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Introducing Irrigation Water into GTAP Data Base Version 9

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Water is an essential input in the production processes of all goods and services. However, most economic models ignore water as an essential factor of production. In contrast with other inputs, economic data do not reflect the role of water in the production processes of goods and services and its final value in the demand side. This makes it difficult to incorporate water in economic models, properly examine its role in economic activities, and study its interaction with other inputs in the production processes. Introducing water into an economy-wide database such as Global Trade Analysis Project (GTAP) Data Base which has been widely used by many economic modelers across the world could help them to extend their research agendas on the role and importance of water in economic activities. As the first step towards this direction we divided the crop sectors of the GTAP-Power Data Base (which extends the GTAP Data Base Version 9 by disaggregating the electricity sector) into irrigated and rainfed categories and explicitly included water for irrigation into the cost structure of irrigated crops by river basin at the Agro Ecological Zone (AEZ) level.

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1. **Introduction**

The global ecosystem and social and human activities heavily depend on water (UNESCO, 2012). Water is an essential input in the production processes of all goods and services (Liu et al., 2014). However, most economic models ignore water as an essential factor of production; in essence it is available in infinite supply at zero cost, or when represented, the models misrepresent some of the essential market features of water. Unlike other inputs, water is not an ordinary tradable good and usually it is allocated across uses with non-market mechanisms (Savenije, 2002). In the real world, producers and consumers, in many cases, pay nothing or a negligible amount for their water consumption. Therefore, in contrast with other inputs, economic data do not reflect the role of water in the production processes of good and services. This makes it difficult to incorporate water in economic models, properly examine its role in economic activities, and study its interaction with other inputs in the production processes.

In recent years, several attempts have been made to bring water into economic models and provide economic analyses around this essential input. The more successful efforts in this area aimed at bringing water into the stylized models which have attempted to study small economies at a river basin level. In a background paper for the U.S. Environmental Protection Agency (EPA) on the importance of water to the U.S. Economy (U.S. EPA, 2013), Fadali et al. (2012) have reviewed many of these models. Only a few notable attempts were made to introduce water into multi-sectoral multi-regional large scale economic models which trace production and consumption of a wide range of goods and services at the global scale. Important efforts were limited to Berrittella et al. (2007), Calzadilla et al. (2011), Rosegrant et al. (2013), Robinson et al. (2016), and Winchester et al. (2016).

Though largely un- or under-represented in most economic models, water is clearly an essential input to economic activity. There are several reasons to consider water in a general equilibrium context and thus the need for developing an economy-wide database for water use and markets:

- Water is used in almost all economic activities and thus impacts on water use in one sector clearly have implications in other sectors. The observed droughts around the world (currently in California, and many parts of Middle East) clearly illustrates these economy-wide impacts and the trade-offs between agricultural and non-agricultural use of water.
- There are strong indirect linkages across sectors that are influenced by water use. A drought will put pressure on the price of raw agricultural commodities with feedbacks on downstream sectors—food processing,

transportation, and trade—and with ensuing impacts on consumer food prices.

- Water influences development patterns. Water scarcity will induce countries to put more resources into activities less dependent on water and/or to choose water-saving production technologies.
- Water availability can have consequential impacts on short- and long-term trade patterns. In the short-term, trade can be influenced by events such as droughts and also create volatility in food prices as witnessed in 2007/08. In the long-term, water-scarce countries are likely to be more dependent on food imports with potential concerns about food security.
- There is a growing national and international interest in the so-called energy-food-water nexus. This refers to the linkages across these three key sectors. Energy requires water for extraction and power generation. Delivery of water to end-users requires energy. Energy is required to produce food—to power farm equipment and for the production of fertilizers and chemicals. The emergence of biofuels as a substitute for conventional energy may impact on food production and water demand.

More recently, irrigation water has been introduced into the Global Trade Analysis Project (GTAP) Data Base as an explicit input.[1] Using this database and an extended GTAP model which explicitly traces demand for and supply of water at the global scale by river basin, several applications have been developed that examine the nexus among climate change, water scarcity, food security and assess their economic and environmental consequences (Taheripour et al., 2013a; Taheripour et al., 2013b; Liu et al., 2014; Liu et al., 2016; and Taheripour et al., 2016).[2] While these publications provide insight on the approach followed to develop these applications and highlight the steps undertaken to introduce water into the GTAP Data Base, they do not provide detailed information on these steps. Moreover, the water-augmented GTAP database developed through these

[1] The focus on agricultural water use is due to the fact that agriculture is the largest user of water resources, with 70% of global freshwater withdrawals being used in irrigation. Given the large share of irrigation in water withdrawal and due to the availability of data here we focused on irrigation water. Clearly, to assess the energy-water-food nexus, water use data in other sectors and in final demand are needed to complete the picture.

[2] Prior to these papers, Calzadilla et al. (2011) introduced water as an explicit input at the national level into an older version of the GTAP Data Base and developed the GTAP-W model. The latest version of MIT's Emissions Prediction and Policy Analysis (EPPA) Model also explicitly includes water (Paltsev et al., 2005).

publications has not been available for use by the broader Computable General Equilibrium (CGE) community.

The key objective of this paper is to provide full details on how water for irrigation has been introduced into the GTAP-Power Data Base (Peters, 2016), which extends version 9 of the GTAP Data Base (Aguiar et al., 2016) by representing the electricity sector in greater detail and provides a snap shot of the global economy in 2011. The water-augmented database, which we call GTAP-Water, is available to users who have a license for the GTAP9 Data Base.

The rest of this paper is organized as follows. The next section introduces biophysical data (including land and water) used in incorporating water into the GTAP-Power Data Base. Section 3 explains the steps which we follow to introduce water in the database. Section 4 highlights some of the key emerging findings from the water-augmented GTAP-Power Data Base such as the allocation of water withdrawals across countries, crops, agro-ecological zones and water basins. Section 5 highlights existing applications of the water database in global CGE models. Section 6 offers concluding remarks and ideas for next steps in using and possibly extending the database.

2. Background and implemented biophysical data

The GTAP-Power Data Base represents cropping activities in 8 distinct sectors: paddy rice (pdr), wheat (wht), coarse grains (gro), vegetable and fruits (v_f), oilseeds (osd), sugar crops (c_b), plant-based fiber (pfb), and other crops (ocr).[3] As explained in the next section, to introduce water for irrigation into the database we first divide each of these sectors into two distinct sectors of irrigated and rainfed. For instance, the wheat sector (wht) is divided into irrigated wheat (whti) and rainfed wheat (whtn) and so on for other crops. Hence, the new database has 16 crop sectors—split into 8 irrigated crop sectors and 8 rainfed crop sectors. Subsequently, each country is divided into several river basins (with a maximum 20 river basins) and each river basin into 18 agro ecological zones (AEZs)[4] to represent heterogeneity in water and land use within each country. The

[3] The list of crops sectors and their coverages are presented in the supporting materials which are available at: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5168.

