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Determinants of Food Consumption Water Footprint in the MENA Region: The Case of Tunisia

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Abstract: Tunisia, like most countries in the Middle East and North Africa (MENA) region, has limited renewable water resources and is classified as a water stress country. The effects of climate change are exacerbating the situation. The agricultural sector is the main consumer (80%) of blue water reserves. In this study, to better understand the factors that influence the food water footprint of Tunisian consumers, we used a multiple linear regression model (MLR) to analyze data from 4853 households. The innovation in this paper consists of integrating effects of socio-economic, demographic, and geographic trends on the food consumption water footprint into the assessment of water and food security. The model results showed that regional variations in food choices meant large differences in water footprints, as hypothesized. Residents of big cities are more likely to have a large water footprint. Significant variability in water footprints, due to different food consumption patterns and socio-demographic characteristics, was also noted. Food waste is also one of the determining factors of households with a high water footprint. This study provides a new perspective on the water footprint of food consumption using "household" level data. These dietary water footprint estimates can be used to assess potential water demand scenarios as food consumption patterns change. Analysis at the geographic and socio-demographic levels helps to inform policy makers by identifying realistic dietary changes.

Keywords: consumer behavior; food water footprint; modeling; sustainability; Tunisia

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1. Introduction

1.1. Water Supply in Tunisia

In the Middle East and North Africa (MENA) and particularly in Tunisia, the limits of water resource use are being reached due to economic development, population growth (expected increase in population of 20% between 2010 and 2050), and water demands associated with new lifestyles [1]. Unsustainable use has led to deterioration of resources and increasing water scarcity.

According to the World Health Organization (WHO), water stress begins when water availability per capita/year is less than 1700 m^3. When availability is less than 1000 m^3/inhabitant/year, there is a water shortage in the country. Below 500 m^3/inhabitant/year, water becomes a constraint on development. Tunisia is now in the latter case of maximal water stress. With population growth, the situation is becoming more and more critical [2].

In addition, the MENA region is greatly affected by climate change, i.e., decreasing rainfall and increasing temperatures [3]. In this region, with the largest water deficit in the world, demands for water have exceeded the local capacity to be self-sufficient in food production. In Tunisia, political and socio-economic changes have contributed to the overexploitation of natural resources, leading to pollution and degradation of the environment, rural exodus, increasing poverty, and deteriorating health, as well as greater food insecurity of the most vulnerable groups. Food security is currently an important challenge for public policies whose main development objectives are reducing poverty and eliminating hunger. This can only be achieved when each person has, at any time, physical and economic access to a sufficient, healthy, and balanced diet [4]. However, food security is not static. In many cases there are normal fluctuations in terms of availability, access, and use, e.g., due to changes in weather or prices. Nevertheless, it is very important to examine the available production factors in the short, medium and long term to be able to assess a country's food security trends.

Water is one of the most important resources to examine. Water's role in food security is specified by its effects on food production, access to food, stability of supply, health, and nutrition [4]. Countries with higher water resources generally have higher levels of food security [4]. The water scarcity in Tunisia affects both the availability and access to food products, since it directly affects local production. The theoretical foundations and general principles linking the concept of food security to water resources indicate that all the axes of food security as defined by the FAO, namely, availability, access, stability, and even use are linked to water scarcity [5].

Even if the total demand for food grows slowly worldwide, meeting this demand will require a 70% increase in production by the year 2050 [6]. This seems inconceivable given worrying signs of the degradation of natural resources, especially water, and the lack of investment in the maintenance and sustainable use of these resources.

In Tunisia, water supply policies were initially based on intense mobilization of water resources (construction of dams, hill lakes, wells, irrigated perimeters, etc.). These post-independence policies have been insufficient to solve the problems of lack of water resources in some regions. Another solution was the exploitation of unconventional resources such as seawater desalination and wastewater recycling. However, the use of these resources has remained limited and expensive [7]. Subsequently, new strategies based on water demand management were developed. Indeed, this was necessary to rationalize water use and to maximize its productivity. Water demand management is currently a priority of the sustainable development strategy adopted in 2005 by all the countries bordering the Mediterranean. This strategy aims to stabilize demand by mitigating losses and inefficient uses and increasing the added value created by each cubic meter of water used [8]. According to the World Bank [9], in Tunisia, the effectiveness of water use at the farm level has improved from 50% to 75% between 1996 and 2006, which represents a very encouraging result according to global standards. Despite this increase in the efficiency of water resource management and the relative improvement in productivity, the demand for these resources continues to grow. Thus, the management of water demand needs to incorporate not only agricultural production but also the role of consumption. Optimizing the use of water requires involving consumers who play an important role during the final stage of water utilization.

