The dynamic nexus between climate changes, agricultural sustainability and food-water poverty in a panel of selected MENA countries

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ABSTRACT

This study attempts to examine the dynamic relationships between climate changes, agricultural sustainability and food-water poverty in a panel of MENA countries over the period 1990–2016. A panel co-integration, pooled least squares regression, pooled fixed effects, and pooled random effects models with the Hausman test for model specification are used to relate three proxies for food poverty and two proxies for water poverty to standard weather variables, agriculture productivity indicators, and environmental sustainability variables. The main results of regression analysis indicate that out of the three food poverty models, two food poverty regressions indicate the low agricultural productivity in low- and middle-income countries, while water poverty in terms of access to improved water is found to increase substantially agricultural value added (coefficient is more elastic, i.e. more than the unity). The results further show that high precipitation and temperature, often accompanied by high CO_2 emissions, increase food poverty in terms of food deficit and prevalence of undernourishment, whilst having no significant effect on water poverty. The overall findings conclude that there is a substantial requirement to increase agricultural sustainability in low- and middle-income MENA countries without deteriorating environment and water reserves.

Key words | agricultural sustainability, climate change, food poverty, MENA countries, water poverty

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INTRODUCTION

The Middle East and North Africa (MENA) is a large, complex, and diverse region, which faces a wide range of economic and food-water security challenges. They are generally classified into two groups; high-income countries, whose economies are dominated by petroleum and natural gas, and low- and middle-income countries with more diversified economic structures and a large contribution of the agricultural sector to the local economics (Pelzman 2012).

Known to be one of the most arid regions in the world, the MENA region is, furthermore, vulnerable to climate-induced impacts on water resources and food production. However, despite this alarming situation, political leadership in the region has low awareness about the need to promote adaptive governance strategies to deal with the increased hydrological risk. It becomes clear that adaptation to climate change and environmental sustainability are closely linked to water availability and food production added to a set of social, economic and political factors. In most of the MENA countries, climate change is associated with reduced average precipitation, which creates a real threat to food security in this dry region. In some cases, an intensification of the water cycle has caused more extreme floods and droughts in the region. Generally, climate change acts as a 'threat multiplier' which increases the vulnerabilities

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of already vulnerable and poor populations, creates threats to security, and raises risks of violence in the region.

In the MENA region, the linkage between food-water poverty, agricultural sustainability, and environment conservation has not received enough policy attraction in favor of the most vulnerable groups who are most affected by the climate change, food security challenges and limited accessibility to water resources. However, rich MENA countries (oil-based countries) have been successful in tackling food-water poverty, at least in the short term, which was made possible by using oil rents.

The idea for an integrated food-water nexus was mainly highlighted in the agenda of the Bonn 2011 conference about the sustainable security systems framework (Leese & Meisch 2015). However before, Blake (1992) emphasized the need to increase food production to fulfill the food requirements of Asia's growing population. His study concluded with policy strategies to attain agricultural sustainability in the region. Schaller (1993) presented the concept of agricultural sustainability as a viable instrument for: (i) sound environmental policies, (ii) amplified economic growth, and (iii) productive rural development, which is responsible for global food production. Heller & Keoleian (2003) explained the long-term sustainability of the US food system to the changes in consumption behavior across agricultural production, distribution, and food disposition.

Zezza & Tasciotti (2010) examined the relationship between urban agriculture, food security, and poverty issues using household survey data of 15 developing countries. They found that the contribution of the agricultural sector to GDP is very low, which underestimates the value added of urban agriculture and its ability to reduce food insecurity and urban poverty. Kemmler & Spreng (2007) confirmed the alignment between human activities and sustainability issues. They added that 'the energy system is a sound framework for providing lead indicators for sustainable development'.

Focusing on North African countries, Stambouli *et al.* (2014) discussed a number of challenges related to sustainable energy and water resources. They confirmed the importance of both clean water and an energy superhighway that abstracted from the 'Sahara Solar Breeder project' to achieve sustainable development in the region. In the same regard, Salim *et al.* (2014) used a panel data from 29 OECD countries (countries that signed the convention of Organisation for Economic Co-operation and Development (OECD) between 1980 and 2012. They found a causality relationship between: (i) energy sources, economic growth, and industrial value added, and (ii) economic growth and non-renewable energy. Economic growth is found to be led by renewable energy consumption in the selected countries. Rasul (2014) confirmed the need for integration of cross-sectoral reforms in South Asian countries to manage food-energy-water security challenges.

In this respect, López-Bellido *et al.* (2014) investigated the potential of developing bioenergy crops in the agriculture sector in the European Union. They found an advantage for energy crops and liquid biofuel production in comparison with the first-generation biofuels. Garrity *et al.* (2010) discussed the association between food insecurity and population growth in Africa. They found that to increase food crop yields and household income, African countries like Zambia, Malawi, Niger, and Burkina Faso have shifted their farming systems from the traditional method of food crop cultivation to restore exhausted soils. Berry *et al.* (2015) investigated the relationship between food security and environmental sustainability, finding that maintaining sustainable diets is a key solution for labor to generate sufficient income for their nations.

Ozturk (2017) investigated the dynamic nexus between agricultural sustainability and food-energy-water poverty in a panel of selected sub-Saharan African countries over the period 1980–2013. He confirmed the importance of water resources for a better quality of life and food challenges, which is deemed desirable for water management mainly in the agricultural sector. He recommended developing sound institutions and technological upgrades to fulfill the energy-water food nexus for sustainable development (see also Kaygusuz (2012) and Rasul (2014)).

This study is expected to contribute to the existing literature by exploring the main determinants of food-water poverty which are associated with the agricultural growth factors, environmental sustainability, and climate change. This is crucial for making policies which are relevant to the long-term agricultural development and ensuring food and water security in the region. The rest of the paper is organized as follows: the next section introduces a brief overview of the MENA region, and why it is pressing to focus on matters like food-water poverty, agricultural sustainability, environmental degradation and climate change in the region. The following section discusses the main data sources and the methodology for empirical analysis. The results and discussion follow, and the last section consists of the conclusions.

THE MENA REGION: AN OVERVIEW

One of the main peculiarities of the MENA countries is their heterogeneity in economic, social, and political situations and environmental conditions. They can be divided into two main groups based on their gross national income (GNI) (see Table 1). The first group includes the least populated and high-income economies, which are mainly based on petroleum and gas rents, and with low contribution of the agriculture sector to employment, exports and GNI due to their severe climate conditions (see Figures A1 and A2, Appendix A). The second group encompasses the low- and middle-income economies, where population growth brings additional challenges. GNI for this group is quite low and the agriculture sector is flourishing despite the insufficiency of water resources (quality and quantity) (see Figures A1 and A2).

