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Analyzing Egypt's water footprint based on trade balance and expenditure inequality

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A B S T R A C T

Egypt is a very arid country, with a rapidly growing population driving water demand beyond its annual constant supply. According to Falkenmark Water Stress Indicator, Egypt has reached a high and chronic water scarcity level that restricts its ability to accomplish economic development goals. To this end, our study has two fundamental goals; [1] tracing the effects of Egypt Virtual Water (VW) trade on its real water availability, and [2] analyzing the effects of household consumption patterns on Egypt's water availability. We have thus conducted a consumption-based analysis of water use in Egypt, using an interregional input-output (IRIO) model between Egypt and the Rest of the World. Achieving the first goal, Egypt's National Water Footprint (NWF) and it`s VW net exports for 57 sectors of production are calculated. Our results indicate that Egypt saves 8% of its NWF through imports, embodied mainly in wheat. However, Egypt virtually net exports 12% of its total available freshwater resources, embodied mainly in feed, alfalfa, and paddy rice. To understand the study second goal, households NWF per product are compared with their annual direct water use. Results indicate that they consume 11% of water directly and 89% virtually. Also, urban, and rural NWF per capita are calculated according to their different patterns of expenditure. Results show that urban NWF per capita is roughly 17% higher than that of rural households, reflecting their different consumption patterns. Urban citizens consume larger amounts of all products, excluding agricultural and textile products. The water embodied in household consumption in Egypt exacerbates the water scarcity crises. This effect is particularly seen in water reliant agricultural and animal products. Also, our results show the need to monitor international trade and the virtual flows of freshwater when exploring issues around freshwater scarcity.

1. Introduction

In line with the UN 17 Sustainable Development Global Goals, in 2016, the Egyptian government launched the Sustainable Development Strategy 2030. The strategy contains a set of economic, social, and environmental goals to be accomplished by the year 2030. However, accomplishing these development goals may be restricted in the coming years by the challenge of water scarcity that Egypt suffers from.

Egypt is a very arid country: with only 1.18% of annual water resources comes from rainfall and 9.03% from underground sources, leaving the Nile river as the main reliable source of water in Egypt (CAPMAS, 2017). Under the 1959 Nile Waters Agreement between Egypt and Sudan, Egypt receives a constant amount of water (55,500 Billion cubic meters (m^3)) through the Nile river annually (FAO, 2016). This amount of water accounts for 72.64% of the Egyptian annual water resources (CAPMAS, 2017).

On another hand, Egypt's rapidly growing population; from 28.5 million in 1962 to 92 million in 2016; has increased the annual water demand to exceed its annual constant supply (FAO, 2017a). As a result, the total renewable water resources per capita in Egypt dropped from 2041 m^3 in 1962 to 637.1 m^3 in 2014 (CAPMAS, 2017; FAO, 2017a). Thus, according to Falkenmark Water Stress Indicator (Falkenmark, 1989), Egypt has reached a high and chronic water scarcity level that negatively affects human health, general wellbeing, and restricts the ability to accomplish economic development goals (Eckstein et al., 2010).

Moreover, based on demographic projections, the Egyptian per capita renewable water resources is projected to drop to 500 m^3 by the year 2030 (FAO, 2016). This limit accounts for the threshold of the absolute water scarcity in Falkenmark Indicator (World Bank 2016; Falkenmark 1989). This would seriously constrain the potential for accomplishing Egypt 2030 goals.

Although agriculture sector consumes 81.6% of Egypt annual water resources, (followed by family use (13.5%), and industry use (1.57%))(CAPMAS, 2017), it contributes by 12% of Egypt`s annual GDP (World bank 2017). Significant changes in Egypt

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water-intensive crops production and trade have been observed during the last 50 years. For example, 570% increase in Egypt wheat production during the period 1961-2015 was observed and accompanied by 1456% increase in Egypt wheat net imports (FAO, 2017b). During the same period, 322% increase in Egypt rice production was observed and accompanied by 590% increase in Egypt rice net exports (FAO, 2017b).

Accordingly, due to the serious current state of Egypt water crisis, a more comprehensive perspective on the role of water in Egyptian trade and consumption is needed. To this end, the study has two fundamental goals; (1) Tracing the effects of Egypt's Virtual Water (VW) trade on its freshwater water availability. This can be achieved through calculating Egypt's National Water Footprint (NWF) and its (VW) net exports for 57 sectors of production. (2) Analyzing the effects of Egypt's households' water use on its water availability. This is done by calculating households NWF per product and comparing it with their direct water use. We also compare urban and rural NWF per product, according to their different patterns of expenditure. Thus, we have conducted the first top-down study of Egypt's water footprint, to our knowledge, using an interregional input-output (IRIO) model between Egypt and the Rest of the World (RoW). The remainder of this paper is organized as follows. Section 2 clarifies literature review. Section 3 introduces the method. Section 4 provides data and their sources. Results are presented in Section 5. Section 6 introduces brief conclusions. A schematic overview of the study framework is clarified in (Figure 1).

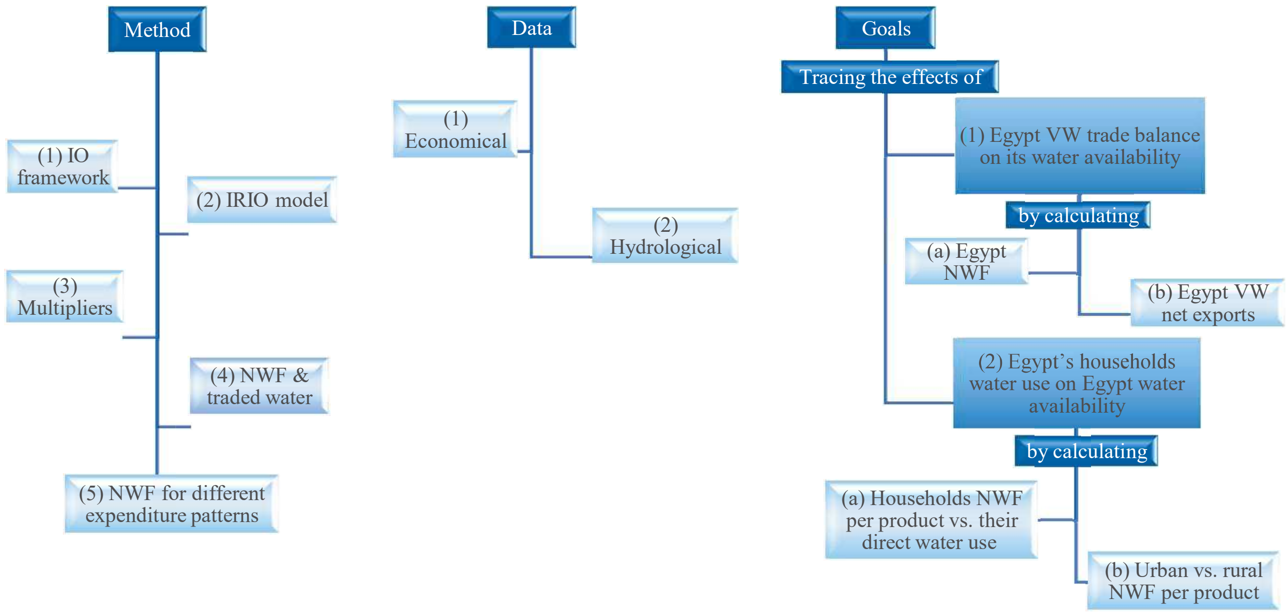

Fig. 1- A schematic overview of the study framework.

2. Virtual water & water footprint

The virtual water concept was first introduced by (Allan, 1993). It is defined as the water embedded in agricultural products through their production and supply chain processes. Allan clarified that virtual water trade can be an effective tool for water-scarce regions to alleviate their water scarcity problem, through importing water-intensive crops rather than growing them domestically.