[4] The concept of AEZ was pioneered by the Food and Agricultural Organization of the United Nations (FAO) (Fischer et al., 2002) and refers to a method of land classification. This method classifies land according to various land characteristics such as soil type, moisture region, climate conditions, etc. The main characteristics of the AEZs are defined in Table A.1 and Figure A.1 represents a global map of AEZs.

International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) developed by the International Food Policy Research Institute (IFPRI) divides the world into 126 river basins,[5] some of which serve several countries (Rosegrant et al., 2013).[6] We follow IMPACT's river basins' boundaries to establish our land and water data. The GTAP land use database divides each country in up to 18 different AEZs (Lee et al., 2005). We mix the layouts of the river basins and AEZs in each country.[7] Therefore, our land and water data items represent the whole world at the spatial resolution of River Basin by AEZ (RB-AEZ).[8]

We use the following data sets to achieve the goals of this paper:

1) **GTAP land use database for 2000 (Lee et al., 2005):** This database provides global harvested area, crop production, and land cover items including forest, pasture, and cropland at a 5-minute spatial resolution for 2000. It builds on the land use database developed by the Center for Sustainability and Global Environment (SAGE) and includes data on harvested area and production for 175 crops[9] using FAO's definitions. This database does not distinguish between irrigated and rainfed crops.
2) **Global irrigated and rainfed crop areas (Portman et al., 2010):** This data set[10] includes global harvested area and crop yields by irrigation type (irrigated and rainfed) at a 5-minute spatial resolution for 2000. It classifies crops into 29 groups.[11] Henceforth, we refer to this data set as PSD.
3) **Crop water requirement (Siebert and Döll, 2010):** This data set represents worldwide information on water requirements for irrigation for 29 crop categories at 5-minute spatial resolution.[12] This database represents water requirements for 2000. Henceforth, we refer to this data set as SD.
4) **Water withdrawal by country in 2011**: This data set is obtained from the FAO's global water information system (AQUASTAT).[13]

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[5] IFPRI divides each basin into several sub regions, named Food Production Units (FPUs).
[6] Mapping of grid cells, river basins, AEZ, and their associated countries is provided in the supporting materials. Table A.3 lists of river basins and their countries/ regions.
[7] As an example, Figure A.2 represents RB-AEZs in the US.
[8] In this paper land area is measured in hectares, crop production in metric tons, and water in cubic meters. In GTAP, monetary values are evaluated in $2011 (at market exchange rates) and the flows in the database are in millions.
[9] The list of these crops are presented in the supporting materials.
[10] Available at: http://www.uni-frankfurt.de/45217892/datensaetze.
[11] The supporting documents list these crops and their mapping to the GTAP 8 crops.
[12] Available at: http://www.uni-frankfurt.de/45217892/datensaetze.
[13] Available at http://www.fao.org/nr/water/aquastat/main/index.stm.

5) **GTAP land use database by country for 2011 (Peña-Lévano et al., 2015):** Unlike the original GTAP land use database for 2000, which provides data at the grid cell level, this database provides data only at the country level. This database does not distinguish between irrigated and rainfed crops. Peña-Lévano et al. (2015) developed this data set using the land use data provided by the FAO Statistical Databases (FAOSTAT).

These data items are used to: 1) split the crop sectors of the GTAP-Power Data Base into irrigated and rainfed categories,[14] and 2) include water as an explicit input into the cost structures of irrigated crops. Including water in the GTAP-Power Data Base provides the potential to include water as an input for hydro power, or for cooling in other power activities, in potential future developments of the database.

3. Steps to introduce water into GTAP Data Base Version 9

The following 7 steps, summarized in Figure 1, describe the processes which we use to develop the new GTAP Data Base.

Step 1. Split GTAP data on harvested area and crop production for 2000 into irrigated and rainfed

Using the harvested area and crop yields embedded in the PSD data set we determine crop production by irrigation type using the following relationship:

$$QPSD_{ij}^{w} = APSD_{ij}^{w} \cdot YPSD_{ij}^{w} \tag{1}$$

In this relationship $QPSD$, $APSD$, and $YPSD$ represent production, harvested area, and yield obtained from the PSD data set, respectively. The indices of i, j, and w stand for crop type (defined over 29 crop categories), grid cell index, and irrigation type (irrigated and rainfed), respectively. This data set (including harvested area and crop production) is then aggregated from the grid cell level to the RB-AEZ level and from 29 crops to the 8 crop categories of GTAP by irrigation type (i.e. 8 for irrigated crops and 8 for rainfed crops).

[14] As noted above, the GTAP-Power Data Base is an electricity-detailed extension of the GTAP9 Data Base. This database splits the single electricity sector in the standard GTAP database into 11 power-generating activities (e.g. coal, gas, nuclear, etc.) plus an additional transmission and distribution activity. If desired, sectors in the GTAP-Power Data Base can be easily aggregated to those represented in the GTAP9 Data Base.