Table 1 | Classification of selected MENA countries

High-income countries		Low- and middle-income countries	
Country	**Population size (1,000 inhab)**	**Country**	**Population size (1,000 inhab)**
Oman	4,636	Jordan	9,702
Qatar	2,639	Syria	18,270
Saudia Arabia	32,938	Palestine	4,921
United Arab Emirates	9,400	Yemen Republic	28,250
Bahrain	1,493	Algeria	41,318
Israel	8,322	Djibouti	957
Kuwait	4,137	Egypt	97,553
Malta	430.8	Iran	81,163
		Iraq	38,275
		Lebanon	6,082
		Libya	6,375
		Morocco	35,740
		Tunisia	11,532
Total	63,995.8	Total	38,0138

Source: FAOSTAT, based on UNDESA (United Nations Department of Economic and Social Affairs Population) – Population Division (2017).

According to the Food and Agriculture Organization's (FAO) statistics in 2016, the proportion of cultivated area for the MENA countries remained low at 11.34%, which is below the world average of 18.33% (see Figure A3) (FAO 2017). This alarming situation is mostly attributed to the inadequacy of water resources for agricultural products. Most of the MENA counties suffer from limited water resources and severe deterioration in water quality, which are attributed to the galloping demographic growth that causes over-extraction of groundwater resources and their contamination.

The hydric situation of the MENA region is also aggravated by the climate-induced influences coupled with steady demographic growth which call for urgent plans and adaptive governance strategies to deal with the increasing hydrological risks (Jemmali & Sullivan 2014). Acceleration in the hydrological cycle is highly correlated with the fluctuation, disruption and irregularity of rainfall, which sometimes brings flooding and desertification. The water crises in the MENA region are expected to continue and reach critical levels in the long run (see Figure A4) if no projections for renewable energy are assumed in the future. A report of the Intergovernmental Panel on Climate Change (IPCC) predicts that the 'annual rainfall is likely to decrease in much of Mediterranean Africa and northern Sahara, with the likelihood of a decrease in rainfall increasing as the Mediterranean coast is approached' (Solomon 2007). Besides, many other studies expected the decrease in precipitation, ranging from 10 to 30% in the region by the end of the 21th century (Arnell 1999; Sánchez *et al.* 2004; Milly *et al.* 2005; Evans 2008, 2009, 2010).

Levant countries (Syria, Lebanon, Palestine, and Israel) are among the most affected by the decrease in precipitation and the increase in surface temperature in the MENA region (Alpert *et al.* 2008). Climate models expect or forecast up to a 4.5 °C annual increase in temperature and a 25% decrease in the annual average of precipitation by the end of the 21st century. For instance, water availability in the Lower Jordan River basin (Israel, West Bank, and Jordan) is decreasing considerably due mainly to climate change (GLOWA 2009).

In Jordan, Oroud (2008) expected that the average annual water yield of fresh water will decrease by a staggering percentage (45–60%) due to a combination of a 2 °C increase in temperature along with a 10% reduction in precipitation. In Israel, declining precipitation has had an unprecedented influence. For example, Mekorot (the National Water Company) stopped its pumping from the Sea of Galilee in January 2009 due to the dramatic drop in water level to a point considered to be near the 'bottom black line'.

North African countries were also affected by the decrease or volatility in precipitation. For example, in Morocco, the precipitation over the Atlas Mountains controls the flow in major rivers and replenishment of several important aquifers of the Souss-Messa, Draa, Ziz, and Tadla basins (Bouchaou *et al.* 2008). In Egypt and Sudan, changes in precipitation patterns over the Ethiopian Highlands are the key to the future flow of the Nile River, yet climatic models are inconclusive for the projected trend (Conway 2005). Higher temperatures, however, produce higher rates of evaporation, particularly in Lake Nasser, the large man-made reservoir behind the Aswan High Dam.

Water availability and food security are tightly coupled. The agriculture sector is the highest consumer of water in the MENA region; it relies on both public or private irrigation sources using surface water, groundwater, or both. On average, the agriculture sector accounts for approximately 80% of water expenditure in the region (World Bank 2007). This means that any plan or action to reallocate water under conditions of scarcity will most likely be at the expense of food security, which has been experienced in Yemen, Jordan, Israel, and Libya (World Bank 2007). Also, climate change is expected to have a significant impact on food production (Cline 2007). Egyptian agronomists have estimated the impact of climate change on food supply using a combination of standard global circulation climate models with multi-year and multi-crop models. They found that water demand increased for most crops (grains, including maize, wheat, sorghum, barley, and rice) due to higher temperatures and lower yields. Also, all crops experienced a significant decline in production, ranging from 9 to 19% for a 2 °C average temperature rise, along with increased water consumption of 2–16% (Eid *et al.* 2007).

Water resources for agriculture in the MENA region are faced with many challenges represented by the overexploitation of water resources from the private actors. For example, in Jordan thousands of private wells were constructed illegally. In the Gaza Strip, the Palestinians pump annually about 150 million km^3 from about 4,000 agricultural wells and 95 municipal wells, of which 40% is used for domestic consumption and 60% for agricultural consumption (Assaf 2001; Moe *et al.* 2001). In Yemen, the government has been unable to prevent the illegal drilling of wells in the Sanaa basin to support the cultivation of qat; a plant widely consumed for its narcotic effects (Kasinof 2009). In North Africa, the decline of aquifer levels in coastal areas is mainly attributed to the uncontrolled and illegal pumping of water for agriculture. Since the 1980s and 1990s, the agriculture sector around the world has experienced many changes in response to the increase in food prices and the spread of new technologies for farming and irrigation. For example, by using mobile diesel pumps, farmers can directly access groundwater sources, contributing to overextraction of aquifers (Achthoven *et al.* 2004). Also, fast steps in the liberalization of the agricultural sectors have been experienced, and governments in many countries have withdrawn from setting crop prices and quotas for most crops, and gradually withdrawn subsidies on some foodstuffs.

Finally, it is worth noting that food insecurity has negative consequences on poverty rates and undernourishment, which are more apparent in rural areas in Iraq, Sudan and Yemen (Lofgren & Richards 2003) (see Figure A5). Studies expect that MENA's population will continue to increase sharply until 2050, whereas the current food production system is expected to face deficiencies in the provision of the region's needs from foods by 2050.

DATA AND METHODOLOGY

The data on MENA countries (the study follows the definition of the MENA region adopted by the World Bank which includes Israel, Iran, Malta and the Arab world, minus Mauritania) for food-water poverty, agricultural sustainability, environment and climate changes (see Table 1) between 1990 and 2016 were obtained mainly from the recent World Development Indicators published by the World Bank (2017) and the International Financial Statistics published by the IMF (2017). Data on rainfall and temperature were taken from the recent statistics of the NOAA (National Oceanic and Atmospheric Administration). In order to avoid omitting some countries due to missing values, the forward and backward interpolation technique was used to fill these gaps.