Nine years later, (Hoekstra and Hung, 2002) broadened the VW concept by introducing the concept of water footprint (WF). They defined the WF of a nation as the total amount of water used by the nation`s population. It is the sum of domestic water and the net virtual water imported from abroad, used directly and indirectly, to produce goods that satisfy population`s final demand, during a certain period. Thus, the concept of WF is much broader than the VW concept. It can be calculated by applying either a bottom-up approach (life-cycle analysis) or a top-down approach (Input-Output Analysis). The bottom-up approach was first applied by (Chapagain and Hoekstra, 2004). Using this approach, the WF of a product can be calculated by summing up the amount of water used directly[1] and indirectly[2] at each stage of production. However, this approach cannot

[1] Water used in the production process directly.
[2] Water used in the supply chain of inputs (during previous production stages).

distinguish between water used in producing a good that satisfies the intermediate (interindustry) demand, and water used in producing the same good that satisfies the final demand directly. Accordingly, double-counting issues prevent the linking of the total WF with final demand. Double counting is averted by the use of Input-Output (IO), which can calculate the WF of a product by tracing its whole domestic or global supply chain (Feng et al., 2011). IO models can be classified according to the number of regions analyzed. Thus, IO analysis can be a single region IO model, an interregional IO (IRIO) model, or a multi-regional IO model (Miller, Ronald E., Blair 2009).

The IRIO analysis of WF and VW has been used by many researchers. (Carter and Ireri, 1970) developed an IRIO model to calculate the VW transfers between California and Arizona as well as the production per unit of water use in each region. They found that California is much more efficient in water use than Arizona. Recently, (Zhang et al., 2011) evaluated the total WF of Beijing and found that 51% of it is imported virtually, with the agriculture sector as the highest water consumer. (Suttinon et al., 2013) evaluated the water demand of each industrial sector in three regions of Japan, taking into consideration the impacts of implementing three different governmental water policies (reduce- reuse- recycle). (Deng et al., 2016) calculated China water footprint for the years 2002 and 2007 and compared them to analyze the changing trend of water use in China. (Chen et al., 2017) applied an IRIO model to estimate the WF of different provinces in China as well as the transfers of virtual water between those provinces. They found that the larger GDP and population, the larger water footprint for the province. They also found that many of the underdeveloped regions are suffering from water shortages. However, they export virtual water to the developed regions. (Zhang et al., 2017) studied the case of the scarcest water region in China, the North China Plain. They found that the water scarcity of this region is alleviated through virtual and actual interregional water transfers. According to the study results, the region is a net water importer through agricultural trade.

2.1 Egypt water footprint literature

During the last two decades, the Egyptian WF has been sparsely researched. (Wichelns, 2001) studied the comparative advantage of virtual water and the role of trading in it as well as trading in other limited resources to achieve food security and other national goals in Egypt. (Chapagain et al., 2006) used a bottom-up methodology to calculate the virtual water content of agricultural products. They calculated national and global water losses and savings because of the international trade in these agricultural products. They also calculated Egypt's blue water savings[3] resulting from imported wheat. (El-sadek, 2010) analyzed the VW concept as a solution for alleviating water scarcity in Egypt. He gathered different previous estimates for Egypt virtual water net imports according to food trade. In line with these results, (Zeitoun et al., 2010) analyzed Egypt virtual water net imports through trading in 17 crops and 4 kinds of livestock, which accounted for 54% of Egypt annual Nile River water flow during the period (1998-2004). (El-gafy, 2014) investigated wheat production, water footprint, and virtual water nexus using a System Dynamic model. She found that the water footprint of wheat production and consumption in Egypt changes according to changes in the crop production, foreign trade, per capita consumption, population, and climate effects. In line with this study, (El-gafy et al. 2017) also used system dynamics to calculate a water–food–energy nexus index and the energy and water footprints for 43 Egyptian agricultural crops, based on production and consumption amounts. Also, they calculated the virtual water and energy imports and exports of the same crops.

Most of these previous studies have focused on WF of agricultural products. The inter-industry effects between all economic sectors may thus be underestimated in their analyses. Also, the effect of final consumption of products on water use has not been considered. Another gap in the literature is the understanding of effects of final expenditure differences related to different expenditure patterns on water use. This study aims to fill these gaps in the literature, employing an IRIO analysis of Egypt's WF, disaggregated by expenditure profiles of rural and urban dwellers.

3. Method framework

The Interdependency effects of economic transactions between sectors and trades among nations are analysed by several approaches, such as the social network and graph theories (Amini et al., 2018; Boccaletti et al., 2006) and the IO analysis, which is a popular methodology in water footprinting analysis. The IO method is originally developed by Wassily Leontief in the late 1930s to analyze the economic system of the United States (W. W. Leontief, 1936; W. Leontief, 1941). This matrix-based methodology is used to analyze the interdependency between industries in an economy using sectoral monetary transactions data (Munksgaard et al., 2005). It has been used to track value-added, labour, and natural or environmental

[3] Water sourced from surface and ground water resources.

resources embedded in final products. Leontief himself (Leontief, 1970) analyzed pollution generation as an undesirable by-product using IO model. Moreover, it is capable of distinguishing between direct (final) and indirect (intermediate) consumption of these resources. Energy is probably the most common of many “environmental extensions” introduced in IO analysis, in part motivated by the oil crises of the 1970s (Blair, 1980; Bullard and Herendeen, 1975; Griffin, 1976; Just, 1973). Since then, the extended IO methodology has been applied by many researchers to more account for other environmental virtual resources embodied in products, such as virtual land (Bicknell et al. 1998; Ferng 2001; Meier et al. 2014; Chen & Han 2015), and virtual water resources (Dietzenbacher and Vela, 2007; Ewing et al., 2012; Feng et al., 2012; Holland et al., 2015; Yu et al., 2010; Zhan-ming and Chen, 2013; Zhang and Diaz, 2014; Zhang et al., 2011; Zhao et al., 2008).

3.1 The IO framework

The traditional IO table describes the interindustry flows of products between economic sectors (from sector i as a seller to sector j as a buyer) in monetary units. Thus, products from sector i are distributed to satisfy the other sectors (interindustry) demand as well as the final consumer demand. This can be shown as follows:

$$x_i = z_{i1} + \dots \dots . + z_{ij} + \cdots + z_{in} + f_i \tag{1}$$

$$x_i = \sum_{j=1}^{n} z_{ij} + f_i \tag{2}$$

where x_i is the total output of sector i, n is the number of sectors in the economy, z_{ij} is the interindustry flows (sales) from sector i to all sectors j (including i itself, when $i = j$), and f_i is the final demand for sector i products. Using the matrix form, let:

$$X = \begin{bmatrix} x_1 \\ \vdots \\ x_i \\ \vdots \\ x_n \end{bmatrix}, \qquad Z = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots\ddots & \vdots & \vdots \\ z_{i1} & \ddots & z_{ij} \\ \vdots & \vdots & \ddots\vdots \\ z_{n1} & \cdots & z_{nn} \end{bmatrix}, \qquad F = \begin{bmatrix} f_1 \\ \vdots \\ f_i \\ \vdots \\ f_n \end{bmatrix} \tag{3}$$

where X is the total output vector of sector i, Z is the intermediate demand matrix on i products (the inter-industry transactions), and F is the final demand vector on i products. We can obtain the technical coefficient matrix (denoted also as direct requirement matrix) A by dividing each z_{ij} by the total output in each corresponding row. Each element in the A matrix $[a_{ij}]$ represents the monetary unit worth of inputs from sector i needed to produce one monetary unit worth of output of sector j. Thus, each element in Z can be replaced by $a_{ij} * x_j$. Accordingly, (1) can be represented as follows:

$$x_i = a_{i1}x_1 + a_{i2}x_2 + \cdots + a_{in}x_n + f_i \tag{4}$$

In matrix notation, (4) can be represented as follows:

$$X = (I - A)^{-1}F \tag{5}$$

where: I is the identity matrix and $(I - A)^{-1}$ is the Leontief inverse matrix (denoted also as the total requirement matrix), which is represented as follows:

$$(I - A)^{-1} = L = [l_{ij}] \tag{6}$$

where: l_{ij} denotes the monetary unit worth from sector i products that are necessary to satisfy one monetary unit worth of final demand of sector j products. Thus, the link between final demand and corresponding direct and indirect production is built with this Leontief inverse matrix.