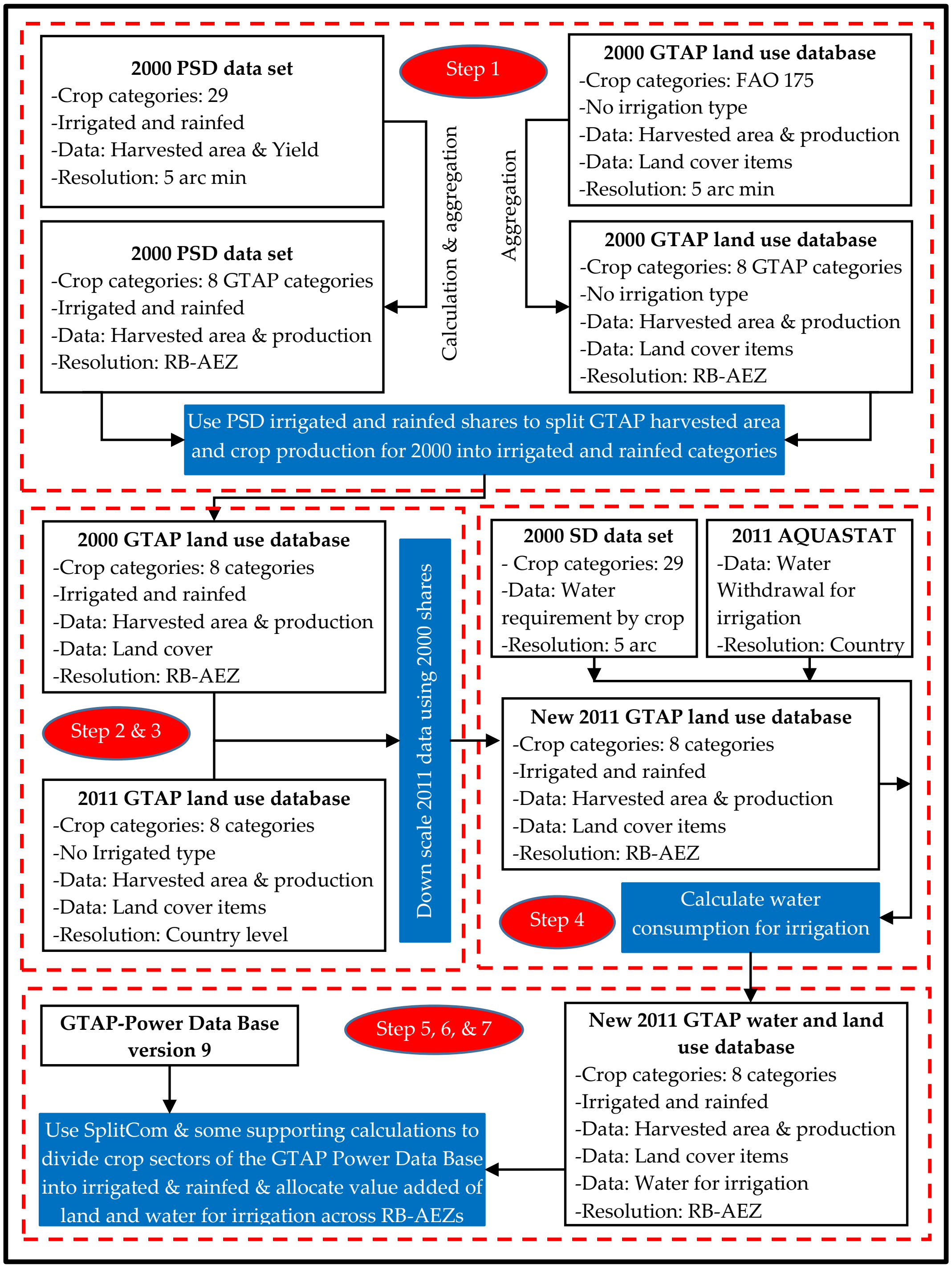

Figure 1. Workflow diagram for the construction of the GTAP-Water Data Base
Source: Authors.

Subsequently, the harvested area and crop production data from the GTAP land use database for 2000 are aggregated from the grid cell level to the RB-AEZ level and from 175 crops to the 8 crop categories of GTAP. Once spatially aggregated, the following relationships are used to split this aggregated data set between the irrigated and rainfed crop categories at the RB-AEZ level:

$$QGTAP_{irz}^{w} = \left[\frac{QPSD_{irz}^{w}}{\sum_{w} QPSD_{irz}^{w}}\right] \cdot QGTAP_{irz} \quad (2)$$

$$AGTAP_{irz}^{w} = \left[\frac{APSD_{irz}^{w}}{\sum_{w} APSD_{irz}^{w}}\right] \cdot AGTAP_{irz} \quad (3)$$

In these relationships variables started with letter "Q" represent the quantity of production and variables started with letter "A" represent harvested area. Other capital letters represent the name of data sets and the indices are i, r, z and w which stand for crop type (including 8 GTAP crop categories), country, RB-AEZ, and irrigation type, respectively. The top panel of Figure 1 summarizes the process used in step 1.

Step 2. Down scale 2011 country-level harvested area and crop production data to the RB-AEZ level by irrigation type

Peña-Lévano et al. (2015) provides data on crop production and harvested area by country for 8 GTAP crop categories for 2011. As shown in the middle left panel of Figure 1, these data items are divided into rainfed and irrigated and down scaled to RB-AEZ according to their corresponding distributions in 2000, obtained from step 1.

Step 3. Down scale 2011 country-level data on land cover items to the RB-AEZ level

Peña-Lévano et al. (2015) also provides data on land cover items by country for 2011. These data items were down scaled to RB-AEZ level according to their corresponding distributions obtained from the GTAP land use database for 2000, as presented in the middle left panel of Figure 1.

Step 4. Calculate water withdrawal for irrigation

To determine water withdrawal (W_{irz}) by crop, country, and RB-AEZ for 2011 we follow two sub steps. First, water requirement ($W0_{irz}$) for irrigation is calculated using the following relationship:

$$(W0_{irz})_{2011} = RSD_{irz} \cdot (QGTAP_{irz}^{irrigated})_{2011} \quad (4)$$

In this relationship RSD represents water requirement for irrigation and is obtained from the SD data set and the indices correspond with those used in equations (2) and (3). Then the following relationship is used to determine W_{irz}:

$$(W_{irz})_{2011} = \left[\frac{(W0_{irz})_{2011}}{\sum_i \sum_z (W0_{irz})_{2011}}\right] \cdot (WAQUASTAT_r)_{2011} \quad (5)$$

In this relationship, $WAQUASTAT_r$ represents water withdrawal for irrigation in country r obtained from the FAO AQUASTAT database. The second step, therefore, scales the initial estimate, $W0$, so that aggregate water withdrawal for irrigation lines up with FAO's aggregate level. The middle right panel of Figure 1 summarizes this step.

Note that $\sum_i \sum_z W_{irz}$ shows total water withdrawn for irrigation in region r from different water sources. A portion of water withdrawal could return to the surface and/or underground resources and be used again. Therefore, water withdrawal may overestimate net consumption of water.