The empirical model includes five dependent variables (response variables), including three food poverty indicators and two water poverty indicators that were separately regressed with a set of explanatory variables (see Appendix C). It is worth noting in this regard that food-water poverty is a buzzword that is widely used by the policymakers to assess the inadequate intake of food calories per day and inadequate access to water resources among households across countries. In order to deeply comprehend the food-water poverty nexus, one may look to the definitions of these concepts (see Appendix B). The used variables were chosen to give broader coverage of food-water poverty and agricultural and environmental sustainability in the region. The descriptive analysis will be followed by both pooled and panel regressions. Following Ozturk (2017), to understand more deeply the food-water poverty, agricultural sustainability and climate change inter-linkages, we used the following models.

Model A: Food poverty

$$\begin{aligned} Ln(FdPOVk)_{it} = \alpha_0 + {} & \alpha_1 Ln(WAT)_{it} + \alpha_2 Ln(PREC)_{it} \\ & + \alpha_3 Ln(TEMP)_{it} \\ & + \alpha_4 Ln(AGR)_{it} + \alpha_5 Ln(CO2)_{it} \\ & + \alpha_6 Ln(ENE)_{it} + \alpha_7 Ln(FOR)_{it} \\ & + \alpha_8 Ln(GDPc)_{it} + \alpha_9 Ln(INF)_{it} + \varepsilon_{it} \end{aligned}$$

where *FdPOVk* represents the three food poverty indicators, i.e. $FdPOV1$, $FdPOV2$ and $FdPOV3$. The first and the third indicators represent, respectively, the depth of the food deficit (kilocalories per person per day) and the prevalence of undernourishment (percentage of the population undernourished) while the second one represents the household final consumption expenditure per capita (constant 2010 US$). *WAT* represents the percentage of population without access to water, *PREC* represents the average precipitation in depth (mm per year), *TEMP* represents the annual average temperature, *AGR* represents agricultural value added, CO_2 represents carbon dioxide emissions, *ENE* represents fossil fuel energy consumption, *FOR* represents the percentage of forest area to total area, *GDPc* represents the GDP per capita, INF represents inflation-consumer price index (see Appendix C), '*Ln*' represents natural logarithm, '*i*' represents cross-section identifiers i.e. the considered countries, '*t*' represents the time period from 1990 to 2016, and ε represents the white noise error term.

Model B: Water poverty

$$\begin{aligned} Ln(WaPOVk)_{it} = \alpha_0 + {} & \alpha_1 Ln(PREC)_{it} + \alpha_2 Ln(TEMP)_{it} \\ & + \alpha_3 Ln(AGR)_{it} \\ & + \alpha_4 Ln(CO2)_{it} + \alpha_5 Ln(ENE)_{it} \\ & + \alpha_6 Ln(FOR)_{it} \\ & + \alpha_7 Ln(GDPc)_{it} + \alpha_8 Ln(INF)_{it} + \varepsilon_{it} \end{aligned}$$

where *WaPOVk* represents the water poverty indicators limited to: wapov1 (percentage of population without access to water sources) and wapov2 (percentage of population without access to sanitation facilities).

Here, we use the conventional panel unit root tests to assess the stationary properties of selected variables. In this regard, different panel unit root tests are used to check the order of integration of the given variable's series. After that, the panel co-integration, namely the Johansen Fisher and KAO tests, are used to evaluate the null hypothesis of no co-integration against the alternative hypothesis of co-integration relationships between variables. In order to obtain robust inferences, the study used, as follows, three separate panel regressions, comprising the panel least squares regression, commonly known as the 'common constant method'; fixed effects, commonly known as the 'least squares dummy variables (LSDV)'; and random effects model, commonly known as the 'dynamic model'.

After taking the logarithm form, the fixed effect models to estimate can be written as below:

$$\begin{aligned} Ln(FdPOVk)_{it} = \alpha_i + {} & \alpha_1 Ln(WAT)_{it} + \alpha_2 Ln(PREC)_{it} \\ & + \alpha_3 Ln(TEMP)_{it} \\ & + \alpha_4 Ln(AGR)_{it} + \alpha_5 Ln(CO2)_{it} \\ & + \alpha_6 Ln(ENE)_{it} + \alpha_7 Ln(FOR)_{it} \\ & + \alpha_8 Ln(GDPc)_{it} + \alpha_9 Ln(INF)_{it} + \varepsilon_{it} \end{aligned}$$

and

$$\begin{aligned} Ln(WaPOVk)_{it} = \alpha_i + \alpha_1 Ln(PREC)_{it} + \alpha_2 Ln(TEMP)_{it} \\ + \alpha_3 Ln(AGR)_{it} \\ + \alpha_4 Ln(CO2)_{it} + \alpha_5 Ln(ENE)_{it} \\ + \alpha_6 Ln(FOR)_{it} \\ + \alpha_7 Ln(GDPc)_{it} + \alpha_8 Ln(INF)_{it} + \varepsilon_{it} \end{aligned}$$

where α_i is a country specific effect.

Subsequently, in order to absorb the MENA countries' specific shocks, the study used a panel random effects model that could take the following forms:

$$\begin{aligned} Ln(FdPOVk)_{it} = \alpha_0 + \alpha_i + \beta_t + \alpha_1 Ln(WAT)_{it} \\ + \alpha_2 Ln(PREC)_{it} + \alpha_3 Ln(TEMP)_{it} \\ + \alpha_4 Ln(AGR)_{it} + \alpha_5 Ln(CO2)_{it} \\ + \alpha_6 Ln(ENE)_{it} + \alpha_7 Ln(FOR)_{it} \\ + \alpha_8 Ln(GDPc)_{it} + \alpha_9 Ln(INF)_{it} + \varepsilon_{it} \end{aligned}$$

and

$$\begin{aligned} Ln(WaPOVk)_{it} = \alpha_0 + \alpha_i + \beta_t + \alpha_1 Ln(PREC)_{it} \\ + \alpha_2 Ln(TEMP)_{it} + \alpha_3 Ln(AGR)_{it} \\ + \alpha_4 Ln(CO2)_{it} + \alpha_5 Ln(ENE)_{it} \\ + \alpha_6 Ln(FOR)_{it} \\ + \alpha_7 Ln(GDPc)_{it} + \alpha_8 Ln(INF)_{it} + \varepsilon_{it} \end{aligned}$$

where β_t represents time variant shocks.

It is noteworthy that the classical Hausman (1978) test could not be used to decide whether the fixed effects regression is better than the random effects or vice versa as the estimates of fixed and random models are all robust. Accordingly, the Sargen–Hansen test is employed to decide which model to take. Similarly, for the Hausman test, if the Sargen–Hanson value is significantly large, the difference between the estimates is major and, therefore, we reject the null hypothesis, i.e. the random effects model is inconsistent, and we accept the alternative hypothesis, i.e. the fixed effects estimator is consistent. Furthermore, the aforementioned test permits us to decide if the random effects model is more appropriate than the OLS model.

RESULTS AND DISCUSSION

A descriptive analysis is performed to show the basic characteristics of data before delving into the main question of the study which discusses the main determinants of food-water poverty in the MENA region. Figure 1(a) and 1(b) show, respectively, the box charts of the three food poverty indicators and the two water poverty indicators among two groups of countries: low- and-middle income countries and high-income countries. As expected, the figures revealed that high-income countries have on average lower levels of food and water poverty compared to the first group of countries, except for the second food poverty indicator (FdPOV2: Household consumption expenditures per capita).