3.2 Interregional IO model

Labelled by the “Isard model”, the structure of the IRIO was first introduced by (Isard, 1951), then reintroduced again in the more detailed analysis in (Isard et al., 1960) book (Miller, Ronald E., Blair, 2009). In the IRIO, one region can be defined as a particular country and the other region can be defined as the RoW (Miller, Ronald E., Blair, 2009). Thus, we can apply the IRIO model with respect to Egypt and RoW by representing (3) in the following partitioned matrices[4]:

$$X = \begin{bmatrix} X^e \\ X^r \end{bmatrix}, \qquad Z = \begin{bmatrix} Z^{ee} & Z^{er} \\ Z^{re} & Z^{rr} \end{bmatrix}, \qquad F = \begin{bmatrix} F^{ee} & F^{re} \\ F^{er} & F^{rr} \end{bmatrix} \tag{7}$$

where: $X^e = [x_i^e]$, and $X^r = [x_i^r]$ are total output of i sectors in Egypt and RoW respectively, $Z^{ee} = [z_{ij}^{ee}], and\ Z^{rr} = [z_{ij}^{rr}]$ are intraregional flows[5] in Egypt and RoW respectively. $Z^{re} = [z_{ij}^{re}]$, $Z^{er} = [z_{ij}^{er}]$ are interregional flows[6] in Egypt and RoW respectively. $F^{ee} = [f_i^{ee}]$, $F^{er} = [f_i^{er}]$ are the Egyptian final demand for sector i goods that are produced in Egypt and RoW respectively. $F^{re} = [f_i^{re}]$, $F^{rr} = [f_i^{rr}]$ are the Row final demand for sector i goods that are produced in Egypt and RoW respectively. The technical coefficients matrix for IRIO model is expressed in the following partitioned matrix:

$$A = \begin{bmatrix} A^{ee} & A^{er} \\ A^{re} & A^{rr} \end{bmatrix} \tag{8}$$

where[7]

$$A^{ee} = Z^{ee}\left(\hat{X}^{e^{-1}}\right),\ A^{rr} = Z^{rr}\left(\hat{X}^{r^{-1}}\right),\ A^{er} = Z^{er}\left(\hat{X}^{r^{-1}}\right),\ A^{re} = Z^{re}\left(\hat{X}^{e^{-1}}\right) \tag{9}$$

Thus, the formula in equation (5) can be represented in the following partitioned matrices

$$\begin{bmatrix} X^e \\ X^r \end{bmatrix} = \left\{\begin{bmatrix} I & 0 \\ 0 & I \end{bmatrix} - \begin{bmatrix} A^{ee} & A^{er} \\ A^{re} & A^{rr} \end{bmatrix}\right\}^{-1} \begin{bmatrix} F^{ee} & F^{re} \\ F^{er} & F^{rr} \end{bmatrix} \tag{10}$$

where: $\left\{\begin{bmatrix} I & 0 \\ 0 & I \end{bmatrix} - \begin{bmatrix} A^{ee} & A^{er} \\ A^{re} & A^{rr} \end{bmatrix}\right\}^{-1} = L =$ is the Leontief invers matrix in the IRIO model.

3.3 Water consumption multipliers

Consider a row vector W of the annual domestic freshwater consumed by j production sectors in Egypt and RoW as follows:

$$W = [W^e \quad W^r] \tag{11}$$

where $W^e = [w_j^e]$, and $W^r = [w_j^r]$ are the annual domestic freshwater consumed directly by j production sectors in Egypt and RoW[8] respectively. The water extended IRIO model can be shown in (Figure 2) as follows:

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[4] The upper case (^{e}) usually refers to Egypt, and (^{r}) refers to RoW in this study.
[5] The intraregional flows z_{ij}^{ee} for example denote the monetary unit worth flow of goods from sector i in Egypt to sector j in Egypt
[6] The interregional flows z_{ij}^{re} for example denote the monetary unit worth flow of goods from sectors i in ROW to sector j in Egypt.
[7] In matrix algebra notation, putting a (^) sign over a vector denotes a diagonal matrix of that vector.
[8] Hybrid units are used in this study; the interindustry transactions are measured in monetary units, while water inputs are measured in physical units.

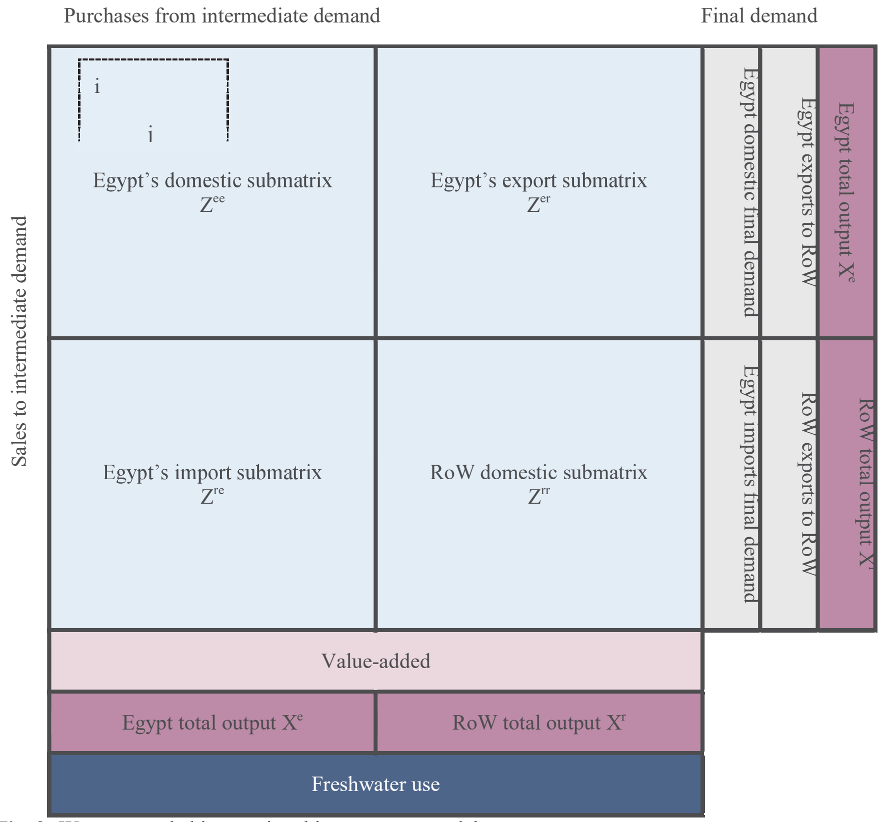

Fig. 2- Water-extended interregional input-output model.

The figure depicts the interindustry sub-matrices: Z^{ee}, Z^{er}, Z^{re}, Z^{rr}, Egypt final demand sub-columns, RoW final demand sub-columns, total output sub-columns X^e, X^r, the value-added row; that presents the other payments from production sectors to the non-industrial inputs of production, such as wages, depreciation of capital, or taxes; and finally the freshwater row W_j. Now, it is possible to calculate water intensity vector D (also called water direct impact coefficient vector) as follows:

$$D = W\hat{X}^{-1} = [D^e \quad D^r] \tag{12}$$

Each element in D^e and D^r specifies the amount of domestic/RoW water required directly per one monetary unit of total output of sector j production in Egypt/ROW respectively. By rearranging (12) we have

$$W = D\hat{X} \tag{13}$$

Recalling back equations (5) and (6), we can simplify (13) to:

$$W = [DL]\hat{F} \tag{14}$$

This formula was first introduced by (Just, 1973). We use this formula to clarify the total impacts of final demand for water use. We can obtain the indirect water use per one monetary unit of total output (water embodied in the intermediate inputs of production) by subtracting $[D]$ from $[DL]$. Also, we use the diagonalized $\hat{D}$ to show the source sector and region of water embodied in all products as follows:

$$W = [\hat{D}L]\hat{F} \tag{15}$$

Let $[\hat{D}L] = T$, defines the water total impact coefficients matrix. It is also known as the water intensity multiplier matrix. Each element of this matrix reflects the amount of water required directly and indirectly to generate one monetary unit of final demand on sector j. We can express T in the IRIO model in the following partitioned matrix:

$$T = \begin{bmatrix} T^{ee} & T^{er} \\ T^{re} & T^{rr} \end{bmatrix} \quad (16)$$

where: T^{ee}, and T^{rr} express the intraregional effects for changes in domestic final demands, and T^{er} and T^{re} express the interregional spillover effects in one region that are caused by changes in another region`s final demand. Then, we can obtain the water consumption multipliers as follows:

$$m\ (w)^{ee} = \acute{\imath}\ [T^{ee}], m\ (w)^{rr} = \acute{\imath}\ [T^{rr}], m\ (w)^{er} = \acute{\imath}\ [T^{er}], m\ (w)^{re} = \acute{\imath}\ [T^{re}] \quad (17)$$

where: $m\ (w)^{ee}$, and $m\ (w)^{rr}$ are the intraregional water consumption multiplier vectors for Egypt and RoW respectively. Each element in each vector represents the total amount of water used in all i sectors in a specific region (Egypt or RoW) to satisfy one monetary unit of final demand for sector j output of the same region (Egypt or RoW). $m\ (w)^{er}$, and $m\ (w)^{re}$ are the Interregional water consumption multiplier vectors. Each element in each vector represents the total amount of water used in all i sectors in a specific region (Egypt or RoW) to satisfy one monetary unit of final demand for sector j in the other region (RoW or Egypt). $\acute{\imath}_{(1\times n)} = [1 \ldots \ldots 1]$ vector.