Steps 5. Split crop sectors in the GTAP-Power Data Base into irrigated and rainfed

We run the *SplitCom* program (Horridge, 2005) sequentially to split each crop sector of the GTAP Power Data Base into irrigated and rainfed. To accomplish this task, we assume that 1) irrigated and rainfed products are homogeneous; 2) irrigated and rainfed crop producers pay the same price for a given input except for land; and 3) input requirements per unit of output are the same for rainfed and irrigated crops except for land which is more productive under irrigation (and earns a higher return). These assumptions imply that the cost shares are the same for each input used in the two irrigated and rainfed counterparts for each crop. Therefore, the value of output per hectare will be higher on irrigated land, and thus the returns to irrigated land will also be higher. That is because yield per hectare is higher on irrigated land. Under these assumptions, we use the irrigated and rainfed shares in the total production of each crop (measured in metric tons and obtained in step 3 as presented in the bottom panel of Figure 1) to split each crop activity into irrigated and rainfed at the country spatial level.[15]

Step 6. Distribution of value added of land across RB-AEZ

The standard GTAP Data Base contains three matrices which represent value added of endowments: land, labor, capital, and resources. These matrices are *EVFA*, *VFM*, and *EVOA*. The first two matrices represent value added of

[15] Note that we split GTAP production value data using estimates of production in metric tons. While this does not create an issue for GTAP crop sectors that include a single crop and or several homogenous crops, for sectors such as "other crops", it implicitly assumes that the share of individual crops in total other crop production is the same on irrigated and rainfed land. It equivalently implies, share of irrigated production is similar for all individual crops across "other crop" category.

endowments by sector for each country at agent and market prices, respectively.[16] The last item represents total value added of each endowment at the national level and represents the post-tax distribution of factor income. In this step, we distribute the land value added of the land-using sectors (i.e. crops, forestry, and livestock) of each country across the RB-AEZs. In what follows, we use *EVFALAND*, *VFMLAND*, and *EVOALAND* to represent the land value added items in the three matrices described above. We add a "0" character at the end of these matrices as a suffix to differentiate the results of this stage from the results of the next step where we split the land value added of the irrigated crop sectors between land and water. Hence, in this step we use *EVFALAND0, VFMLAND0*, and *EVOALAND0* to represent the land value added items.

In each country, the national level land rent paid by crop sectors are downscaled according to their corresponding production distributions across RB-AEZs obtained from previous steps, as shown in the lower panel of Figure 1. For instance, we used the following relationship to distribute the *EVFALAND0* of crop sectors across RB-AEZs:

$$(EVFALAND0_{irz}^{w})_{2011} = \left[\frac{(QGTAP_{irz}^{w})_{2011}}{\sum_z (QGTAP_{irz}^{w})_{2011}}\right] \cdot (EVFALAND0_{ir}^{w})_{2011} \qquad (6)$$

In this relationship indices match those used in equations (2) and (3). We repeat this equation to calculate $(VFMLAND0_{irz})_{2011}$.

For the land value added of the forestry and livestock sectors we implement the following steps:

1) The value added at the national level is allocated across AEZs, according to their corresponding distributions in 2001 in recognition of the work by Lee et al. (2005) in distributing the land value added of forestry and livestock sectors across AEZs.
2) The following relationship is used to divide the AEZ land value added of the forestry and livestock sectors across river basins:

$$(EVFALAND0_{irz})_{2011} = \left[\frac{(AGTAP_{irz|b})_{2011}}{\sum_b (AGTAP_{irz|b})_{2011}}\right] \cdot (EVFALAND0_{irAEZ})_{2011} \quad (7)$$

In this equation $(AGTAP_{irz|b})_{2011}$represents the area of land used in sector *i* (including ruminants (ctl), raw milk (rmk), and forestry (frs)), in region *r*, and RB-AEZ *z* of river basin *b* in 2011, which is an output of step 3 explained above.

[16] In essence, *VFM*, is the payment received by the owner of the endowment, for example labor or land, and *EVFA* represents the cost of the endowment to the producer, i.e. inclusive of factor taxes and/or subsidies.

We repeat this process to calculate $(VFMLAND0_{irz})_{2011}$. Then, given the tax rate on land by country (obtained from the GTAP-Power Data Base and represented by $TOLAND_r$), the following relationship is used to calculate $EVOALAND0_{rz}$ for 2011:

$$(EVOALAND0_{rz})_{2011} = (TOLAND_r)_{2011} * \sum_i (VFMLAND0_{irz})_{2011} \quad (8)$$

In this equation, index i includes all land-using sectors including crops, livestock (ctl and rmk), and forestry (frs).

Step 7. Determine value added of water in irrigated crops by RB-AEZ

In general, productivity of irrigated cropland (in this step measured by rent per hectare of cropland) is higher than its rainfed counterpart in each RB-AEZ. This difference represents the contribution of water to crop production on irrigated cropland. We use this important fact to determine the value added of water (represented by $EVFAWATER$) according to the following formula:

$$EVFAWATER_{irz}^{irrigated} = \left[\frac{EVFALAND0_{irz}^{irrigated}}{AGTAP_{irz}^{irrigated}} - \frac{EVFALAND0_{irz}^{rainfed}}{AGTAP_{irz}^{rainfed}}\right] AGTAP_{irz}^{irrigated} \quad (9)$$

Note that all variables included in this equation represent values (or areas) at estimated 2011 levels. Using the results obtained from this relationship, we then determined the value added of land in irrigated crop sectors for 2011:

$$EVFALAND_{irz}^{irrigated} = EVFALAND0_{irz}^{irrigated} - EVFAWATER_{irz}^{irrigated} \quad (10)$$

In using equation (9) we enforce the following restriction as well:

$$0.1 \le \frac{EVFAWATER_{irz}^{irrigated}}{EVFAWATER_{irz}^{irrigated} + EVFALAND_{irz}^{irrigated}} \le 0.9 \quad (11)$$

This restriction is used to take into account two unusual cases. First, in some cases the difference between the irrigated and rainfed yields are negative, positive but negligible, or zero. In these cases, equation (9) is replaced with $EVFAWATER_{irz}^{irrigated} = 0.1 \times EVFALAND0_{irz}^{irrigated}$. Second, in some cases where $AGTAP_{irz}^{irrigated}$>0 and $AGTAP_{irz}^{rainfed}$=0, then equation (9) is replaced with $EVFAWATER_{irz}^{irrigated} = 0.9 \times EVFALAND0_{irz}^{irrigated}$.

We follow the same process to determine $VFMWATER_{irz}$ and $VFMLAND_{irz}$. Then, assuming that the tax rates on land and water are identical, we also determined $EVOAWATER_{rz}$ and $EVOALAND_{rz}$. Finally, it is important to note that for the rainfed crops and other land-using sectors (forestry and livestock) we assume that water does not contribute to value added.

4. Alternative versions of GTAP-Water Data Base

Four versions of the water-augmented GTAP-Power Data Base are available for use by the GTAP community.[17] These versions all use the same underlying data but differ with respect to the spatial representation of irrigated and rainfed crop production and regional aggregation. The first two versions represent water and land use at the national level for 140 countries/regions.[18] The next two versions represent the water and land use by RB-AEZ, but aggregate the 140 regions in the full database into 19 regions. This aggregation was implemented because RB-AEZs are not additive across countries/regions. A special program is needed to accomplish this task and the full version of the GTAP-Water Data Base will be available after we have developed a user-friendly program to aggregate RB-AEZs across countries/regions.