Table 1 shows the descriptive statistics and the correlation matrix among pooled observations. Statistics show that the depth of the food deficit (FdPOV1) has a minimum value of 3 kcal per person per day and a maximum value of 695 kcal per person per day with an average value of 81.56 kcal per person per day and a standard deviation of 121.73 per person per day. Household final consumption expenditures per capita (FdPOV2) have a minimum value of US$968.70 and a maximum value of US$39,470.99 with an average value of US$6,698.097 and a standard deviation of US$7,946.524. Around 12.02% of the whole population of the region has a tendency towards being undernourished (FdPOV3) with a standard deviation of 13.47%, a minimum percentage of 5% and a maximum value of 76.80%. The skewness and kurtosis statistics show that the distributions of the three food poverty indicators are positively skewed (asymmetric distribution) and more peaked than a Gaussian distribution.

Turning to water poverty indicators, the percentage of the population without access to improved water (WaPOV1) ranges between 0 and 45.70% with a mean value of 10.39% and a standard deviation of 11.22%, while the percentage of population without access to sanitation facilities (WaPOV2) ranges between 0 and 76.30% with a mean value of 13.36% and a standard deviation of 15.74%. Similarity, the skewness and kurtosis statistics reveal that the distributions of WaPOV1 and WaPOV2 are positively skewed and more peaked than the Gaussian distribution.

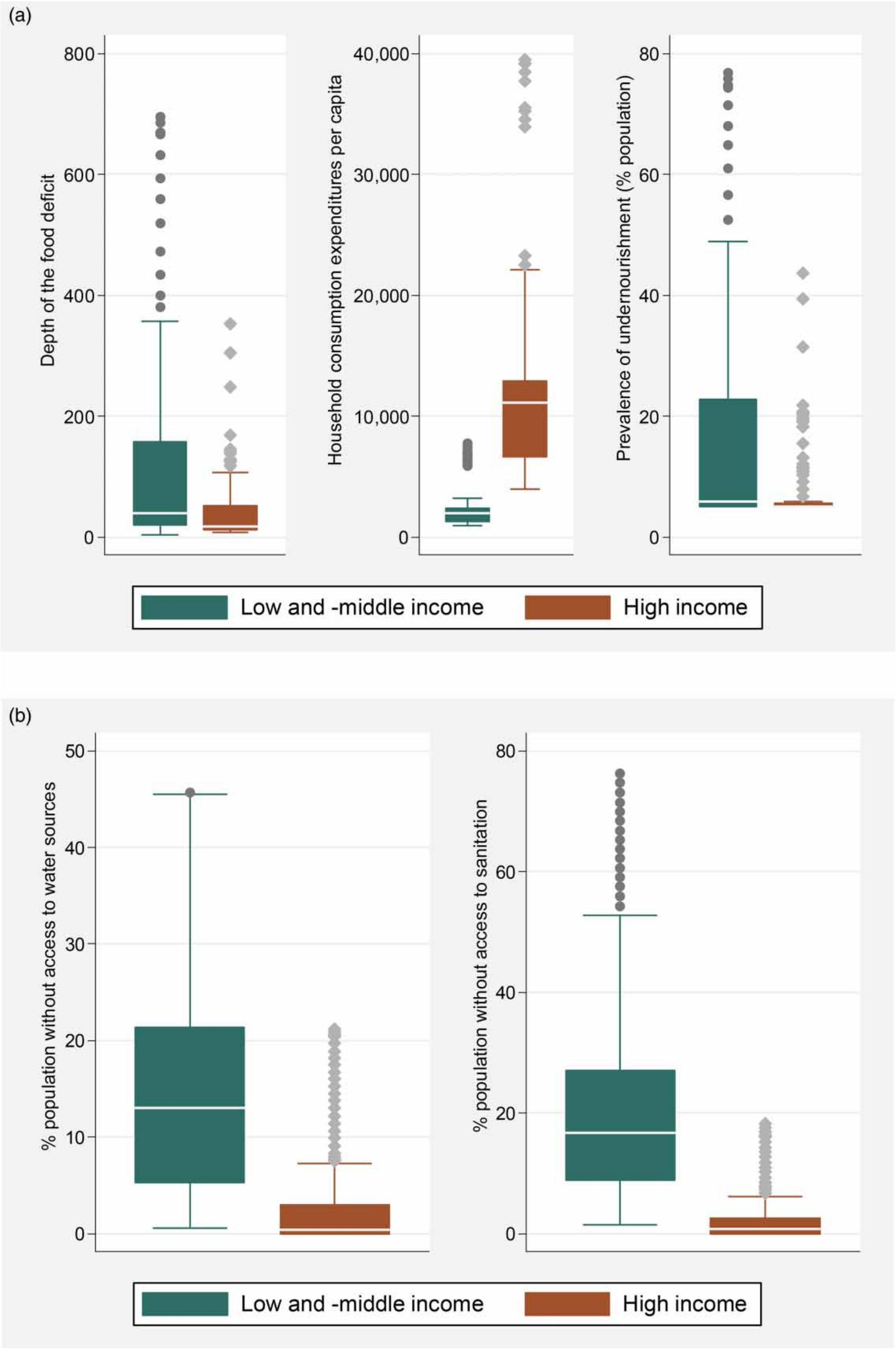

Figure 1 | Box charts of (a) food poverty indicators, (b) water poverty indicators among low- and- middle income and high-income countries. *Note*: Each box plot indicates the 25/50/75 percentiles, whisker caps denote the 5/95 percentiles.

The descriptive statistics of climate covariates show that the average precipitation in depth (PREC) is 17.75 mm per year, ranging between 1.09 and 73.10 mm per year, while the average annual temperature (TEMP) is 22.52 °C, ranging between 11.95 and 29.01 °C. The distribution of the precipitation variable is positively skewed and has a considerable peak compared to the temperature distribution which has a lower positive skewness and kurtosis values (0.01 and 1.91).

Table 2 also shows that the agricultural value added (AGR) and cereal yield (CER) have minimum values of 0.09% per GDP and 86.10 kg per hectare respectively, and maximum values of 34.44% per GDP and 74,205.60 kg per hectare respectively with average values of 7.63% and 3,853.42 kg per hectare respectively, and standard of deviation of 7.09% and 7,447.74 kg per hectare respectively. The CER variable has a more positively skewed distribution with a considerable peak compared to the distribution of the AGR variable. CO_2 emission is found to have a minimum value of 22.22% of the total fuel combustion and a maximum value of 89.67% with an average value of 50.47% and a standard deviation of 16.01%. The forest area has a median value of 1.09% of the land area with a standard deviation of 3.76% and a maximum value reaching 13.42%. Fossil fuel energy consumption has a mean value of 92.57% of total energy with a standard deviation of 21.61% and a considerable peak and negatively skewed distribution. GDP per capita (GDPc) has a minimum value of US$679.67 and a maximum value of US$72,670.96 with an average and median value of US$15,269.19 and US$5,757.83. Inflation (INF) has positive mean and median values of 30.97 and 3.71% with a standard deviation of 89.25%. The distribution of the two former variables is positively skewed and has a considerable peak, particularly for the inflation variable.