1.2. Water Footprint of Food Consumption

A new concept to examine this issue, the water footprint, was developed by Hoekstra [10]. It measures the direct and indirect use of water by consumers or producers. In particular, it highlights the pressures exerted globally or locally on water resources. According to Lacirignola et al. [11], diets have an impact on agriculture, the environment, and the interacting economy. Many studies have mentioned the impact of diets and consumer habits on the evolution of the water footprint at the international or national/regional levels and the role this concept could play in overcoming problems of water management in several countries [12–18]. The water footprint of food consumption represents more than 86% of the total water footprint [19]. According to Mekonnen and Hoekstra [19], the Tunisian national water footprint surpasses 2226 m^3/capita/year. It is higher than the annual per capita water footprints in other North African countries, estimated at 2044 m^3 in Libya, 1715 m^3 in Morocco, and 1606 m^3 in Algeria. In Tunisia, the average water footprint for the main food categories has increased by 31% during the last decades, from 1208 m^3/capita/year in 1985 to 1586 m^3/capita/year in 2010 [18]. Despite the decline in cereal consumption, the water footprint has continued to increase as a result of increased consumption of animal products. This growth is associated with regional variations in food choices that imply differences in water footprints [20]. Despite the fact that the Mediterranean diet has a lower average water footprint than other diets [21], and that the Tunisian diet is still considered Mediterranean, the water footprint of food consumption is very high compared to the other Mediterranean countries, except Italy and Spain [19].

This leads to our main research questions: what are the main factors that influence the food consumption water footprint of Tunisian households and how to reduce this water footprint? The paper uses a multiple regression model to estimate the relationships between the main relevant variables related to consumption habits, demographic, geographic and socio-economic characteristics of Tunisian households that may affect the water footprint of food consumption. The assessment of the water footprint and the model results may show ways to reduce the food consumption water footprint and can be used to assess potential water demand scenarios as food consumption patterns change in order to reduce impacts on food and water security. Analysis at the geographic and socio-demographic levels helps to inform policy makers by identifying realistic dietary changes, taking into account social and regional disparities to effectively plan interventions and recommendations for a sustainable diet using the existing nutrition programs.

The novel contributions of this work are three-fold. First, building on the analysis of Souissi et al., (2019) [18] we use the household level data to examine factors that affect the water footprint. Secondly, to our knowledge, few studies focusing on the management of water resources in Tunisia have taken into account the water footprint of food consumption. The study of Chouchane et al. [22] who assessed the economic productivity of irrigation water by analyzing the production water footprint of some foodstuffs, is one of the rare works that evokes the concept of the water footprint in Tunisia. A final innovation is integrating socio-economic trends related to food into the assessment of water and food security.

The existing literature includes a number of studies on environmental degradation and agriculture [23–25], but very little on the direct link between food consumption and water resource degradation. At the national level, studies linking the consumption of food products and the management of water resources are rare. To understand this problem that threatens food security, especially in countries facing water scarcity, we have chosen to study this link through the case of Tunisia.

The water footprint of food consumption generally exceeds 90% of a consumer's total water footprint. Using this tool to assess food security in a region, in a country or even at a global scale can be very useful [16,26]. It also helps measure the impact of consumption patterns and food preferences on natural resources. By considering the water footprint of food consumption across the country, we aim to shed light on the relevant variables related to consumption habits and their impacts on food and water security. Indeed, several authors underlined the effect of demographic, socio-economic and geographic variables such as the degree of urbanization, income and poverty on the diet [27,28]. The consumption of dairy products is higher in urban areas (Tunis and central East), where households generally have better standards of living and better access to animal products and processed products [29]. On the other hand, households residing in the northwest and in the centre-west, where the poverty rates are the highest, have the highest tendency to consume cereals [30,31]. In turn, Dehibi and Khaldi [32] underlined the diversification of the consumption of processed animal products and also pointed out the importance of being able to differentiate the behavior of the Tunisian consumer according to socio-demographic characteristics. Recent studies in China analyzed the effect of factors such as region, income, and food waste on the water footprint [33,34].