4.1 GTAP-Water-V9-A

This version represents the split of crop sectors into irrigated and rainfed and includes the value added of water in the irrigated crop sectors. However, it aggregates away the land and river basin dimensions and thus represents value added of land and water at the national level. This database preserves the main characteristics of the standard GTAP database and represents one activity for each commodity and vice versa. Hence, this version represents 16 crop production activities (8 irrigated crop producers and 8 rainfed crop producers) and 16 crop commodities (including 8 irrigated crops and 8 rainfed crops). In this database, for each crop type, we have two producers and two commodities. For example, we have irrigated and rainfed wheat producers and also two commodities of irrigated wheat and rainfed wheat.

4.2 GTAP-Water-V9-B

This database is similar to the first database regarding the number of production activities, but it represents only 8 crop commodities on the demand side, as irrigated and rainfed varieties of each crop are considered to be homogenous for consumers. For example, in this database, there are two wheat

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[17] These databases are available at: https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=5168. Note that The data are available as header array (.har) files and can be viewed using the ViewHAR program, which can be downloaded (for free) from http://www.copsmodels.com/gpwingem.htm.

[18] The GTAP9 Data Base represents 120 individual countries and the remaining countries are aggregated into 20 composite regions, for example "rest of South Asia".

producers (rainfed and irrigated), but there is only one type of wheat. Therefore, in this database numbers of activities and commodities are different. In modeling terms, the first database (GTAP-Water-V9-A) implies that we have a diagonal make matrix—each production activity produces one and only one commodity. The second database (GTAP-Water-V9-B) implies a non-diagonal make matrix, where, for example, wheat produced by irrigated and rainfed farms, is aggregated to form a single wheat commodity for both domestic and export markets.

4.3 GTAP-Water-V9-RB-AEZ-A

Similar to the first database, this database represents 16 crop producers and 16 crop commodities. Therefore, similar to the standard GTAP Data Base each commodity is produced by only one activity and vice versa. Unlike the first two databases, this database is defined at the RB-AEZ spatial level for crop production (including land and water use) and land in other land using sectors. In this database the land matrices and their corresponding value added items are presented in 360 rows for land (20 river basin times 18 AEZ) and 360 rows for water (20 river basin times 18 AEZ). The same arrangement is used for water. In the value added headers (i.e. *EVFA*, *VFM*, and *EVOA*), the 360 land rows are listed first and the next 360 rows represent water. The land rows are labeled as *XL_BX_AEZX*. Where "*L*" stand for land, the left "*X*" represents the row number in the list of endowments, from 1 to 360. The middle "*X*" shows the number of river basins in a country (from 1 to 20 in each country). The right "*X*" indicates the AEZ number. For example, the first and last rows for the land endowment are labeled as *1L_B1_AEZ1* and *360L-B20_AEZ18*. The same method is used to label the water endowment. So, example, the first and last rows for the water endowment are labeled as *361W_B1_AEZ1* and *720W_B20_AEZ18*.

As mentioned before, in each region there are up to 18 AEZs which indicate different climate and land types as explained in Lee et al. (2005). Also as noted above, each country is divided between several river basins (up to 20 basins). Since many countries only have limited numbers of basins and or AEZs, we aggregate the GTAP-Water-V9-RB-AEZ-A into a 19-region aggregation.[19] The regional description of this database is presented in Table A.2 of the appendix.[20] Tables A.1 of the appendix shows the characteristics of AEZs. And Table A.3 depicts names of river basins by country/region.

[19] Each region in the database is provided space for the full 720 rows, many of which could be full of zeros. A country like Singapore will have values in only a handful of rows.
[20] See the supporting materials for a mapping between GTAP regions and each region of the 19-region aggregation.

4.4 GTAP-Water-V9-RB-AEZ-B

This database is similar to the *GTAP-Water-V9-RB-AEZ-A,* but irrigated and rainfed varieties of each crop are homogenous and sales of these crops are merged together. For example, while there are irrigated and rainfed wheat producers in each region, on the demand side there is only one row (i.e., just one commodity).

5. A descriptive overview of the GTAP-Water Data Base

This section provides a descriptive overview of the GTAP-Water Data Base. We discuss the share of irrigation in harvested area and production. We will also review crop yields. Finally, we summarize water withdrawal data.

5.1 Irrigated and rainfed harvested areas

The GTAP-Water Data Base provides information on irrigated and rainfed harvested areas. Table 1 summarizes this information for a 19 region aggregation of the database and shows the share of each region in global harvested area.

Table 1. Irrigated and rainfed harvested areas in 2011

Region	Area (million hectares)			Distribution across regions (%)		
	Irrigated	Rainfed	Total	Irrigated	Rainfed	Total
USA	19.1	107.1	126.2	6.1	9.2	8.6
EU27	10.3	102.9	113.2	3.3	8.9	7.7
BRAZIL	2.7	65.5	68.2	0.9	5.7	4.6
CAN	0.6	32.8	33.4	0.2	2.8	2.3
JAPAN	2.1	1.5	3.7	0.7	0.1	0.2
CHIHKG	73.1	103.6	176.7	23.4	8.9	12.0
INDIA	74.9	134.1	209.0	24.0	11.6	14.2
C_C_Amer	7.0	19.8	26.8	2.3	1.7	1.8
S_o_Amer	6.0	57.7	63.7	1.9	5.0	4.3
E_Asia	1.9	2.9	4.7	0.6	0.2	0.3
Mala_Indo	8.2	38.5	46.7	2.6	3.3	3.2
R_SE_Asia	18.6	52.5	71.2	6.0	4.5	4.8
R_S_Asia	27.2	19.8	47.0	8.7	1.7	3.2
Russia	3.1	71.5	74.6	1.0	6.2	5.1
Oth_CEE_CIS	13.6	79.9	93.4	4.4	6.9	6.4
Oth_Europe	0.2	1.2	1.4	0.1	0.1	0.1
MEAS_NAfr	22.3	26.9	49.2	7.2	2.3	3.3
S_S_AFR	9.3	200.7	210.1	3.0	17.3	14.3
Oceania	11.6	39.2	50.7	3.7	3.4	3.5
Total	311.8	1158.0	1469.8	100.0	100.0	100.0

Notes: Descriptions of each region label is available in Table A.2. *Source:* Authors' calculations.

As Table 1 shows, global harvested area is about 1,470 million hectares in 2011. Four regions including Sub-Saharan Africa, India, China, and USA had the largest shares in the global harvested areas. Shares of these regions in global harvested area were about 14.3%, 14.2%, 12%, and 8.6% in 2011, respectively. Note that around half of the global irrigated harvested area was located in China and India.