The second part of Table 2 exhibits the correlation matrix at different levels of significance. It reveals that the depth of food deficit (FdPOV1) is significantly and positively correlated to FdPOV3, TEMP, ENE, and INF with an estimated correlation value of 0.964, 0.299, 0.262 and 0.227, respectively, while FdPOV1 is negatively correlated to PREC, CER and FOR with estimated correlation values of −0.177, −0.158 and −0.248, respectively. Household final consumption expenditure per capita (FdPOV2) has a positive correlation with TEMP, CER, CO_2, ENE, and GDPc. The prevalence of undernourishment (FdPOV3) is positively correlated with TEMP, AGR, ENE and INF and negatively with CER, CO_2, and FOR in the panel of selected MENA countries. Inadequate access to improved water (WaPOV1) has a positive correlation with both FdPOV1 and FdPOV3, WaPOV2 and AGR and a negative correlation with CER, CO_2, and GDPc. Inadequate access to sanitation facilities (WaPOV2) has a positive correlation with both food poverty indicators FdPOV1 and FdPOV3 and PREC, AGR, FOR, and INF and a negative correlation with FdPOV2, TEMP, CER, CO_2, ENE, and GDPc.

Table 3 introduces the stationary properties and integration levels of the variables using a wide range of unit root tests. It reveals different orders of integration between variables. Household consumption expenditures (FdPOV2), average annual temperature (TEMP) and per capita GDP, and to a lesser degree the two water poverty indicators (WaPOV1 and WaPOV2), agriculture value added (AGR), CO_2 emissions (CO_2), and forest (FOR) exhibit non-stationary series at level 1, and become stationary at the first difference at 1% level of significance (I(1)). The two poverty indicators (FdPOV1 and FdPOV3), precipitation (PREC), cereal yields (CER), fossil energy consumption, forest, and inflation variables are both stationary at the level (I(0)). The second food poverty indicator (FdPOV2), TEMP and GDPc exhibit a constant increase or decrease over time, while the other food-water poverty indicators (PREC and CER) contain the dynamic properties in their respective data sets. In this regard, policymakers should adopt policies according to the dynamic and constant properties of the respective variables in their data sets as suggested by Ozturk (2017).

To find out if there is a co-integration or long-run association between the variables, we use two known tests: the Johansen Fisher Panel co-integration test and the Kao residual co-integration test based on the null hypothesis of no co-integration against the alternative hypothesis of the co-integration equation among the variables. The results in Table 4 reject the null hypothesis of no co-integration, while it accepts the alternative hypothesis of a co-integration relationship in the five food-water poverty models. According to the Fisher-type Johansen test, the co-integrating equations that exceed four equations imply the presence of

Table 2 | Descriptive statistics and correlation matrix

	FdPOV1	**FdPOV2**	**FdPOV3**	**WaPOV1**	**WaPOV2**	**PREC**	**TEMP**	**AGR**	**CER**	**CO_2**	**ENE**	**FOR**	**GDPc**	**INF**
Mean	81.56	6698.10	12.02	10.39	13.36	17.75	22.52	7.63	3853.42	50.47	92.57	2.80	15,269.19	30.97
Median	34.00	3587.13	5.00	6.30	8.40	14.37	22.69	5.36	1911.75	47.92	98.93	1.09	5757.83	3.71
Min.	3.00	968.70	5.00	0.00	0.00	1.09	11.95	0.09	86.10	22.22	0.00	0.00	679.67	−16.12
Max.	695.00	39,470.99	76.80	45.70	76.30	73.10	29.01	34.44	74,205.60	89.67	100.00	13.42	72,670.96	448.50
Std. Dev.	121.73	7946.52	13.47	11.22	15.74	13.77	3.74	7.09	7447.74	16.01	21.61	3.76	18,105.10	89.25
Skewness	3.00	2.57	2.64	1.29	1.60	1.23	0.01	1.22	6.20	0.56	−3.92	1.64	1.56	3.74
Kurtosis	13.22	10.26	10.83	4.11	5.29	4.39	1.91	4.35	47.82	2.55	16.91	4.60	4.51	15.64
Observations	378	486	378	567	567	567	567	486	540	513	540	567	540	567
Correlation matrix														
FdPOV1	1													
FdPOV2	−0.0360	1												
FdPOV3	0.964***	−0.0774	1											
WaPOV1	0.629***	−0.420***	0.697***	1										
WaPOV2	0.516***	−0.519***	0.587***	0.866***	1									
PREC	−0.117*	0.103	−0.104	0.149*	0.264***	1								
TEMP	0.299***	0.243***	0.297***	0.0339	−0.176**	−0.646***	1							
AGR	0.112	−0.702***	0.177**	0.484***	0.758***	0.118*	−0.256***	1						
CER	−0.158**	0.426***	−0.183**	−0.371***	−0.378***	−0.295***	0.247***	−0.239***	1					
CO_2	−0.0801	0.778***	− 0.127*	−0.416***	−0.561***	−0.0777	0.353***	−0.673***	0.368***	1				
ENE	0.262***	0.341***	0.226***	−0.141*	−0.298***	−0.468***	0.504***	−0.512***	0.223***	0.298***	1			
FOR	−0.248***	−0.0381	−0.267***	0.0806	0.254***	0.851***	−0.745***	0.216***	−0.298***	−0.149*	−0.627***	1		
GDPc	0.0647	0.895***	0.0118	−0.373***	−0.515***	−0.208***	0.512***	−0.674***	0.438***	0.761***	0.427***	−0.320***	1	
INF	0.227***	−0.317***	0.258***	0.202***	0.438***	−0.0964	−0.100	0.462***	−0.120*	−0.448***	0.154**	−0.110	−0.267***	1