3.4 National Water Footprint model and traded water

According to (Hoekstra and Chapagain, 2006), the National Water Footprint (NWF) of a country consists of internal and external WF. The internal WF is the amount of domestic water used to produce products that are consumed domestically. It can be calculated as follows:

$$WF_{intrnal} = T^{ee}F^{ee} + T^{er}F^{er} \quad (18)$$

where: $T^{ee}F^{ee}$ is the domestic water embodied in Egypt's products that are sold to Egypt's final consumers. $T^{er}F^{er}$ is the domestic water embodied in Egypt exports to the RoW industries, and then, re-imported to Egypt through Egyptian imports to be sold directly to Egypt's final consumers. On the other hand, the external WF is the VW imported into the country to satisfy inhabitant's annual final demand. It can be calculated as follows:

$$WF_{external} = T^{re}F^{ee} + T^{rr}F^{er} \quad (19)$$

where $WF_{external}$ is the amount of virtual water embodied in products that are transmitted from RoW to Egypt, $T^{re}F^{ee}$ is the RoW water embodied in imports to Egypt intermediate demand, $T^{rr}F^{er}$ is the Row water embodied in imported final products that are sold directly to Egypt's final consumers. Accordingly, the NWF by sector is presented as follows

$$NWF_{sector} = \begin{bmatrix} WF_{intrnal} \\ WF_{external} \end{bmatrix} \quad (20)$$

According to this formula, each element in the NWF_{sector} vector attributes the total amount of water to satisfy Egypt's final demand to the source sector and region where the water was directly consumed. This formula distinguishes between domestic and foreign water. Exports of virtual water $VW^{e}_{exp.}$ are calculated as follows:

$$VW^{e}_{exp.} = \left[T * \begin{bmatrix} F^{re} \\ F^{rr} \end{bmatrix} \right] \quad (21)$$

On the other hand, we can calculate the Egyptian NWF by product as follows:

$$NWF_{product} = [\widehat{DL}]\mathrm{F} = \begin{bmatrix} m\ (w)^{ee} + m\ (w)^{re} & 0 \\ 0 & m\ (w)^{er} + m\ (w)^{rr} \end{bmatrix} * \begin{bmatrix} F^{ee} \\ F^{er} \end{bmatrix} \quad (22)$$

According to this formula, each element in the $NWF_{product}$ vector attributes water consumption to the final product it becomes embodied in. This formula does not distinguish between domestic and foreign water use, but identifies the virtual water embodied in final demand of each product.

3.5 National Water Footprint for different expenditure patterns

Introduced by (Miyazawa, 1976), household's final expenditure is separated into distinct groups according to their different income classes. Due to limited expenditure data across income groups for Egypt, we attempt to make a more simplified analysis than Miyazawa`s. Using two Egyptian final expenditure patterns; for rural and urban geographical areas; we can calculate National water footprint for each area as follows:

$$NWF_{urban} = [\widehat{DL}]F^{e}_{urban} \tag{23}$$

$$NWF_{rural} = [\widehat{DL}]F^{e}_{rural} \tag{24}$$

where: NWF_{urban} and NWF_{rural} represent national water footprint for urban and rural areas respectively. F^{e}_{urban} and F^{e}_{rural} represent Egypt final demand on j sectors products for urban and rural households respectively.

4. Data

4.1 Economic data

The method and data sources have been adapted from Holland et al. (2015), who integrated the hydrological model Water Gap with a multi-region IO model. The transactions matrix was extracted from The Global Trade Assessment Programme (GTAP) for the year 2007 (Peters et al., 2011) as it has a disaggregated agricultural sector. The original GTAP table includes 113 regions with 57 sectors in each region. We have merged the 113 regions into only two regions: Egypt and the RoW. However, we have kept the 57 GTAP sectors without merging. Accordingly, the technical coefficients matrix (A) in this study has a dimension of 114 rows by 114 columns. Also, the RoW final demand data was obtained from the same data source (Peters et al., 2011).

With respect to the final demand in Egypt, we used two classifications of data for two purposes of calculations. First: we used the total Egyptian final demand (contains households and government) to calculate the WF of final demand of each product. Data of total Egyptian final demand are obtained directly from the (GTAP) database (Peters et al., 2011). Second: we have distinguished between household final demand in rural and urban areas to calculate the WF by product of each area. The final demand data for each of these areas are not available directly, and hence need to be derived. Firstly, we directly obtained the 2008 average final expenditure per family for urban and rural areas from the Egyptian Statistical yearbook of the Egyptian Central Agency for Public Mobilization and Statistics (CAPMAS, 2015)[9]. Secondly, we calculated the total final expenditure for each classification as follows:

$$E^{r}_{2008} = AVE^{r}_{2008} * N^{r}_{2008} \tag{25}$$

$$E^{u}_{2008} = AVE^{u}_{2008} * N^{u}_{2008} \tag{26}$$

where: E^{r}_{2008} and E^{u}_{2008} are the 2008 total final expenditure in rural and urban areas respectively, AVE^{r}_{2008} and AVE^{u}_{2008} are the 2008 final expenditure per family in rural and urban areas respectively. N^{r}_{2008} and N^{u}_{2008} are the 2008 number of families in rural and urban areas respectively, which again are not directly available. They have been calculated as follows:

$$N^{r}_{2008} = N^{r}_{2006} * P^{r}_{2008}/P^{r}_{2006} \tag{27}$$

$$N^{u}_{2008} = N^{u}_{2006} * P^{u}_{2008}/P^{u}_{2006} \tag{28}$$

where N^{r}_{2006} and N^{u}_{2006} are the 2006 number of rural and urban families respectively. P^{r}_{2008} and P^{u}_{2008} are the 2008 total population in rural and urban areas respectively. P^{r}_{2006} and P^{u}_{2006} are the 2006 total population in rural and urban areas respectively. Data of rural and urban population for the years 2006 and 2008 as well as the number of rural and urban families for the year 2006 were obtained directly from CAPMAS (CAPMAS, 2014).

[9] The 2007 data for the average final expenditure per family in each area are not available. So, we used the 2008 data.

The calculated final expenditure data cover the households' expenditure on 50 different product groups in Egypt. We have allocated these product groups to the 57 GTAP sectors according to the GTAP final demand ratios per sectors[10]. Finally, we proportionated these allocated final expenditures to the GTAP households final demand data to obtain the final demand for urban and rural areas in Egypt as follows:

$$\underset{2007}{F^{e}_{rural}} = \frac{AE^{r}_{2008}}{AE^{r}_{2008} + AE^{u}_{2008}} GTAPF^{e}_{2007} \quad (29)$$

$$\underset{2007}{F^{e}_{urban}} = \frac{AE^{u}_{2008}}{AE^{r}_{2008} + AE^{u}_{2008}} GTAPF^{e}_{2007} \quad (30)$$

where $\underset{2007}{F^{e}_{rural}}$ and $\underset{2007}{F^{e}_{urban}}$ are the 2007 Egyptian final demand for rural and urban areas respectively. AE^{r}_{2008} and AE^{u}_{2008} are the 2008 allocated expenditure for rural and urban areas respectively. $GTAPF^{e}_{2007}$ is the 2007 GTAP Egyptian households final demand (here, governmental final demand is excluded).

4.2 Hydrological data:

The study accounts for only the freshwater consumption which is defined as the amount of freshwater that is completely withdrawn from the system and not returned. We obtained the RoW freshwater consumption data from (FLÖRKE et al., 2013; Holland et al., 2015).

With respect to Egypt freshwater consumption, we distinguished between two categories of data: (1) the agriculture water use data, and (2) the other sectors water use data. We obtained the detailed 2007 agriculture water use data per 30 crops in Egypt directly from the CAPMAS Irrigation and water resources statistics report (CAPMAS, 2008). Then, we aggregated these data with the 8 GTAP crop categories. See supplementary material, (Table S2).

With respect to the other sector`s water use data, it is defined in this study as the amount of water consumed by all sectors except that which is consumed by agriculture and households. Thus, we obtained these data from the CAPMAS annual report (CAPMAS, 2011) by subtracting the amount of water consumed by agriculture and households from the total amount of water consumed by all sectors.