2. Materials and Methods

2.1. Data

The food consumption data used in this study come from the national consumption survey carried out by the National Institute of Statistics [30]. This survey follows an approach based on the direct measurements of consumed food quantities. At the household level, measurements are made by participatory observation. Direct measurements are carried out through weighing surveys during seven full days that are not successive. A systematic weighing of food is performed for the entire selected sample. The data relating to the number of people for whom these foods are intended are also recorded [31].

This type of measure is repeated several times a year to take into account seasonal variations in consumption. This method provides a set of detailed quantitative data on the structure of food consumption of different socio-economic, cultural, and geographical groups. It is possible to determine the relationships between household characteristics and food consumption. By assessing energy and nutrient intakes, it is also possible to use this type of data to identify nutritional problems in a given population [35].

The term household is less restrictive than family unit, since it designates all the occupants of the same house (one person or more) without these people necessarily being relatives. The household represents a relatively stable and homogeneous structure, which makes it relevant for decision makers [36,37].

2.2. Water Footprint Estimation

The water footprint (WFP) of a group of consumers can be expressed in terms of water volume per unit of time per capita. For food products, to assess the water footprint we need to consider the process of growing the crop or tree. The total WFP of the process of growing crops or trees is the sum of the green, blue, and grey components. The green (rainwater) and blue (surface and groundwater) components in crop water use are calculated by accumulating the daily evapotranspiration over the total growing period. The grey water part represents the theoretical volume of water required to dilute all the pollutants released during the production in order to achieve a water quality standard [26]. To assess the water footprint of food products of animal origin consumption, we resorted to the water footprint network database, which takes account of the blue, green, and grey water footprint of animal origin products.

The assessment of the consumer's water footprint is based on the methodology developed by the water footprint network described in the water footprint assessment manuals [26,38]. The process begins with an inventory of water requirements for each stage of the product production and processing. The water footprint of a "process step" forms the basis of all water footprint inventories. The water footprint of a good is the aggregate of the water footprints of the various relevant stages in the production of that good. A consumer's water footprint is the sum of the water footprints of the different consumed products. The water footprint of a group of consumers can be expressed in terms of the volume of water per unit of time per capita.

As previously mentioned, to assess the water footprint of the main groups of food products in the different regions of Tunisia, we used food and nutrition survey data published in 2015 as well as the database developed by Mekkonen and Hoekstra [19,39] on the water footprint of crop production as described in detail in [18]. Concerning food products of animal origin, the water footprint includes both the water footprint of feedstuffs and the water directly used for breeding animals and for processing dairy and meat products. A database, grouping the majority of the water footprints of animal products is also available on the Water Footprint Network website [19,39]. However, it is important to note that one of the limits of this work, which affects the precision of the estimates, is the absence of data on the water footprint of fish and seafood, an important component of the Tunisian diet. For more details about determination of the main food products and the water footprint assessment method used, we refer readers to Souissi et al. [18], which presents these steps in detail.

The water footprint may depend on the specific characteristics of a household that usually influence food consumption patterns. The INS survey also includes data on households' socio-economic and demographic characteristics such as region, family size, income, etc. As we noted previously, according to the literature such characteristics influence diets within households [27–29]. The characteristics of the households in the sample are presented in Table 1. The sample includes both urban and rural populations from all regions of the country. We note that more than 62% of the sample live in urban areas. There are eight different income categories, ranging from less than TND 500 to more than TND 4500 (exchange rate during the year of data collection: 1 USD = 1.44 TND). The most common category of employment is laborer. The most common household size is 5–6 members. About 14% of the respondents are classified as poor. The poverty line is estimated using the methodology of the World Bank. The monetary approach is used to determine this poverty line (or minimum income), which will be considered as the absolute poverty standard. The population categories with a level of income below this threshold have a high risk of living in conditions of absolute poverty. This method is based on the assessment of the cost necessary to meet the minimum calorie requirement of a low-income segment of the population. This is the category of the population living with a per capita income hovering around the 20th percentile of household spending. The 20th percentile is the level of per capita income below which the poorest 20% of the population live. The head of household is typically a married man. About 29% of the respondents were illiterate.