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

Table 3 | Panel unit root tests

Method	FdPOV1	FdPOV2	FdPOV3	WaPOV1	WaPOV2	PREC	TEMP	AGR	CER	CO_2	ENE	FOR	GDPc	INF
Level														
LLC	−2.337***	2.583	−2.976***	−3.295***	−4.595***	−7.153***	9.540	−2.343***	−3.585***	−2.393***	−7.377***	−3.108***	−1.356*	−2.301**
HT	0.956	0.986	0.932	0.939	0.966	0.107***	0.788***	0.916	0.619***	0.847**	0.767***	0.951	0.900	0.322***
Breitung	−2.863***	3.227	−2.187**	−1.411*	−2.086**	−6.328***	−0.539	0.408	−1.348*	−0.113	−0.773	−2.421***	2.109	−3.654***
IPS	−2.271**					−8.667***	0.956	−1.907**	−2.946***	−0.803			1.1745	
Fisher	4.201***	−2.634	8.521***	−0.685	−2.241	15.557***	−0.207	6.941***	3.458***	1.313*	11.770***	0.837	−0.889	4.564***
1st Diff.														
LLC	−3.504***	−1.790**	−5.719***	0.854	−4.595	−15.848***	−0.926	−8.835***	−11.481***	−9.330***	−10.132***	−1.824	−3.122***	−11.870***
HT	0.731***	−0.024***	0.606***	0.009***	0.085***	−0.440***	−0.165***	0.009***	−0.378***	0.046***	−0.191***	0.701***	−0.021***	−0.426***
Breitung	−5.613***	−5.089***	−0.755	−3.358***	−4.337***	−8.601***	−5.137***	−8.404***	−2.749***	−5.914***	−3.228***	0.566	−4.092***	−7.932***
IPS	−2.636***					−19.534***	−7.756***	−11.096***	−14.844***	−11.209***			−6.443***	
Fisher	3.337***	7.462***	9.716***	2.911***	2.941***	55.619***	16.084***	27.778***	37.110***	24.876***	33.690***	−1.145	10.924***	36.851***

Note: ***Significance at 1% level; ** Significance at 5% level; * Significance at 10% level.

a long-run association among FoodPOV1, FoodPOV2, FoodPOV3, WatPOV1, and WatPOV2, which is also confirmed by the Kao residual co-integration.

Furthermore, the study employs a multivariate framework to investigate the prior expectations and possible associations among the aforementioned variables in terms of magnitude and direction. For this purpose, three analytical methods are used to relate three proxies for food poverty and two proxies for water poverty: pooled least squares regression, pooled fixed effects, and pooled random effects models.

The results of the statistical tests confirmed the goodness-of-fit for the three methods in Tables 5–7 below, as the values of the F-statistics (OLS and fixed effect model) and Wald Chi_2 statistic (random effect model) are higher than those of the critical values; therefore, the soundness of all these models is empirically accepted. In order to test the appropriateness of the random effect model, the Sargan–Hansen test is used instead of the Hausman classical because we opted for the robust estimation of regressions. The result of the Sargan–Hansen test confirms the suitability of the fixed effects regression compared to the random effects regression in the case of the FdPOV2 and the WaPOV2 models, while for the WaPOV1, the test confirms the suitability of the random effects regression results. The OLS regression results are found to be more appropriate compared to the random effects regression in the case of the FdPOV1 and FdPOV3 models.

The pooled least squares regression method is used first to obtain the estimates for each model. Table 5 reveals the results of food-water poverty in relation to climate change indicators (precipitations and temperature), environment sustainability indicators (CO_2 emissions and forest coverage), energy indicator (fossil fuel energy consumption), agriculture sustainability indicators (agriculture value added and cereal yields) and economic indicators (GDP per capita and inflation) in the region. The estimation results of model 1 are for the depth of food deficit (FdPOV1). They show that a 1% increase in the food deficit leads to a 0.353% decrease in agricultural value added, 0.433% decrease in cereal yields, and a 0.594% decrease in GDP per capita. The results are consistent with the previous studies of Long *et al.* (2006), Trostle (2010), McMichael (2009), and Ozturk (2017) which also confirmed the strong association

Table 4 | Panel cointegration tests

Hypothesized No. of cointegrations	**Model I/1: FoodPOV1**	**Model I/2: FoodPOV2**	**Model I/3: FoodPOV3**	**Model II/1: WatPOV1**	**Model II/2: WatPOV2**
a) Johansenfisher panel cointegration test (Probabilities are computed using asymptotic Chi-square distribution. Fisher-statistics used from trace test)					
At most 2	26.74**	9.704	5.545	26.74**	43.77***
At most 3	43.77***	9.704	5.545	77.84***	77.84***
At most 4	94.88***	77.84***	22.58***	128.9***	111.9***
At most 5	128.9***	111.9***	73.68***	128.9***	128.9***
At most 6	128.9***	128.9***	73.68***	83.26***	140.8***
At most 7	128.9***	128.9***	73.68***	62.70***	58.87***
At most 8	128.9***	128.9***	73.68***	42.85***	40.58***
At most 9	91.99***	80.55***	58.96***	23.54*	31.50***
At most 10	41.02***	45.14***	52.59***		
b) Kao residual cointegration test (Newey–West automatic bandwidth selection and Bartlett kernel)					
ADF statistic	−2.8059***	−2.2850**	−1.8306**	0.7263	1.6312*

Note: ***, ** and * indicate 1, 5 and 10% significance level.

between food challenges and agricultural and environmental sustainability and economic growth.

Another interesting result in Table 5 shows that an increase in the food deficit leads to an increase in carbon dioxide emissions and fossil fuel energy consumption by 0.540 and 9.393%, respectively, which implies that environmental degradation is strongly associated with the depth in food poverty. This requires cleaner production techniques in the region to transform food production into a sustainable mode (see Lebel & Lorek 2008; Cohen 2010; Bogdahn 2015). In other words, the need for sustainable consumption and production by renewable, clean and efficient energy sources is strongly recommended.

Results for the variables rainfall and lack of access to water in model 1 are surprising. When precipitation and access to adequate water increase, the depth of the food deficit also increases with positive coefficients of 0.4 and 0.377 respectively. This may be explained by rainfall variability. It is known that variability of high-frequency precipitation may reduce land suitability and crop yields and accordingly may have a negative effect on food production.

Table 5 also indicates that the second food poverty (FdPOV2) exhibits a positive relationship with cereal yields (0.236%), GDP per capita (0.303%), fossil fuel consumption (1.831%), and CO_2 emissions (0.371%) which means that household final consumption expenditures significantly increase cereal yields on the cost of environment and environmental conservation. High rainfall is found to have a positive and significant impact on household expenditures with an estimated coefficient of 0.193%, while temperature exhibits a negative and significant effect (−0.515%) on FdPOV2. These results are consistent with the previous studies which called for a policy agenda for tackling climate change and food security issues by sustainable agriculture instruments.

