We applied it to two databases: Web of Science and Scopus. Since foodsheds are defined by the geographic areas (Schreiber, 2021), we considered articles dealing with models at territorial, regional and landscape level but not those focused on plot or farm levels.

We also excluded articles without operational modelling outcomes. Finally, we focused our study on primary and peer reviewed articles, excluding review protocols and proceeding papers.

Once duplicates have been eliminated, we screened all identified articles on the basis of titles and abstracts and according to the eligibility criteria listed in Table 1 via the Rayyan® systematic review tool (Ouzzani et al., 2016). This selection of articles involved at least two authors and diverging opinions on whether or not a paper should be included in the corpus were solved by a discussion between all authors. Afterwards, in the second screening stage, papers deemed suitable by the first screening phase have been checked by reading the full text. The eligibility criteria remain those used during the first stage, but we also excluded articles with: (i) No origin of the full text; (ii) Full text not accessible.

Further, we analysed the resulting corpus of articles to highlight the different modelling approaches and the possible ways to integrate constraints linked to water availability, accessibility and demand in spatial foodshed models. The analytical grid covers the following fields: context, aims, data sources, calculation method, spatial representation, temporal changes, limits, advantages as well as water dimensions (access, availability and demand).

3. First findings

Based on eligibility criteria, 51 scientific articles were identified during the screening phases. A first overview of this corpus allowed us to identify different criteria of analysis, reported and detailed in Figure 1. The first criterion corresponds to the modelling objective, with five modalities: (i) to estimate the degree of local food self-sufficiency; (ii) to determine the spatial foodshed extent; (iii) to evaluate the local water availability for food production; (iv) to evaluate the water footprint; (v) to evaluate other environmental footprints. The second criterion describes the model according to its type, the implementation of geographic information system (GIS) and the represented process (Figure 1). The third one deals with the foodsheds being the object of the modelling (pluviometric area, geographic area, spatial extent, support units, type of farm and farming system considered). The fourth describes the databases used. The last criterion is the determination of the ways in which the models can be used, that is the description, the simulation or the scenarization of a local food system (Figure 1).