2.3. Modeling of the Determinants of the Food Consumption Water Footprint of Tunisian Households

Multiple linear regression (MLR) is used to quantify the relationship between several independent variables and a dependent variable. We also created a multinomial logit model by converting the dependent variable Y into three food water footprint classes; however, to keep Y as a continuous variable, we finally opted for a semi log multiple regression model. This method has been successfully used by different authors to establish a statistical model [40–42]. In this study, the MLR method provides an equation linking the dependent variable Y_i (food consumption water footprint) to the independent variables Xi using the following form:

$$Yi = \beta_0 + \beta_1 X_{i1} + \cdots + \beta_n X_{in} + \varepsilon_i \quad (1)$$

The intercept (β_0) and the regression coefficients of variables (β_i) are determined by the least square method [41]. X_i variables are used to explain the water footprint of food consumption, (n) is the number of households in the sample, and ε is the error of estimation in the statistical regression model. The best equation is selected while being based on the highest (R^2), lowest standard deviation (SD), and F-ratio value. The MLR modeling method was performed using STATA software.

The original dependent variable was Yi = "food consumption water footprint". To get around the problems of the large values and highly skewed dependent variable, we used the log-transformation of the dependent variable. Specifically, we used a semi-log model applying the natural log of Y (ln Y). Logarithmically transforming variables in a regression model is useful where a non-linear relationship exists between the independent and dependent variables [43]. Using the logarithm of one or more variables makes the effective relationship non-linear, while still preserving the linear model. Such transformation is also a convenient means of transforming a highly skewed variable distribution into one that is normally distributed.

Table 1. Characteristics of the household sample (n = 4854).

Variables	Variable Name	Percentage (%)
Demographic variables		
Size of Household	Size	
1 to 2 persons		13.9
3 to 4 persons		37.6
5 to 6 persons		36.4
7 to 8 persons		9.8
+8 persons		2.3
Geographic variables		
Area of residence	Area	
Municipal		62.7
Non-municipal		37.3
Geographic stratum	City size	
Big cities		23.6
Small and medium cities		76.4
Region	Region	
Tunis		16.7
North-east		13.3
North-west		14.8
Centre-east		18
Centre-west		16.5
South-east		11.2
South-west		9.5
Socio-economic variables		
Poverty	Poverty	
No		86
Yes		14
Level of education of the household head	Education	
Illiterate		29.3
Primary		41.9
Secondary		23.6
University		5.2
Socio-professional category of household head	SPC	
Freelance		7.3
Employee		7.4
Independent industry/trade		9.9
Farmer		9.9
Laborer		31.1
Retired		15.3
Inactive and others		19.1
Gender of the household head	Gender	
Male		84.5
Female		15.5
Marital status of the household head	Status	
Unspecified		0.1
Single		1.7
Married		85.6
Widowed		11.4
Divorced		1.2
Expenditure range (TND/month)	Expenditure	
≤500		1.9
From 500 to 750		4.4
From 750 to 1000		7.1
From 1000 to 1500		18.5
From 1500 to 2000		17.6
From 2000 to 3000		23.6
From 3000 to 4500		15.8
≥4500		11.1

Source: Own calculations from [30].

In a first step, all the variables correlated with the dependent variable were introduced into the model. Then, for the next iterations, the non-significant variables with the highest *p*-values were eliminated one by one until the best model is obtained. To choose the optimal set of independent variables we used a backward selection, based on the Akaike's Information Criterion (AIC) [44] and Bayesian Information Criterion (BIC) (Appendix A). The Breusch–Pagan/Cook–Weisberg test indicated a problem of heteroscedasticity. Specifying the robust variance-covariance estimator (VCE robust) option is equivalent to requesting White-corrected standard errors in the presence of heteroscedasticity (Appendix B). Using the variance inflation factor (VIF) test we concluded that the selected independent variables in the final model do not present a problem of multicollinearity (Appendix C).

The independent variables correspond to the geographic, socio-economic, and demographic characteristics of the households. The variables used in the final model are summarized in Table 2.

Table 2. Variables used in the multiple linear regression model.

Variable Name	Description	Type	Modality
Dependent variable			
Ln WFP	Natural log of household food water footprint	Continuous	
Independent variables			
Demographic variables			
Size of household	Number of persons in the household	Continuous	
Age	Age of head of household (years)	Continuous	
Geographic variables			
City size	Geographic stratum	Discrete	1 Big city * 2 Medium and small city
Region	Region	Discrete	1 Tunis * 2 Northeast 3 Northwest 4 Centre-east 5 Centre-west 6 Southeast 7 Southwest
Socio-economic variables			
Poverty	Poor household	Discrete	0 No * 1 Yes
Education	Education level of the head of household	Discrete	1 Illiterate 2 Primary * 3 Secondary 4 University
SPC	Socio-professional category of the head of the household	Discrete	1 Freelance 2 Employee 3 Independent industry/trade 4 Farmer 5 Laborer * 6 Retired 7 Inactive and others
	Variables related to food consumption		
Expenditure	Food expenditure per capita and per year (TD/capita/year)	Continuous	
Waste	Number of dishes thrown away per household/year	Continuous	

* The reference level for categorical variables is selected according to the modality with the greatest number of observations.