The third column of Table 5 is devoted to the prevalence of undernourishment (FdPOV3) in the MENA region. It is clear that there is a similarity between estimation results in the two models FdPOV1 and FdPOV3. Increasing agricultural productivity and per capita GDP negatively affects the prevalence of undernourishment, whereas high temperature and inflation are positively associated with a prevalence of undernourishment. These results support the findings of Welch & Graham (1999) who claimed there was a need for nutritious, sustainable and productive food supply. From the food poverty models, it is easy to conclude that rainfall and temperature variability added to lack of access to improved water can have adverse effects on the viability of economic systems, food production, and food availability. They may increase the percentage of total undernourished population and food deficit depth. Agricultural sustainability

Table 5 | Pooled least square regression

	Food poverty models			**Water poverty models**	
Variables	**Model 1 FoodPOV1**	**Model 2 FoodPOV2**	**Model 3 FoodPOV3**	**Model 4 WatPOV1**	**Model 5 WatPOV2**
WaPOV1	0.400***	−0.0163***	0.226***		
	(0.0650)	(0.00451)	(0.0382)		
PREC	0.377***	0.193***	0.277***	−0.243	0.135
	(0.106)	(0.0285)	(0.0533)	(0.219)	(0.287)
TEMP	0.614	−0.515***	1.071***	5.410***	−4.544***
	(0.384)	(0.120)	(0.251)	(1.099)	(1.375)
ENE	9.393***	1.831***	2.964***	−3.155	−12.99***
	(1.252)	(0.319)	(0.487)	(2.449)	(2.391)
AGR	−0.353***	−0.194***	−0.303***	0.740***	1.527***
	(0.0900)	(0.0218)	(0.0515)	(0.232)	(0.229)
CER	−0.0430	0.236***	−0.0290	−1.360***	−1.336***
	(0.122)	(0.0420)	(0.0820)	(0.241)	(0.311)
CO_2	0.540**	0.371***	0.224*	−3.407***	−5.860***
	(0.222)	(0.0849)	(0.125)	(0.703)	(0.697)
FOR	−0.108***	0.0312***	−0.0516**	0.0771	−0.978***
	(0.0322)	(0.00782)	(0.0239)	(0.0684)	(0.0799)
GDPc	−0.594***	0.303***	−0.403***	0.235	−0.314
	(0.0797)	(0.0270)	(0.0522)	(0.179)	(0.313)
INF	0.0988**	−0.0365**	0.108***	−0.0475	−0.0135
	(0.0394)	(0.0159)	(0.0251)	(0.105)	(0.142)
Constant	−39.18***	−4.729***	−12.78***	19.90	105.8***
	(6.096)	(1.409)	(2.736)	(13.39)	(12.93)
R-squared	0.566	0.931	0.641	0.476	0.678
F-statistics	116.7***	722.92***	67.38***	19.03***	105.98***
No. Obs.	297	351	297	378	378

Robust standard errors in parentheses.
***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

is shown, therefore, to play a key role in combating food poverty issues.

Turning to water poverty models, models 4 and 5 in Table 5 reveal that an increase in temperature leads to more water poverty in regards to limited accessibility to improved water (5.410%) and less water poverty in regards to more accessibility to sanitation facilities (−4.544%). Temperature variability may offset the water resources available for drinking. Also, the prevalence of undernourishment is negatively associated with cereal yields (−1.36%) and with CO_2 emissions (3.407%), and sanitation poverty is negatively associated with cereal yields (−1.336%) and CO_2 emissions (−5.86%). In this regard, previous literature suggested a set of sustainability options to improve agricultural productivity and ensure water security under climatic variations.

Table 6 shows the estimates of different food-water poverty models using the fixed effect regression method. The results show that climate changes denoted by temperature have no significant impact on food-water poverty models, except for the FoodPOV3 model which exhibits a significant and negative relationship between temperature and the

Table 6 | Pooled fixed effect regression

	Food poverty models			**Water poverty models**	
Variables	**FoodPOV1**	**FoodPOV2**	**FoodPOV3**	**WatPOV1**	**WatPOV2**
WaPOV1	−0.110	−0.00660	0.0866		
	(0.206)	(0.0158)	(0.131)		
PREC	0.0389	0.000978	−0.0443	0.345	0.00878
	(0.100)	(0.0146)	(0.0832)	(0.294)	(0.233)
TEMP	−0.407	−0.231	−0.550**	1.252	1.450
	(0.661)	(0.143)	(0.226)	(0.720)	(1.329)
ENE	7.245	1.141	4.484	−3.908	−6.237
	(9.024)	(2.013)	(4.009)	(12.20)	(5.897)
AGR	−0.0816	−0.206**	−0.0598	1.954*	1.251
	(0.199)	(0.0807)	(0.106)	(1.095)	(1.736)
CER	0.0694	−0.0115	−0.0658	−0.380	0.0498
	(0.106)	(0.0170)	(0.0519)	(0.338)	(0.133)
CO_2	0.485	−0.321***	0.571	−0.291	0.746
	(0.628)	(0.0986)	(0.428)	(1.069)	(1.089)
FOR	−3.744*	0.483	−1.802	2.256	−0.528
	(1.874)	(0.273)	(1.079)	(2.060)	(1.254)
GDPc	0.456	0.617***	0.375	−2.169*	−0.671*
	(0.891)	(0.176)	(0.438)	(1.192)	(0.367)
INF	0.0416	0.0117	0.0680	−0.0752	−0.0951
	(0.0581)	(0.0138)	(0.0417)	(0.120)	(0.187)
Constant	−35.00	0.105	−22.00	36.86	24.89
	(38.03)	(8.791)	(17.86)	(53.05)	(23.51)
R-squared	0.339	0.694	0.360	0.298	0.095
F-statistics	1177.41***	15.25***	4134.74***	3.92**	2.11*
No. Obs.	297	351	297	378	378
No. of ID	11	13	11	14	14

Note: Robust standard errors in parentheses, ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.
All the variables are in natural log form.

prevalence of undernourishment (−0.550%). Unlike the results of pooled OLS models in Table 5, no significant impact of the percentage of fossil fuel consumption on different food-water poverty indicators is found. In this regard, Stambouli *et al.* (2014) claimed that some North African countries started to rely on the 'Sahara Solar Breeder project', aimed at raising their portfolio of sustainable energy for its long-term development. The environmental sustainability indicators, namely CO_2 emissions and forest area, are found to be negatively associated, respectively, with household consumption expenditures (0.321%) and food depth (3.744%). This means that an increase in household income may be accompanied by an increase of CO_2 emissions by 0.321% and a decrease of food poverty in terms of food deficit may be accompanied by a considerable increase in the percentage of forest area by 3.744%. It is worth mentioning that no significant impact of these variables on water poverty is observed according to the fixed effect regression results.

The results shown in Table 6 relating to water poverty in terms of access to improved water exhibit a significant, positive and more elastic influence with agriculture value