Because of the non-availability of data about how each sector consumes water from the other sectors, we have split the other sectors water use of Egypt across the GTAP sectors except agriculture ones, based on what each of these GTAP sectors spends on water, as done in (Holland et al., 2015). The more a sector spends on water, the higher the proportion of the water use it is assigned. We get the Egyptian sectoral spending on water from the 2007 GTAP input-output transaction matrix (Peters et al., 2011).

5. Results and discussions

5.1 Egypt NWF and VW trade balance

Egypt's total NWF is calculated to be 53.45 Billion m^3 in 2007, with 92% from domestic water, and 8% from the RoW's.[11] According to (figure 3), the NWF of Egypt is exceeded by its direct water consumption (W^e), which means that Egypt is a net VW exporter. Thus, Egypt VW net exports is calculated to be 8.4 Billion m^3 in 2007 which accounts for 12% of Egypt total water resources in the same year (70 Billion m^3(CAPMAS, 2011)). Egypt VW net export for each 57 production sectors are presented in (Figure 4)[12]. The 'Other crops' sector (feed plant, alfalfa, beans, fenugreek, chickpeas, lentils, lupine, medical and aromatic plants, henna) has the largest amounts of Egypt's VW net exports, followed by paddy rice, and vegetable and fruits. Wheat has the largest amounts of Egypt VW net imports. Thus, water intensities of products should be more considered

[10] Ex.: we disaggregated the (Bread and cereals) category in the Final expenditure data to three GTAP categories: paddy rice, wheat, and cereal grains, using ratios of final demand for each category, the more the category has final demand, the more it has final expenditure. See supplementary material, (Table S1).
[11] For further detailed results about Egypt NWF_{sector}, Egypt $NWF_{product}$, Egypt direct and indirect water use, RoW direct water use, see supplementary material, (Table S3) and (Figure S1).
[12] According to results, we found too big and too small values of Egypt VW net exports to be presented using one scale. Thus, two different scales are used to show the big values (figure 4-(a)) and small values (figure 4-(b)) of Egypt VW net exports separately.

while putting the Egyptian international trade policy, especially exporting water-intensive crops such as feed plant, alfalfa, and rice.[13]

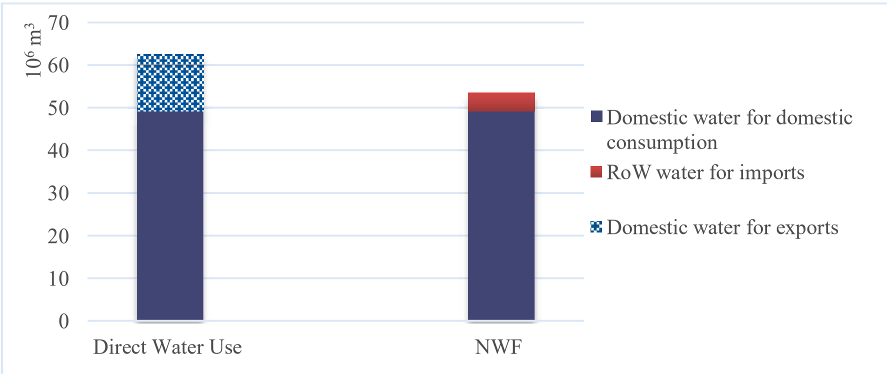

Fig. 3- Sectoral direct water use vs. NWF for Egypt 2007.

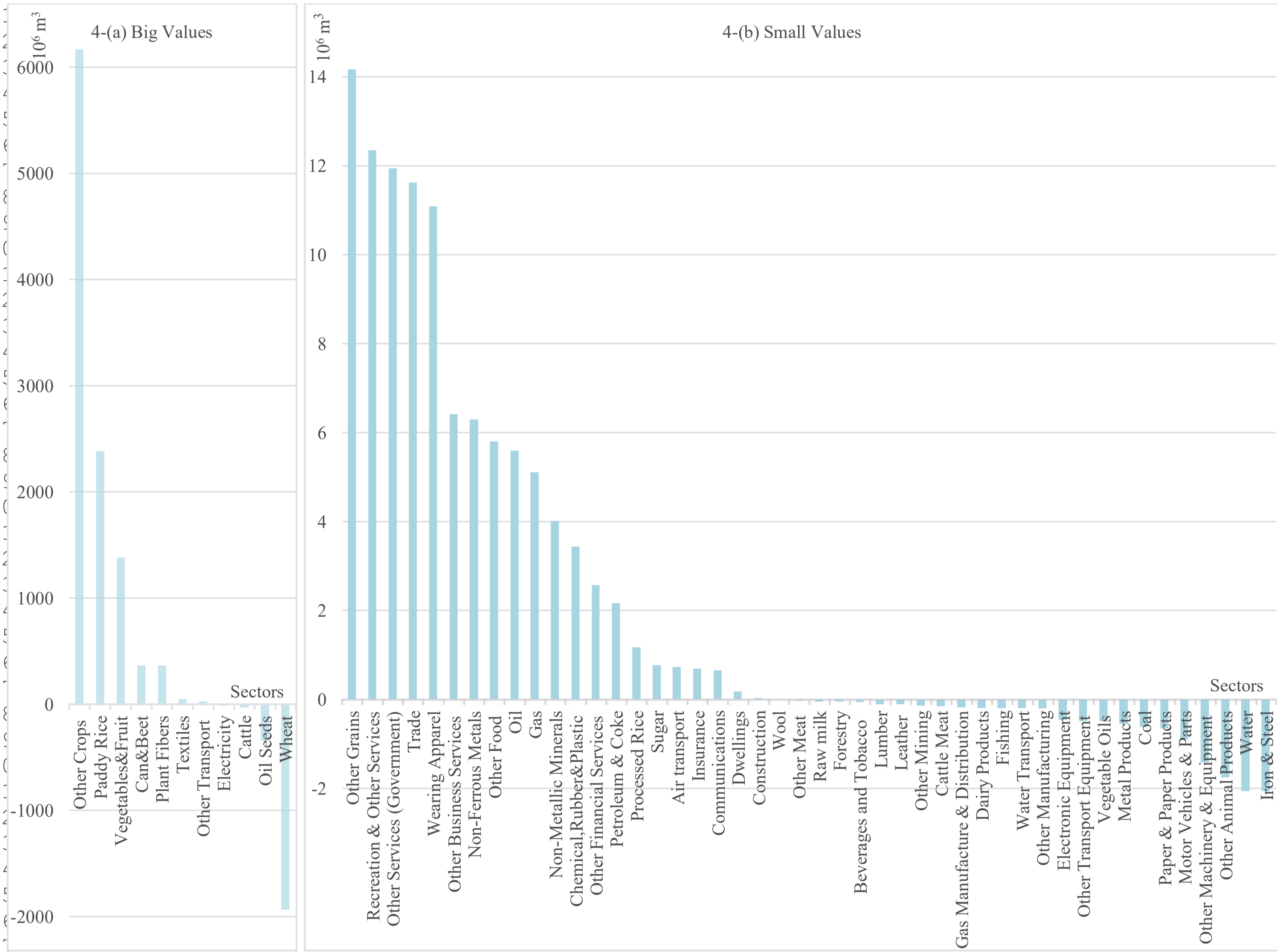

Fig. 4- Egypt 2007 virtual water net exports per sector of production.

[13] The Egyptian government has decided to stop exporting rice in the year 2017.

5.2 Egypt's households water use

5.2.1 Households NWF Vs. direct water use

Egypt households NWF ($NWF_{product}$, excluding government NWF) accounts for 7.8 folds of the family direct water use (they consume 89% of water virtually and 11% directly). The latter is compared with the top 25 NWF products in (Figure 5). It shows that the water consumed directly accounts for 14% of the water embodied in edible products that they consume annually. Changing households' diets and monitoring their consumption of such water-intensive food crops can contribute to conserving Egypt water resources.