In order to identify the healthiest and most sustainable diets at the same time, several studies are starting to look at the quantification of the dietary water footprint [18,45,46].

However, only a few recent studies in China and Spain incorporated regional, income and food wastage effects in household consumption water footprint [33,34,47].

3. Results and Discussion

The descriptors and the regression coefficients of the model are presented in Table 3. Together, the independent variables are statistically significant in estimating the water footprint ($p < 0.00$). According to the R squared statistic, 43% of the total variation of WFP is explained by the model. The model was also checked for multicollinearity as mentioned above. The variance inflation factor (VIF) value obtained was close to one and, thus, there was no evidence of multicollinearity [48]. To evaluate the relative importance of the independent variables, it is common to calculate the beta coefficients (standardized regression coefficients). In a regression of standardized variables, the (beta) coefficient estimates express the rank of independent variables in terms of the effect on the dependent variable. The independent variable with the largest (absolute) beta coefficient has the biggest effect on the dependent variable. The intercept in such a regression is zero by construction. According to the results, the F-ratio test confirms that the overall regression model is a good fit for the data (Table 3). The output shows that the independent variables statistically significantly predict the dependent variable.

Table 3. Results of the semi-log multiple linear regression model (n = 4853).

Variables	Coef.	Robust Std. Err.	Beta
Demographic variables			
Size of household	−0.044 ***	0.112	−0.157
Age	0.002 ***	0.014	0.056
Geographic variables			
City size (base = large)			
Medium and small cities	−0.031 *	0.506	−0.026
Region (base = Tunis)			
Northeast	0.116 ***	0.646	0.078
Northwest	−0.064 ***	0.594	−0.045
Centre-east	0.165 ***	0.594	0.125
Centre-west	0.155 ***	0.599	0.114
Southeast	0.026	0.616	0.016
Southwest	0.089 ***	0.764	0.051
Socio-economic variables			
Poverty (base = no)	−0.221 ***	0.429	−0.151
Education (base = primary)			
Illiterate	−0.040 ***	0.430	−0.037
Secondary	−0.001	0.419	−0.001
University	0.007	0.965	0.003
SPC (base = laborer)			
Freelance	0.053 *	0.785	0.027
Employee	0.035 *	0.579	0.018
Independent (industry/trade)	0.042 **	0.533	0.025
Farmer	0.108 ***	0.545	0.064
Retired	0.037	0.596	0.026
Inactive and others	−0.011	0.460	−0.008
Variables related to food consumption			
Expenditure	0.0004 ***	0.001	0.456
Waste	0.015 ***	0.071	0.069
constant	2.714 ***	1.202	
F (21, 4831) = 176.2 ***			
R-squared = 0.4337			
Adjusted R-squared = 0.4313			
Root MSE = 0.3812			

*, **, and ***, statistically significant at 10%, 5%, and 1%, respectively.

According to Table 3, both demographic variables (household size and age of the head of the household) are very significant (at 1%) in the prediction of the water footprint of food consumption of the household with coefficients −0.044 and 0.002, respectively. The city/geographic variable it is statistically significant at the 5% level; people with higher water footprints are more likely to be found in big cities than in small and medium ones. Region is very significant, with only the southeast not differing from the base of Tunis. The centre-east, centre-west and northeast have the highest coefficients: 0.165, 0.155, and 0.116, respectively. Concerning the socio-economic variables, poverty (−0.221), education particularly illiterate people (−0.040), and the socio-professional categories (SPC), especially farmers (0.108), are also very significant. Finally, variables related to food habits (Expenditures and Food waste) are also significant at the 1% level.