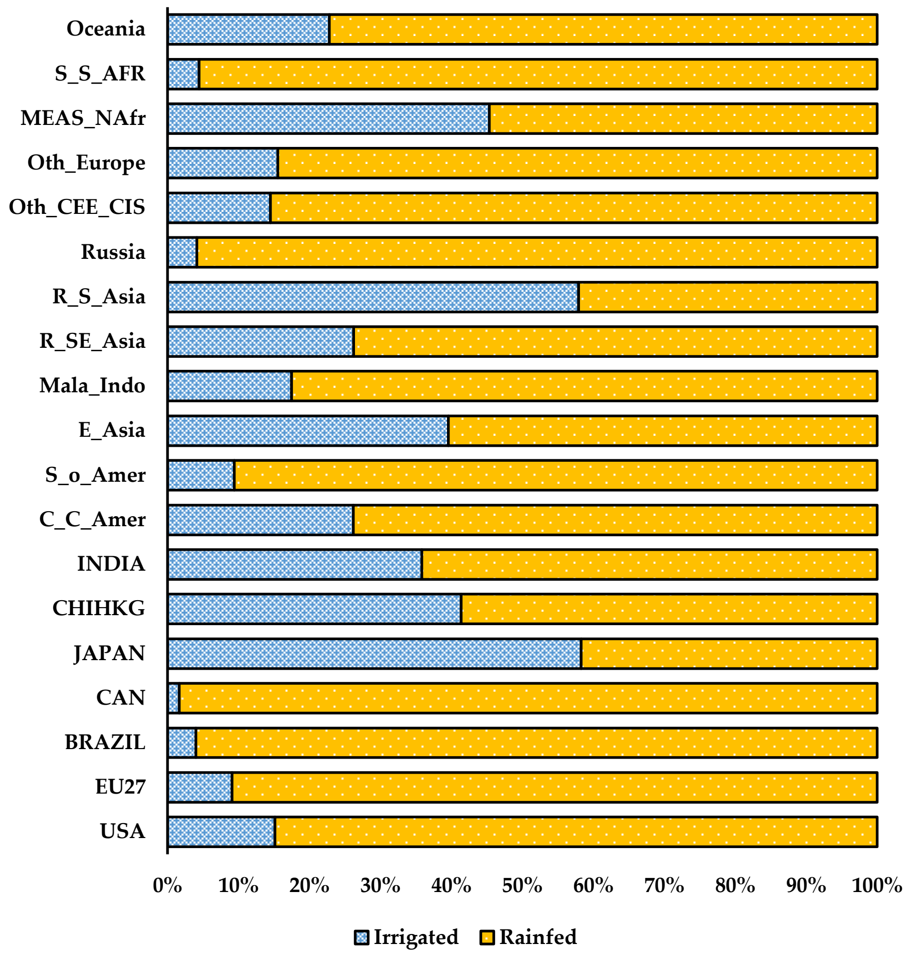

Figure 2. Shares of irrigated and rainfed areas in total harvested areas by region

Source: Authors' calculations.

Figure 2 represents the shares of irrigated and rainfed land in total harvested area of each region. At the global scale, only about 21.2% of the global harvested area was irrigated in this year. However, this share varies significantly by region, as presented in Figure 2. In general, the share of irrigated area in Asia and Oceania was larger than the rest of the world. The share of irrigated harvested area in total harvested area of China and India was 41.4% and 35.8%, respectively. Figure 2 shows that relatively small shares of land are irrigated in Canada and Russia, and also in Brazil and Sub-Saharan Africa, though likely for different reasons.

5.2 Irrigated and rainfed production value

The GTAP-Water Data Base also provides information on production of irrigated and rainfed crops, measured in metric tons and in monetary terms. Table 2 illustrates the monetary values of irrigated and rainfed crop output by region in 2011. The total value of all crops was around $2,725 billion at the global scale in 2011. China, India, European Union, Sub-Saharan Africa, and USA had the largest shares in the global crop production value in 2011. They jointly produced about 60% of the global production in this year.

Table 2. Irrigated and rainfed production value in 2011

Region	Production value (billion US dollars)			Distribution across regions (%)		
	Irrigated	Rainfed	Total	Irrigated	Rainfed	Total
USA	98.8	137.8	236.6	10.9	7.6	8.7
EU27	59.1	217.5	276.6	6.5	12.0	10.2
BRAZIL	21.0	116.9	137.9	2.3	6.4	5.1
CAN	1.0	30.0	31.0	0.1	1.7	1.1
JAPAN	33.5	40.8	74.2	3.7	2.2	2.7
CHIHKG	199.4	336.4	535.8	21.9	18.5	19.7
INDIA	113.7	179.6	293.3	12.5	9.9	10.8
C_C_Amer	31.5	37.0	68.5	3.5	2.0	2.5
S_o_Amer	31.2	90.6	121.9	3.4	5.0	4.5
E_Asia	10.9	16.4	27.3	1.2	0.9	1.0
Mala_Indo	17.7	98.5	116.3	2.0	5.4	4.3
R_SE_Asia	26.2	65.9	92.2	2.9	3.6	3.4
R_S_Asia	43.3	31.4	74.7	4.8	1.7	2.7
Russia	3.5	45.1	48.6	0.4	2.5	1.8
Oth_CEE_CIS	50.0	72.7	122.7	5.5	4.0	4.5
Oth_Europe	1.0	5.2	6.2	0.1	0.3	0.2
MEAS_NAfr	134.0	32.5	166.5	14.7	1.8	6.1
S_S_AFR	20.8	239.5	260.3	2.3	13.2	9.6
Oceania	12.9	21.6	34.5	1.4	1.2	1.3
Total	909.6	1815.6	2725.2	100.0	100.0	100.0

Source: Authors' calculations.

Figure 3 represents the shares of irrigated and rainfed in the total value of crops produced in each region. Globally, about 33% of the production value was irrigated in 2011. As shown in Figure 3, the share of irrigated crop production in the total value of crops varies significantly across regions. Similar to harvested area, the share of irrigated production in the total value of crops produced was relatively large in Asia and Oceania in 2011.