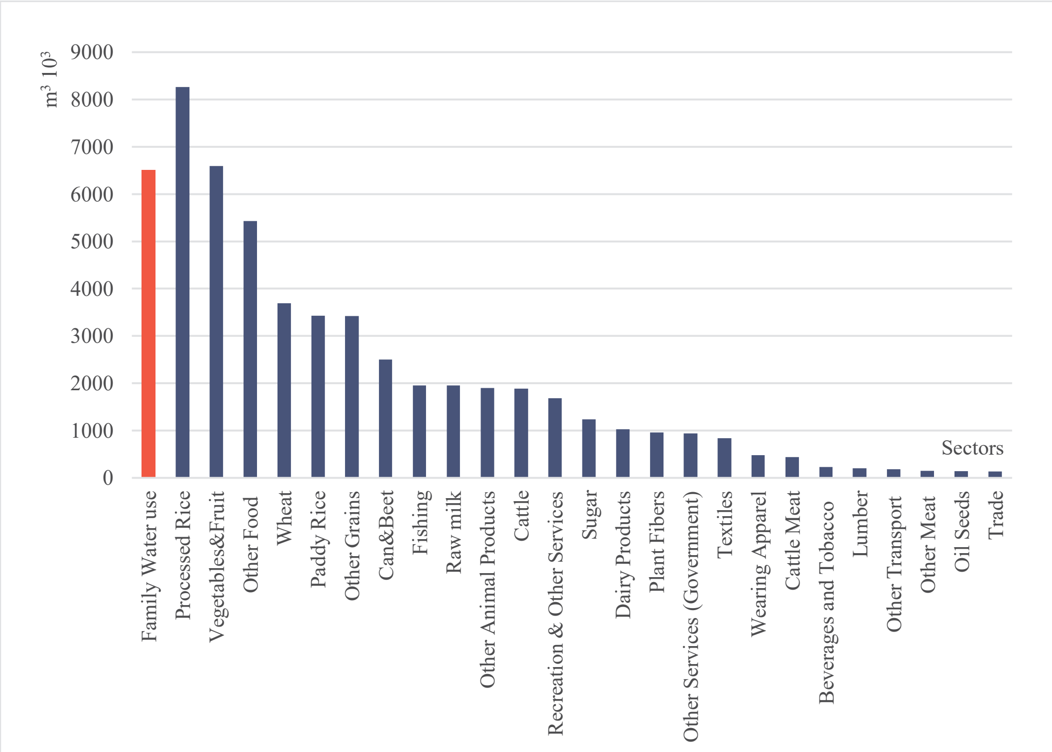

Fig. 5- Households $NWF_{product}$ vs. family water use for top 25 NWF products.

5.2.2 Urban/ rural households water use

Using two Egyptian final expenditure categories for urban and rural areas, $NWF_{product}$ is calculated for each area (government`s NWF is excluded). Results of 57 products are summed up into 23 product groups and presented in (Table 1). Because of the larger population, total $NWF_{product}$ for the rural exceeds that for the urban. However, the average $NWF_{product}$ per capita for the urban is 16.6% higher than that for the rural. This is due to the following reasons: (1) different consumption patterns between urban and rural. The cattle and animal product, for example, accounts for 18% of the urban $NWF_{product}$ per-capita, while it accounts for 13% of the rural $NWF_{product}$ per-capita.[14] (2) different intraregional (domestic) water consumption multipliers for Egypt products; where edible products have the highest fractions.[15] Thus, we can conclude that reducing urban and rural intakes from domestically water reliant products that they consume heavily (agricultural, cattle and animal products for urban, and agricultural and other food for rural) can significantly contribute to reduce their NWF and conserve the country's domestic water.

[14] Fractions of $NWF_{product}$ per-capita of 23 product group for urban & rural populations are presented in (Figure S2) in the supplementary material.
[15] For further detailed results about the intraregional $m\ (w)^{ee}$ and interregional $m\ (w)^{re}$ water consumption multipliers for 57 Egypt products, see supplementary material, (Table S3), and (figure S3)

Table 1- Egypt $NWF_{product}$ for Urban and Rural Categories		
Product Groups	NWF_{rural}	NWF_{urban}
Units	10^6 m^3	10^6 m^3
Textiles	841.9	616.9
agricultural products	15,392.2	11,472.2
Other Manufacturing	4.3	3.3
Fishing	1,108.1	870.4
Trade	72.6	62.9
Insurance &Financial Services	16.8	15.4
Other Food	3,471.4	3,152.9
Beverages and tobacco	120.8	109.8
Other Business Services	4.1	3.8
cattle and animal products	3,444.4	3,937.4
Water	0.02	0.03
Electronic &Machinery Equipment	4.2	5.5
Dwellings	13.9	18.1
Paper & Paper Products	9.7	13.2
Other Transport	97.6	135.7
Lumber	84.9	120.2
Chemical, Rubber, Plastic	32.4	46.1
Non-Metallic Minerals	5.8	10.8
Communications	32.7	61.9
Other Services (Government)	324.7	622.2
Recreation & Other Services	546.4	1,143.3
Energy	8.6	23.1
Motor Vehicles & Transport Equipment	3.9	10.4
Total (10^6 m^3)	25,641.4	22,455.3
population (10^6 m^3)	42.9	32.2
NWF (per-capita)	597.1	696.3

6. Conclusion and implications

The conservation or depletion of a country`s water resources can be significantly affected through its international trade volume, as well as its population's patterns of expenditure on goods and services. Due to the serious current state of Egypt water crisis, this study had two fundamental goals: [1] Tracing the effects of Egypt Virtual Water (VW) trade on its real water availability; and [2] analyzing the effects of household's consumption patterns on Egypt's water availability. We thus conducted a consumption-based analysis of water use in Egypt, using an interregional input-output (IRIO) model between Egypt and the Rest of the World (RoW). Achieving the first goal, Egypt's National Water Footprint (NWF) and it`s (VW) net exports for 57 sectors of production are calculated. Our results indicate that Egypt saves 8% from its NWF through importing water-intensive products, especially wheat. However, Egypt virtually net-exported 12% of its total available freshwater resources embodied mainly in the "Other crops" product group (Feed plant, alfalfa, beans, fenugreek, chickpeas, lentils, lupine, medical and aromatic plants, henna) as well as paddy rice, and vegetable and fruits. To fulfil the study's second goal, we compared the households' NWF per product with their direct water use. We also distinguished urban and rural NWF per product, according to patterns of expenditure. Our results indicate that (a) the water embodied in edible products that households consume annually is more than sevenfold their direct water consumption, and (b) the NWF per capita is roughly 17% higher for the urban population than for the rural. This is because urban citizens consume larger quantities of almost all products. The water embodied in household consumption in Egypt can be seen to be exacerbating the water scarcity crisis. This effect is particularly seen in the consumption of water-intensive agricultural and animal products.

Our results show the need to monitor the virtual flows of freshwater when exploring freshwater scarcity. Focusing on direct water use, as is conventional practice, ignores the role of trade as a driver of water shortages. Countries must consider both the territorial and international demand for freshwater resources to enhance both our understanding of the security of food supply (which is very water intensive), and broader issues of sustainability through the link between freshwater resources, human well-being, and economic development. Embodied water calculations moreover open up different policy avenues to reduce risks of water shortages. Embodied water use can enable the identification of opportunities to reduce the indirect reliance on scarce water resources, such as how diets or fiscal incentives on water, food and other resources drive freshwater use. By understanding the impact of different socio-demographics (in our case urban and rural), we can explore the distribution of resources across the population and identify demand-side water saving strategies that will not affect people's basic access to food and water.

In Egypt, applying trade policies that stimulate water-intensive imports and reduce their exports, such as pricing irrigation water rather than totally subsidizing it, may have an effect. However, policies need to be evaluated with caution, as they might have important social impacts. Directing household choices towards lower water-intensity products may alleviate water scarcity. However, since household choices are affected by diverse factors, including their awareness, tastes, income, product prices, geographic location, and diet/culture, several complementary specific policies may need to address each of these aspects. Product labelling, for instance, may be a good tool for raising awareness, but alone will not be sufficient to address the issue. Complementary upstream policies, such as incentives subsidizing lower water-intensity products, rather than their thirsty counterparts, and reflecting water costs in the price of water-intensive products, may have a larger effect on changing consumption patterns but should be applied with caution to avoid hindering development.

Finally, this study is an initial attempt to analyze Egypt's NWF through trade and consumption. We chose to use the GTAP-Water GAP model developed in Holland et al. (2015) as it treats the agriculture sector as multiple sectors with different freshwater use requirements, however, the latest year available was 2007. Other IO databases were deemed unsuitable: for example, EORA does not have a disaggregated agricultural sector, and EXIOBASE is a European-centric model and therefore does not represent Egypt as a standalone country.