In terms of the relative importance of the effects on the dependent variable, based on beta coefficients, food expenditure per capita (0.456), household size (−0.157), and poverty (−0.151) have the largest contributions across the model. We also find that the centre-east (0.125) and centre-west (0.114) regions have the largest effects on the water footprint. This is followed by food waste, represented by the number of dishes thrown away with a beta coefficient equal to 0.069, the socio-professional category "farmer" (0.064), the age of household head (0.056), the education level of the household head, and, finally, the variable "City size" determining the size of the city of residence. The City size variable is linked to the degree of the economic development of the city. According to Souissi et al. [18], the evolution and increase in water footprint during the last thirty years in Tunisia is more rapid in urban regions. The more developed the city is and the better the economic situation, the higher the household water footprint. A 1 TND (US$ 0.69) increase in food expenditure is associated with 0.04% increase in the average water footprint. This can be explained by the increased consumption of animal products, which are usually more expensive than plant products [49]. Meat and dairy products have a significant impact on the water footprint. This is an alarming sign, especially since the measured footprint is mainly internal (more than 70% of the water footprint of the main food products comes from local production) [18]. In other words, Tunisia is severely depleted of internal water resources by consumption habits.

A one-unit increase in the size of the household implies a 4% decrease in the average food consumption water footprint, controlling for food expenditure. Poor households have a 22% lower water footprint than other households. Wealthier households seem to consume products with a large water footprint.

Region is also an important factor to determine the water footprint of households. The average water footprint is, respectively, higher by 16%, 15%, 11%, and 8% for households living in the centre-east, the centre-west, the northeast, and the southwest of the country than for people living in Tunis. The centre-east and northeast regions are characterized by high economic development and tourism. Households' incomes are higher and access to more expensive food products, especially of animal origin, is better. Concerning the centre-west and the southwest, these regions are characterised by sheep and goat production, resulting in meat being both available and culturally important. Meat consumption is the highest in the southwest of the country. The average water footprint for people living in the northwest is 6% lower than for people living in Tunis. The diet in the northwest is based on cereal products, which has a lower water footprint. This region is less economically developed and has substantial cereal production. There is no significant difference between the water footprint for households living in the southeast and those living in Tunis. These results can be explained by the variation in culinary habits from one region to another. Regional food patterns are often very pronounced in Tunisia, particularly for meats [49].

Regarding food waste, all other variables being constant, we found that for each dish thrown away by the household the water footprint increases by 1.5%. Li et al. [33] found similar results showing that the increase in food waste contributes to a higher water footprint. For the socio-professional categories of the head of the household, the average water footprint is, respectively, higher by 10%, 5%, 4%, and 3% for farmers, freelance jobs, industry and commerce independents, and employees than for labourers.

Considering the effect of the head of the household's age, the unstandardized coefficient for the variable age is equal to 0.002. This means that for each one-year increase in the age, there is an increase in the average water footprint of 0.2%, all other variables held constant. It is hard to explain this small but very significant effect of age on the water footprint. On one hand, the increase with age may imply the presence of children, whose food consumption is characterised by incorporation of dairy products, meats, and cold cuts [50]. On the other hand, studies in other countries have shown that the oldest consumers ate more vegetables and fruits as well as less meat and fewer sugary desserts [50,51]. For education, the average water footprint is 4% lower for illiterate heads of households than for those with primary education. There is no significant difference between the other categories. Finally, regarding the city size, results show that the average water footprint is 3% lower in medium and small cities than in big cities. The effect of urbanization should not be overlooked. Urbanization was involved in our analyses due to the association of urbanization and the structure of the diet in many studies [52–56]. The literature examined shows that, unlike rural diets, urban diets are more characterized by the consumption of flour, more fat and animal products, more processed food, more sugar, and more food consumed outside the home. All of these elements necessarily impact the water footprint, which continues to climb in urban areas.

4. Conclusions and Policy Implications

The determinants of a consumer's water footprint depend on the water footprint of the goods produced. It also depends on what the consumer chooses to consume and the consumed quantities. Until now, studies related to the water footprint have not highlighted the factors affecting these choices nor their contributions to the water footprint of consumers.

In this paper, to better understand the factors that influence the food water footprint of Tunisian consumers, we used a semi-log multiple regression model. Results show that the increased consumption of animal origin products is necessarily linked to the increase in food expenditure per household and has a significant role in the water footprint increase. Demographic and economic characteristics such as household size and poverty are among the factors that contribute to the decrease in the consumer's water footprint. Moreover, regional disparities in food choices mean substantial differences in water footprints. Residents of the most developed cities and coastal cities in the centre-east, centre-west and northeast are more likely to have a large water footprint than residents of Tunis. Significant variability in water footprints, due to the different modes of food consumption and socio-demographic characteristics, was also noted. Food waste is one of the determining factors of households with a large water footprint.