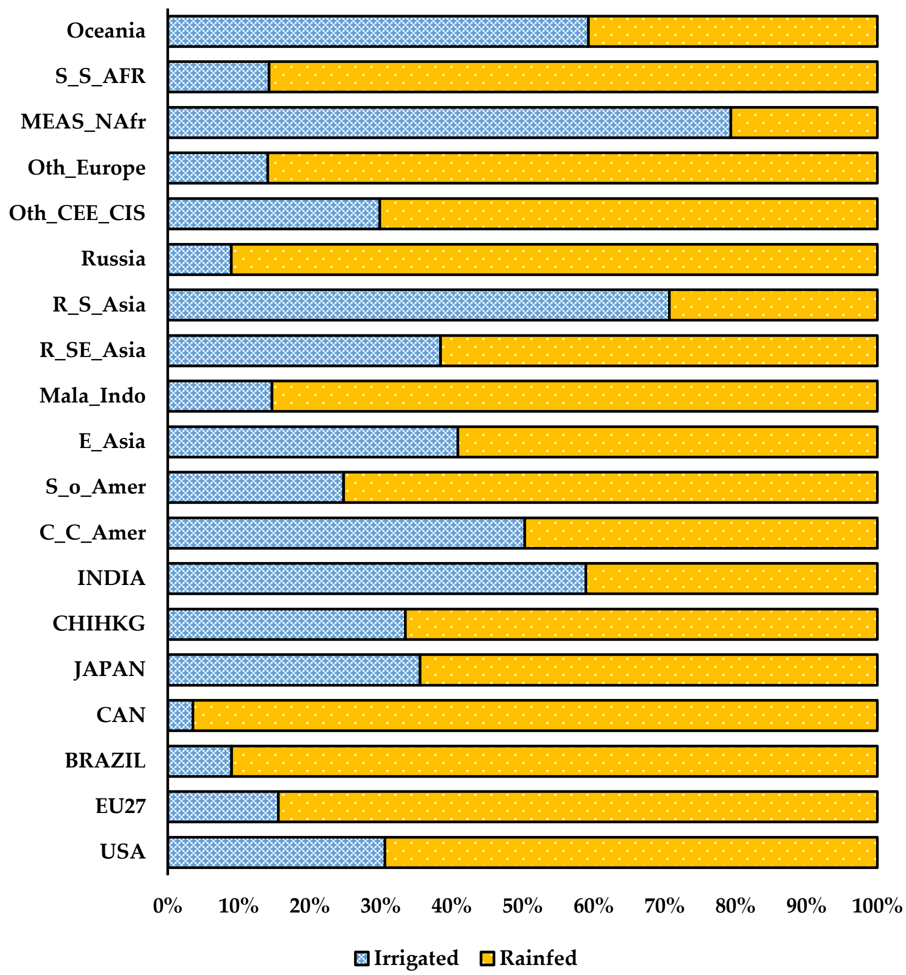

Figure 3. Shares of irrigated and rainfed in total production value by region

Source: Authors' calculations.

5.3 Harvested area by AEZ

Looking at irrigated area by AEZ identifies the relative importance of irrigation in each agro-climatic zone of the planet. The global harvested area by AEZ is presented in Table 3. According to the GTAP-Water Data Base, about 39% of the global harvested area is divided among the three tropical dry AEZs of AEZ7 (10.8%), AEZ8 (14.2%), and AEZ9 (13.5%). The table also shows that the share of irrigated land is relatively large in total harvested area of each of these three AEZs with 47.9% in AEZ7, 28.1% in AEZ8, and 25.4% in AEZ9.

Table 3. Irrigated and rainfed harvested area by AEZ in 2011

AEZ	Area (million hectares)			Distribution across regions (%)			Distribution in each region (%)		
	Irr.	Rfd.	Total	Irr.	Rfd.	Total	Irr.	Rfd.	Total
AEZ 1	8.7	12.6	21.3	2.8	1.1	1.5	40.8	59.2	100
AEZ 2	6.1	48.9	55.0	2.0	4.2	3.7	11.1	88.9	100
AEZ 3	31.1	92.7	123.7	10.0	8.0	8.4	25.1	74.9	100
AEZ 4	26.2	104.9	131.1	8.4	9.1	8.9	20.0	80.0	100
AEZ 5	20.4	117.9	138.3	6.5	10.2	9.4	14.7	85.3	100
AEZ 6	16.4	96.0	112.4	5.3	8.3	7.6	14.6	85.4	100
AEZ 7	33.8	36.7	70.5	10.8	3.2	4.8	47.9	52.1	100
AEZ 8	44.1	112.7	156.8	14.2	9.7	10.7	28.1	71.9	100
AEZ 9	42.1	123.4	165.5	13.5	10.7	11.3	25.4	74.6	100
AEZ 10	24.9	180.3	205.2	8.0	15.6	14.0	12.2	87.8	100
AEZ 11	22.7	88.5	111.2	7.3	7.6	7.6	20.4	79.6	100
AEZ 12	31.4	92.0	123.4	10.1	7.9	8.4	25.5	74.5	100
AEZ 13	1.4	20.7	22.1	0.4	1.8	1.5	6.3	93.7	100
AEZ 14	1.3	9.2	10.5	0.4	0.8	0.7	12.4	87.6	100
AEZ 15	0.9	19.9	20.8	0.3	1.7	1.4	4.5	95.5	100
AEZ 16	0.2	1.6	1.8	0.1	0.1	0.1	9.9	90.1	100
AEZ 17	0.0	0.0	0.0	0.0	0.0	0.0	19.7	80.3	100
AEZ 18	0.0	0.0	0.0	0.0	0.0	0.0	3.4	96.6	100
Total	311.8	1158.0	1469.8	100.0	100.0	100.0	21.2	78.8	100

Notes: "Irr." is used for irrigated and "Rfd." is used for rainfed crops.

Source: Authors' calculations.

5.4 Irrigated and rainfed crop yields

Using harvested area and production information for each crop, we compare the irrigated yield vs rainfed yield. In general, yield is higher for irrigated crops. However, irrigated and rainfed yield difference varies around the world and across crops as presented in Table 4. According to this table USA, EU, and China generate higher irrigated yields in production of various crops compared to other regions. In paddy rice (pdr) production, Oceania, USA, Brazil, and China have the highest irrigated yield among 19 regions while Sub-Saharan Africa has the lowest irrigated yield. In the production of wheat (wht), EU, USA, and Brazil show high irrigation yield and East Asia has the lowest irrigated yield. Looking at cereal grains (gro), USA, EU, Canada, and China have the highest yields while Japan and South Saharan Africa have the lowest yields.