An up-to-date IO table would clearly improve this study - however, GTAP is not updated on an annual basis, making it difficult to capture dynamic changes. On the other hand, water use, and availability are constantly influenced by dynamic changes in both the economy and natural circumstances. For example, floating the exchange rate, an economic policy action taken at the end of 2016, affects the Egyptian trade balance and indirectly its water resources. Those effects could be traced in further analysis using an updated IO table for the time following the implementation of this policy. Further research could analyze households' water footprint according to their income distribution, to identify which income class has the highest domestic water footprint. This could open avenues for policymakers in Egypt to apply more socially inclusive water policies.

Acknowledgements

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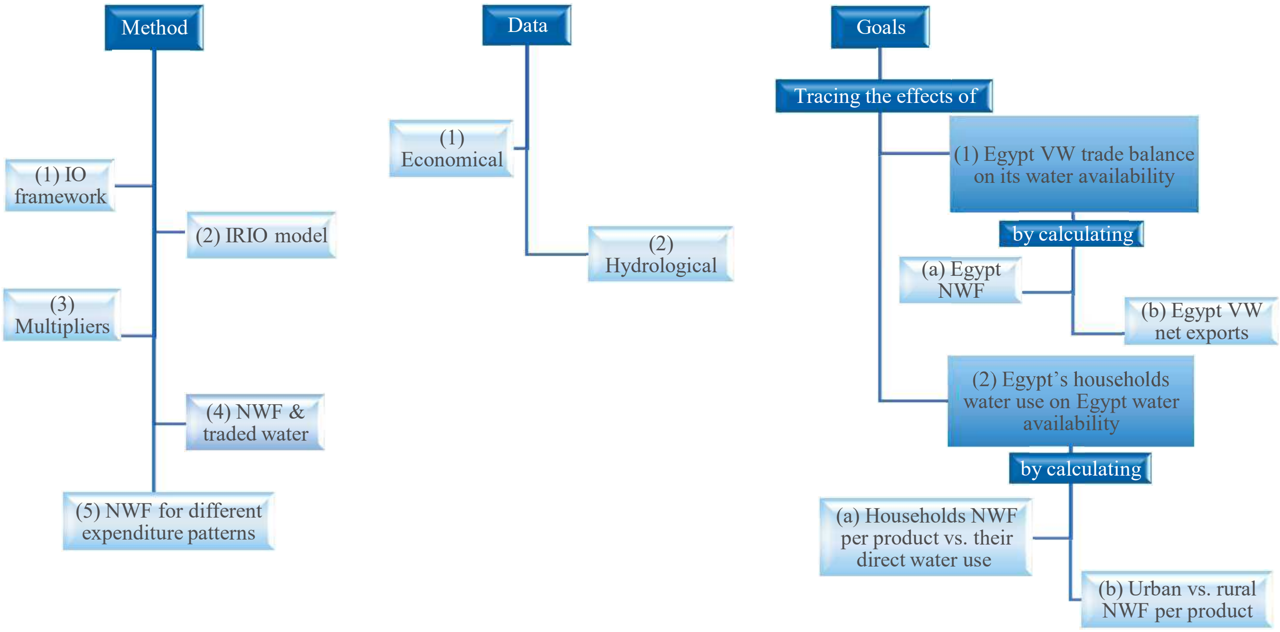
Figure captions List

Highlights (for review)

- Egypt saves 8% of its National Water Footprint through imports.
- Egypt virtually net exports 12% of its total available freshwater resources.
- Households consume 11% of water directly and 89% virtually.
- Urban households national water footprint per capita is 17% higher than rural’s.
- Water Footprinting can be used to make national policy recommendations.

Figure 1



Method
(1) IO framework
(2) IRIO model
(3) Multipliers
(4) NWF & traded water
(5) NWF for different expenditure patterns
Data
(1) Economical
(2) Hydrological
Goals
Tracing the effects of
(1) Egypt VW trade balance on its water availability
by calculating
(a) Egypt NWF
(b) Egypt VW net exports
(2) Egypt's households water use on Egypt water availability
by calculating
(a) Households NWF per product vs. their direct water use
(b) Urban vs. rural NWF per product

Figure 2

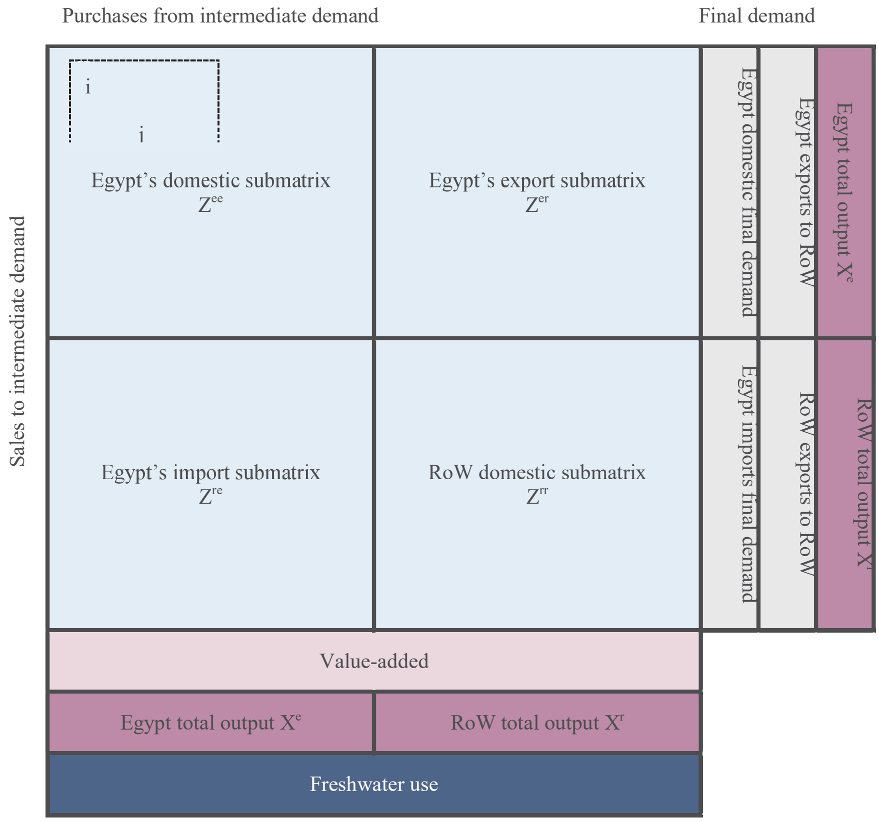
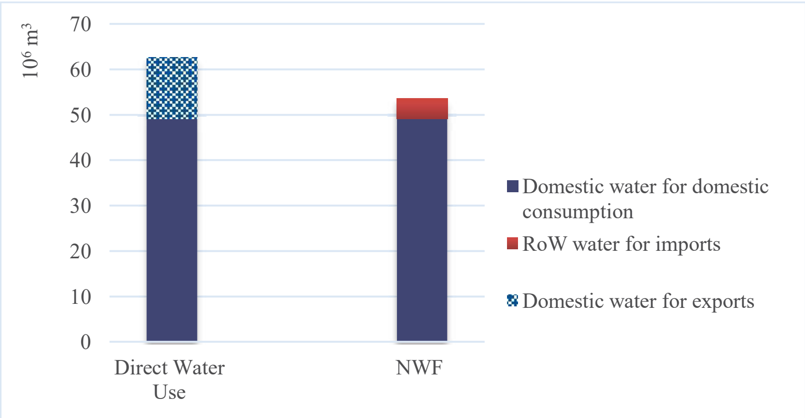

Purchases from intermediate demand
Final demand
Sales to intermediate demand
i
j
Egypt’s domestic submatrix
Z^ee
Egypt’s export submatrix
Z^er
Egypt domestic final demand
Egypt exports to RoW
Egypt total output X^e
Egypt’s import submatrix
Z^re
RoW domestic submatrix
Z^rr
Egypt imports final demand
RoW exports to RoW
RoW total output X^r
Value-added
Egypt total output X^e
RoW total output X^r
Freshwater use

Figure 3



10^6 m^3
70
60
50
40
30
20
10
0
Direct Water Use
NWF
Domestic water for domestic consumption
RoW water for imports
Domestic water for exports