This study contributes to the literature on the water footprint of food consumption using household level data. Estimates of the food water footprint can be used to assess potential scenarios for water demand as food consumption patterns change. Reducing the water footprint to sustainable levels is possible if consumption patterns change.

Analysis at geographic and social levels helps inform policy makers by identifying realistic dietary changes, taking into account socio-economic and regional disparities to effectively plan interventions and recommendations for a sustainable diet. It would be important to encourage more sustainable diets rich in vegetables and fruits, in particular through schools and advertising campaigns. In addition, in accordance with sustainable development goals and, in particular, objectives two (SDG2), six (SDG6), and twelve (SDG12), namely, to end hunger, ensure availability, and sustainable management of water and reduce food waste, it will be necessary to reconsider import and export strategies for food/agricultural products as well as food subsidy policies. For example, the wheat import strategy is effective during years when world prices for cereal products are lower than the cost of production. This allows Tunisia to save very important volumes of water. However, for reasons of food security and food sovereignty, the cultivation of wheat should be encouraged especially in more humid areas, especially in the north-west where the diet depends mainly on these products.

Several economic and political mechanisms aimed at reducing the water footprint of food consumption are possible. On the one hand, this may be achieved by relying on supply chain marketing strategies such as labeling. On the other hand, on an international scale, the ISO 14046 standard specifying the principles, requirements, and directives relating to the evaluation of the water footprint of products and processes has been established. Other measures based on food price and subsidy policies as well as consumer awareness campaigns can yield tangible results. Agricultural policies can also be an effective tool to reduce the water footprint of food consumption.

However, conclusions and recommendations should be viewed with caution since several limitations are noted in the use of this concept. The main limitations are the imprecision of the estimates, which is due to the difficulty of estimating water consumption at all stages of the food chain. Water volumes for products vary depending on production systems, rainfall, soil quality, yields, irrigation, etc. Other factors affect other aspects of the food chain, so imprecision accumulates. In addition, only the main food groups are considered and the data do not include fish products. In addition, the insufficiency of the volumetric approach should not be overlooked, since in addition to the volume of water consumed, the quality and conditions of access to water also play a role in decision-making regarding the use of resources. Another difficulty is the evaluation of grey water; determining the volumes of water "hypothetically" necessary to dilute the pollution to a tolerable level is quite arbitrary and very complex. To conclude, we can say that the use of the water footprint must take into account several limits depending on the context and the objective.

Finally, the absence of previous work that models the factors influencing the water footprint of food consumption opens up several perspectives for future research. The exploration and identification of new influencing variables (such as diet diversity, processed food consumption, etc.) and the use of more recent data that take into account post-revolutionary political and social changes in Tunisia are a priority.

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Appendix A

Table A1. Akaike's information criterion and Bayesian information criterion.

Model	Obs	ll(null)	ll(model)	df	AIC	BIC
	4853	−3574.867	−2194.987	22	4433.975	4576.696

Note: N = Obs used in calculating BIC.

Appendix B

estat hettest, rhs

Breush–Pagan/Cook–Weisberg test for heteroscedasticity

Ho: Constant variance

Variables: AgeChefMe Nombredeplatsjetes vuln taille DAP 1b.newstrate 2.newstarte 1.DNiveau 2b.DNiveau 3.DNiveau 4.DNiveau 1b.region 2.region 3.region 4.region 5.region 6.region 7.region 1.DCSP 2.DCSP 3.DCSP 4.DCSP 5b.DCSP 6.DCSP 7.DCSP
Chi2(21) = 467.20
Prob > chi2 = 0.0000

Appendix C

Table A2. Estat vif.

Variable	VIF	1/VIF
AgeChefMe	1.79	0.560112
Nombredelp~s	1.07	0.932759
vuln	1.23	0.813381
taille	1.29	0.773943
DAP	1.43	0.699650
2.newstrate	1.68	0.594018
DNiveau		
1	1.75	0.570375
3	1.37	0.728827
4	1.79	0.559360
region		
2	2.00	0.499027
3	2.34	0.428069
4	2.02	0.494502
5	2.28	0.437904
6	1.89	0.529240
7	1.91	0.523663
DCSP		
1	1.85	0.540077
2	1.21	0.828135
3	1.23	0.815850
4	1.29	0.773944
6	1.70	0.588099
7	1.59	0.630741
Mean VIF	1.65	

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