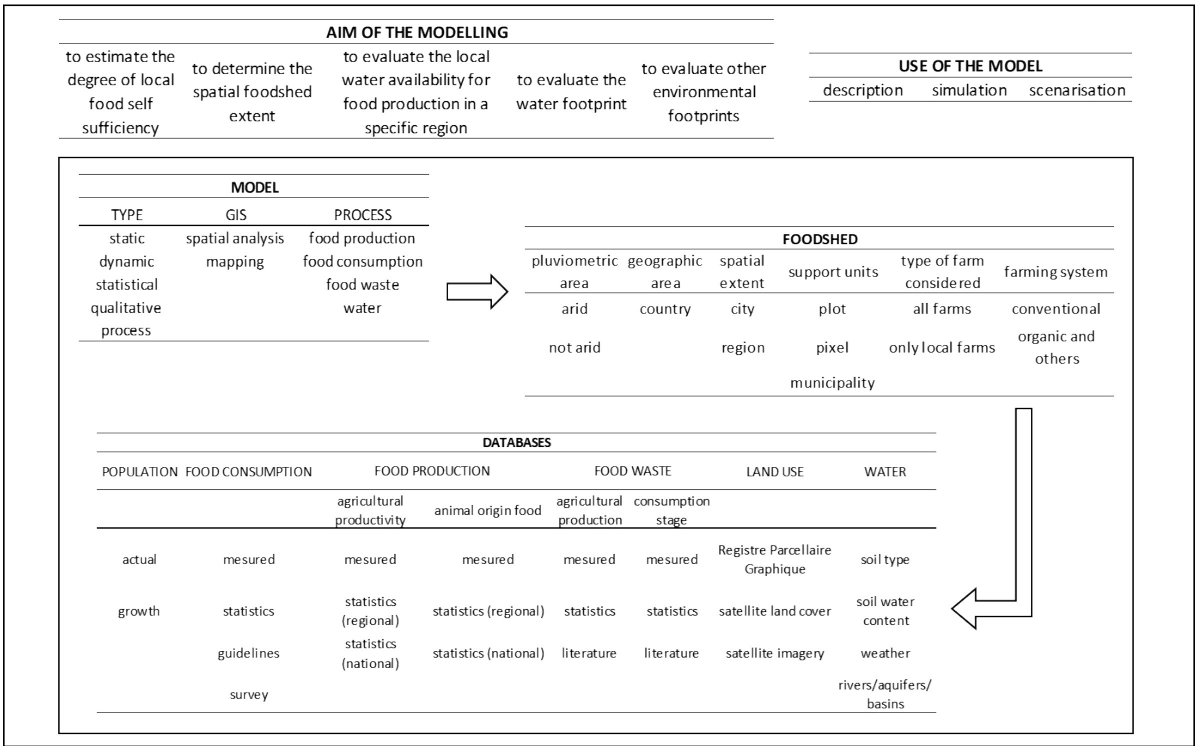

Figure 1. Diagram showing the aims of the modelling, the uses of the models, the types of models, the constituent elements of the modelled foodshed and the various databases used.

The articles of our corpus cover all modelling objectives, including local food self-sufficiency models, agricultural land allocation models, water availability for food production models and environmental footprint of food production models, but here we present only some preliminary and partial results.

We highlight firstly that most articles (40 out of 51) do not make explicit reference to the water resource as a factor of the foodshed model. Among these, some investigate the degree of regional self-sufficiency of arable crops derivatives, livestock products and primary agricultural biomass comparing the food demand of a population with local production levels (Kaufmann et al., 2022), but without considering the water factor as a limiting element of the production stage. Other papers try to determine how much farmland, considered as a spatial extent, is needed to feed a city and its surrounding area, and if that area could produce enough food on its own. In order to do this, specific conditions of each region are considered, but also future scenario alternatives, various food waste levels as well as demographic variations (Zasada et al., 2019). More recent models add other factors to the previous ones, such as some data about crop rotations, soil characteristics and topography (Vicente-Vicente et al., 2021). These studies do not make explicit reference to the endowment of water resources in the territory.

The studies of the corpus that explicitly refer to the water issue (11 out of 51) can be classified according to the type and spatial resolution of the mobilised data, which

corresponds also to different aims of the modelling First, we identified studies that implement climate and soil type databases available on a global scale in order to determine the food security of the world's major metropolises (e.g. Hennen et al., 2018). A second group of studies refers to tabular data estimated by state or region in order to calculate the water footprint of agri-food production (Boyer and Ramaswami, 2020). The third group of studies introduces a larger number of variables at the regional or sub-regional level (weather conditions, soil characteristics, irrigated or non-irrigated status of arable land) and aims to determine the regional food self-sufficiency. More specifically, these studies aim to obtain a GIS model of biophysical suitability of arable lands (e.g. Saavedra Cardoso et al., 2017), or to appreciate the direct impact of scenarios with limited water availability on crop yields (e.g. Resop et al., 2014) or different crop spatial distribution depending on irrigation water demand (Hou et al., 2023). Finally, a last group includes studies using data of freshwater withdrawals from surface and groundwater resources at the regional level with the purpose of determining the impact of local food production on land and water consumption or food wastage reduction on irrigation water consumption (Liao et al., 2023).

4. Practical Implications

Although the scientific literature currently shows shortcomings when it comes to taking water into account in foodshed modeling, it nevertheless provides formalisms that will enable such models to be developed. By taking water-related constraints into account, foodshed models will make it possible to quantify the minimum quantities of irrigation water required for local food production to meet the nutritional and caloric needs of a given population, or to assess the impact of drought episodes on local food production.

This knowledge will raise awareness at local level of how water availability affects agricultural production for local food supply and, consequently, it will enable the agricultural sector to better adapt to biophysical conditions at territorial level.

5. Theoretical Implications

Including water considerations into the ways of studying or representing foodsheds have theoretical implications in the various disciplines involved. In geography, the spatial allocation of the water resource will have to be accounted for when shaping the food basins in addition to the social processes of transition, the actors, the arrangements involved and the underlying values. While agronomy will provide insights about local growing conditions and yields, it will have to account for local food demand in the territorial design of cropping patterns with possible inclusion of innovative cropping systems. In water science, further efforts may be required on how and where to implement water storage systems and on how to optimise water resource management at territorial level. In the field of logistics, food flows could change, possibly accentuating the difference between arid and non-arid geographical areas and hence importing or exporting regions. In economy, productive and commercial strategies could need many innovations to adapt to new agri-food systems.

Our research brings food to governments and actors in charge of adapting policies and tools to reach long-term sustainability goals, led by shared socio-cultural, political and/or economic visions and objectives.

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