Figure 4

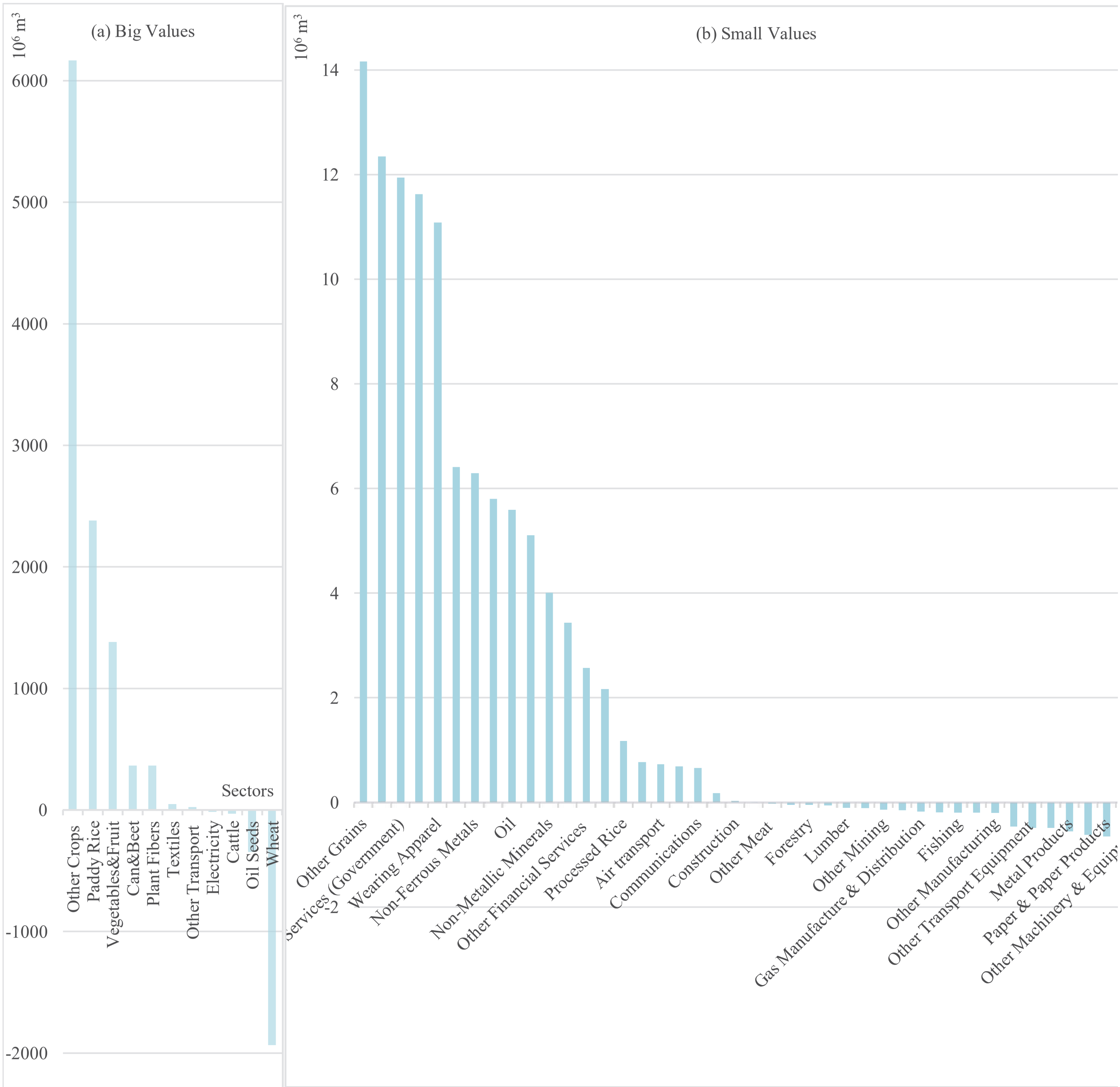
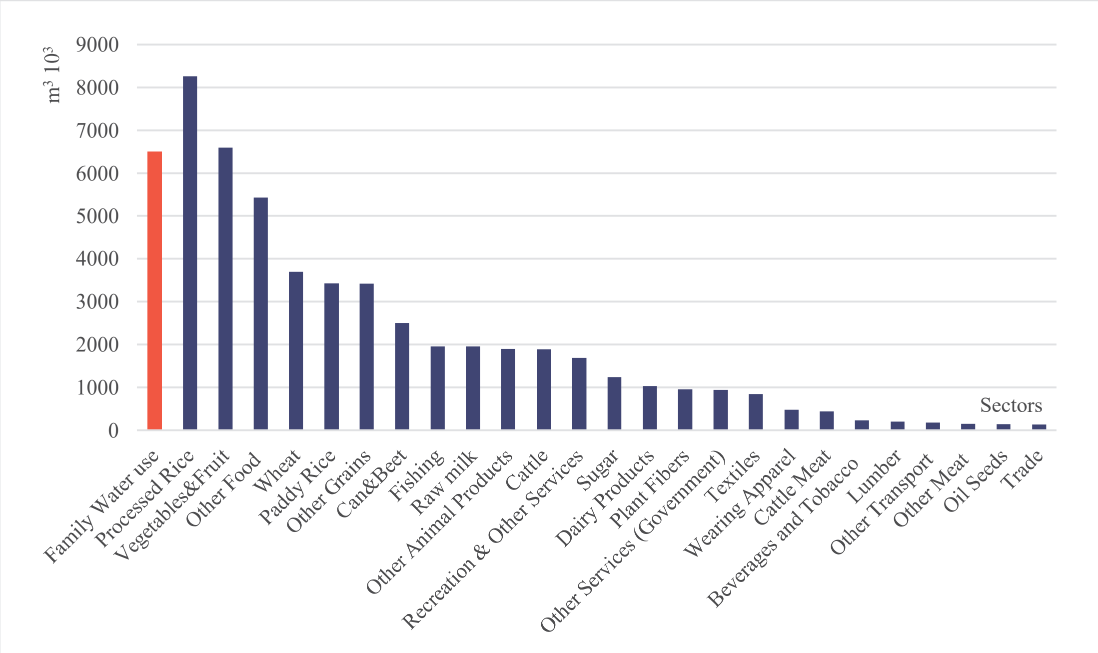

(a) Big Values
10^6 m^3
6000
5000
4000
3000
2000
1000
0
-1000
-2000
Sectors
Other Crops
Paddy Rice
Vegetables&Fruit
Can&Beet
Plant Fibers
Textiles
Other Transport
Electricity
Cattle
Oil Seeds
Wheat
(b) Small Values
10^6 m^3
14
12
10
8
6
4
2
0
-2
Other Grains
Services (Government)
Wearing Apparel
Non-Ferrous Metals
Oil
Non-Metallic Minerals
Other Financial Services
Processed Rice
Air transport
Communications
Construction
Other Meat
Forestry
Lumber
Other Mining
Gas Manufacture & Distribution
Fishing
Other Manufacturing
Other Transport Equipment
Metal Products
Paper & Paper Products
Other Machinery & Equip

Figure 5



m³ 10³
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Sectors
Family Water use
Processed Rice
Vegetables&Fruit
Other Food
Wheat
Paddy Rice
Other Grains
Can&Beet
Fishing
Raw milk
Other Animal Products
Cattle
Recreation & Other Services
Sugar
Dairy Products
Plant Fibers
Other Services (Government)
Textiles
Wearing Apparel
Cattle Meat
Beverages and Tobacco
Lumber
Other Transport
Other Meat
Oil Seeds
Trade

Table 1

Table 1- Egypt $NWF_{product}$ for Urban and Rural Categories		
Product Groups	NWF_{rural}	NWF_{urban}
Units	10^6 m^3	10^6 m^3
Textiles	841.9	616.9
agricultural products	15,392.2	11,472.2
Other Manufacturing	4.3	3.3
Fishing	1,108.1	870.4
Trade	72.6	62.9
Insurance &Financial Services	16.8	15.4
Other Food	3,471.4	3,152.9
Beverages and tobacco	120.8	109.8
Other Business Services	4.1	3.8
cattle and animal products	3,444.4	3,937.4
Water	0.02	0.03
Electronic &Machinery Equipment	4.2	5.5
Dwellings	13.9	18.1
Paper & Paper Products	9.7	13.2
Other Transport	97.6	135.7
Lumber	84.9	120.2
Chemical, Rubber, Plastic	32.4	46.1
Non-Metallic Minerals	5.8	10.8
Communications	32.7	61.9
Other Services (Government)	324.7	622.2
Recreation & Other Services	546.4	1,143.3
Energy	8.6	23.1
Motor Vehicles & Transport Equipment	3.9	10.4
Total (10^6 m^3)	25,641.4	22,455.3
population (10^6 m^3)	42.9	32.2
NWF (per-capita)	597.1	696.3