Table 7 | Panel random effect regression

	Food poverty models			**Water poverty models**	
Variables	**Model 1 FoodPOV1**	**Model 2 FoodPOV2**	**Model 3 FoodPOV3**	**Model 4 WatPOV1**	**Model 5 WatPOV2**
WaPOV1	0.400**	−0.0103	0.226***		
	(0.192)	(0.0150)	(0.0596)		
PREC	0.377*	0.00236	0.277**	0.291	−0.0102
	(0.205)	(0.0248)	(0.118)	(0.239)	(0.267)
TEMP	0.614	−0.292*	1.071**	0.891	1.502
	(0.722)	(0.155)	(0.509)	(0.588)	(1.076)
ENE	9.393*	1.364	2.964***	2.931	−9.565
	(5.092)	(1.612)	(1.133)	(12.39)	(7.347)
AGR	−0.353**	−0.191**	−0.303***	1.875*	1.294
	(0.139)	(0.0764)	(0.0943)	(1.100)	(1.634)
CER	−0.0430	0.0202	−0.0290	−0.279	−0.000767
	(0.121)	(0.0181)	(0.0734)	(0.273)	(0.101)
CO_2	0.540	−0.206	0.224	−0.0828	0.425
	(0.534)	(0.151)	(0.263)	(1.058)	(1.298)
FOR	−0.108	0.104***	−0.0516	−0.453	−0.387
	(0.0681)	(0.0244)	(0.0402)	(0.281)	(0.321)
GDPc	−0.594***	0.631***	−0.403***	−1.355	−1.065**
	(0.162)	(0.108)	(0.135)	(0.913)	(0.492)
INF	0.0988*	0.00630	0.108***	−0.0818	−0.0802
	(0.0546)	(0.0152)	(0.0350)	(0.118)	(0.190)
Constant	−39.18*	−1.854	−12.78**	−4.302	45.15
	(22.98)	(7.018)	(6.152)	(54.44)	(38.55)
Wald Chi^2	1393.87***	509.61***	960.26***	25.60***	80.44***
Sargan – Hansen statistic	–	1500***	–	14.180	63.081***
No. Obs.	297	351	297	378	378
No. of ID	11	13	11	14	14

Note: Robust standard errors in parentheses, $***p < 0.01$, $**p < 0.05$, $*p < 0.1$.
All the variables are in natural log form.

added, 1.954%, which means that the bulk of water is used by agriculture at the cost of domestic and environmental uses. In this respect, Falkenmark (2013) focused on the need for water resource management for agricultural production. She attempted to take into account the future uncertainty which would have an adverse effect on agricultural industry and biological diversity worldwide. Regarding the impact of economic welfare on food-water poverty, the results show that an increase of GDP per capita is associated with an increase of household consumption of 0.617% and a significant decrease of both water poverty indicators of 2.169% and 0.671% respectively.

Finally, Table 7 shows the estimates of pooled random effects regression for the food-poverty model. The weather factors (rainfall and temperature), which are widely considered as the main indicators of climate change, are found to have a positive effect on the prevalence of undernourishment similarly to the OLS results. As explained above, the positive effect of rainfall on food deficit (0.370%) and prevalence of undernourishment (0.277%)

may be explained by the rainfall variability which may reduce land suitability and crop yields and accordingly have a negative influence on food production. The results show further that temperature has a negative effect on household income (−0.292%) and a positive (elasticity more than 1) relationship with the food prevalence of undernourishment. This could be explained by the fact that an increase in temperature may reduce seasonal agriculture which is critical for food security in many low- and medium-income countries, as stated in many previous studies.

The first and third columns of Table 7 show that food deficit and prevalence of undernourishment significantly decrease agricultural value added by 0.353 and 0.303%, respectively, while they noticeably increase the fossil fuel consumption by 9.393 and 2.964%, respectively. This result is consistent with many of the previous studies that confirmed the negative impact of fossil fuel consumption on food poverty. Higher price levels are found to be linked with food deficit (0.099%) and prevalence of undernourishment (0.108%), while economic growth has a negative influence on food deficit and prevalence of undernourishment (i.e. −0.594 and −0.403%, respectively). We also found that the agricultural sustainability indicator significantly decreases along with an increase in household consumption expenditures (i.e. −0.191%), while the forest area variable is found to have a positive relationship with this food poverty indicator of about 0.104%.

The results shown in Table 7 reveal that water poverty in term of access to improved water significantly increases agricultural value added by 1.875% which means, as found previously when using the fixed effect model, that access to improved water becomes more limited when the economy is based heavily on agriculture. It is known that this sector is the main consumer of water in the region, accounting for 80% of total water withdrawals. Many studies claimed that the majority of the MENA population lives under severe water scarcity (Jemmali & Sullivan 2014). Turning to the second water poverty indicator, GDP is found, as expected, to have an elastic and negative effect on the lack of access to sanitation facilities (−1.065%). This leads to the conclusion that access to such a basic service is somewhat limited to the population living in highly developed countries in the region.

CONCLUSIONS

In this study, the food-water poverty nexus was investigated against climate changes and agriculture sustainability. The current study used the depth of the food deficit, final household consumption expenditure per capita, and the prevalence of undernourishment as three proxies for food poverty, and the percentage of the population without access to a safe water sources and percentage of the population without access to sanitation facilities as two proxies for water poverty. These proxies served in the empirical analysis as the dependent variables for different food-water models. In addition, this study used as independent variables two climate variables, namely annual average of temperature and rainfall, and some agricultural and environmental sustainability indicators, i.e. agricultural value added, cereal yields, forest area, carbon dioxide emissions, and fossil fuel energy consumption. A few other variables were also added to different models to take into account economic welfare and the global level of prices, including GDP per capita and inflation.

We found some limitations in using the same food-poverty proxies mentioned in the literature. For instance, we may use the Water Poverty Index, widely used to assess the multidimensional water poverty at different scales (Jemmali & Sullivan 2014) in the regression analysis to replace the simple water access indicators. Also, other food security indices (e.g. the Global Food Security Index – index developed by The Economist Group) may be used instead of the aforementioned food indicators. One of the main advantages of using such food security indices in a dynamic (quantitative and qualitative) benchmarking model is the ability to assess the exposure of a country to the impacts of a changing climate, its susceptibility to natural resource risks, and how it can adapt to these risks.

The main findings in different regression approaches revealed that out of the three food poverty indicators, two of them indicated the low agricultural productivity among low- and middle-income countries in the region. Regarding the impact of climate changes on the food-poverty nexus, we found that precipitation and temperature positively affect food poverty in terms of food deficit and prevalence of undernourishment, but not for water poverty indicators. The increase and high variability of rainfall in some countries added to the remarkable increase in temperature may contribute to reducing food production and cause high levels of food poverty. Agriculture value added was negatively associated with three food poverty indicators, and positively associated with the lack of access to improved water. Also, the results exhibited that CO_2 emission positively influenced food deficit and prevalence of undernourishment, which means that an increase of food poverty could be accompanied by environmental degradation and high levels of air pollution in some MENA countries. Fossil fuel energy consumption and economic growth were found to have different impacts on the aforementioned food poverty indicators. In an unexpected result, we found that the lack of access to improved water may increase substantially with an increase in agricultural value added, while the economic growth tends to show a negative association with water poverty.

Thus, to alleviate food-water poverty levels, it is crucial to prompt agricultural productivity without damaging the environment. This dilemma of food-water poverty and agricultural sustainability should be a priority on the agenda of policymakers in the MENA region. There is an increasing need to formulate appropriate policies that align between food security for poor people and regular access to improved water and sanitation facilities. It is found that less developed countries in the region are the most exposed to climate changes and severe water and food insecurity. In order to mitigate the unpredictable impacts of high rainfall variability and increasing temperature, more sustainable and efficient agricultural practices should be implemented.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this paper is available online at http://dx.doi.org/10.2166/wcc.2019.309.

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