Table 4. Irrigated and rainfed crop yields by region in 2011 (metric tons per hectare)

Region	pdr		wht		gro		v_f		osd		c_b		pfb		ocr	
	Irr.	Rfd.	Irr.	Rfd.	Irr.	Rfd.	Irr.	Rfd.	Irr.	Rfd.	Irr.	Rfd.	Irr.	Rfd.	Irr.	Rfd.
USA	8.1	3.7	6.2	2.8	11.8	8.3	29.3	8.0	3.4	2.7	76.7	54.1	3.9	1.7	36.6	19.4
EU27	6.6	2.2	5.8	5.3	9.7	4.6	27.8	12.7	5.1	2.3	86.2	74.6	2.7	0.6	36.9	26.4
BRAZIL	8.1	3.4	3.9	2.7	4.6	4.1	15.9	9.0	3.3	3.2	99.3	74.5	4.8	3.1	3.0	1.0
CAN			5.4	2.9	7.2	4.5	37.7	4.7	2.5	2.0		64.0	1.2		19.8	12.9
JAPAN	6.7		3.3	3.6	1.8	1.7	20.8	23.5		1.7	56.1	53.3			22.7	36.1
CHIHKG	7.0	4.6	5.1	4.3	6.0	5.0	25.8	16.6	2.6	2.1	65.5	64.0	4.1	3.8	11.6	11.3
INDIA	4.6	2.4	3.2	1.7	2.4	1.4	11.4	4.6	2.0	1.3	72.5	40.3	2.0	1.5	11.3	7.8
C_C_Amer	4.9	3.2	5.5	0.6	3.4	2.5	21.9	5.7	2.8	7.9	75.3	49.6	3.6	0.8	33.4	5.9
S_o_Amer	6.3	3.3	5.9	3.1	4.6	4.3	20.8	9.4	2.9	2.7	88.3	61.0	2.1	1.5	15.9	15.3
E_Asia	6.3	4.7	2.1	1.6	3.4	2.8	16.8	12.6	1.2	1.2			2.3	1.1	3.0	3.0
Mala_Indo	5.8	4.1			5.4	4.5	1.2	12.7	6.7	14.8	49.0	45.8		1.3	1.5	0.7
R_SE_Asia	4.8	3.1	2.2	1.6	4.4	3.3	10.3	8.3	1.3	3.9	81.6	57.2	2.7	1.5	2.7	2.1
R_S_Asia	4.1	3.6	2.8	1.2	3.2	2.1	15.5	4.9	1.3	2.0	61.0	18.1	2.3	2.1	5.2	2.0
Russia	5.1	5.2	3.4	2.2	3.9	2.1	9.9	10.9	2.6	1.3	51.7	37.8	0.9	0.3	15.5	8.2
Oth_CEE_CIS	5.7	0.5	4.1	2.4	5.3	3.4	28.1	9.2	4.6	1.6	62.5	34.8	2.7	1.3	14.3	9.1
Oth_Europe			8.2	5.2	3.6	4.1	20.8	26.8	3.2	3.0	94.2	94.4			17.4	28.4
MEAS_NAfr	6.6	0.4	3.5	1.3	4.2	1.0	18.1	4.7	2.5	0.4	68.7	98.8	3.0	0.3	33.3	12.9
S_S_AFR	2.9	1.7	3.8	2.0	1.9	1.2	11.8	5.1	1.4	1.4	87.1	41.6	0.6	0.8	15.2	2.0
Oceania	10.0	3.6	3.6	2.0	5.2	2.2	21.4	4.2	1.7	2.1	119.7	56.8	3.6	4.4	20.9	6.4
World	5.5	3.0	3.8	2.9	5.9	3.3	19.8	8.6	2.7	3.1	75.2	63.0	2.7	1.9	23.3	12.1

Notes: "Irr." is used for irrigated and "Rfd." is used for rainfed crops. Blank means very low or no production.

Source: Authors' calculations.

The GTAP-Water Data Base can also be used to compare yields across regions. For example, as Table 4 displays, irrigated yields for all crops are below the world average in India, Rest of South Asia, and Russia. Furthermore, rainfed yields for all crops are below the world average in India and Sub-Saharan Africa. However, the user must be careful when comparing broad crop categories like vegetable and food (v_f) or other crops (ocr). It is important to consider the different crop composition of these commodities. For example, yield of oil seed production (osd) is very high in Malaysia-Indonesia compared to the world average for both irrigated and rainfed production technology. This is because palm yield produced in these two countries is large compared to other oilseeds. The next section looks at crop yields in more details.

5.5 Irrigated and rainfed crop yields by AEZ and river basin in USA and China

To learn more about yield differences, we look at yield by AEZ and then by river basin for USA and China. These two regions are selected as they display a variety of AEZs and river basins. In this comparison, we only concentrate on four crop categories: paddy rice ("pdr"), wheat ("wht"), coarse grains ("gro"), and oil seeds ("osd"). There are only a few crops in each of these crop categories. Hence, heterogeneity in each of these crop categories is limited.

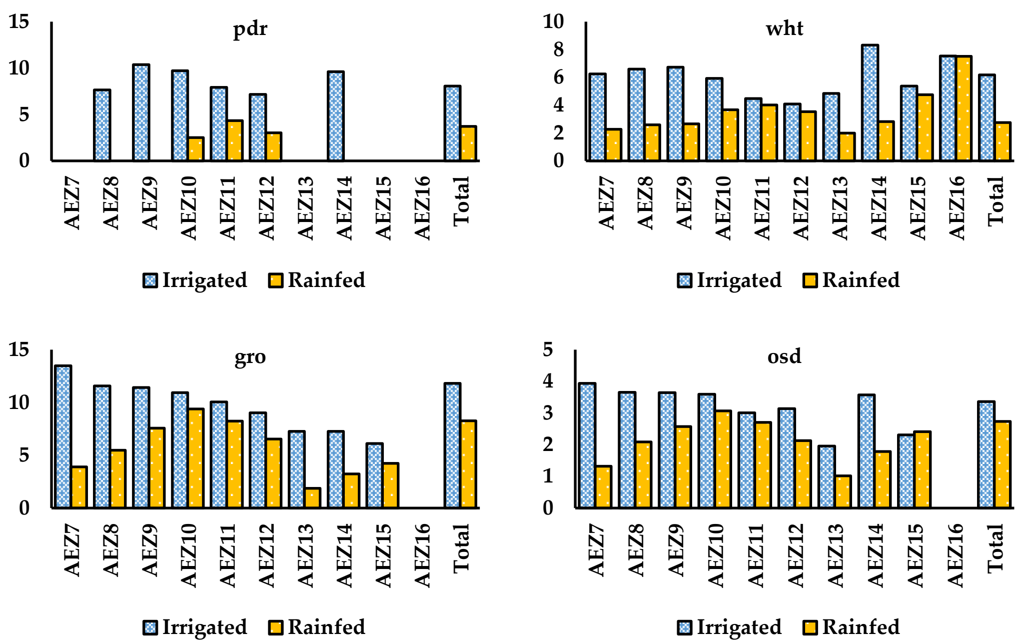

Figure 4. Crop yields by AEZ for USA in 2011 (metric tons per hectare).

Source: Authors' calculations.

Figure 4 illustrates yield for these crops by AEZ in USA. It indicates that for each crop type the irrigated and rainfed yields are very different in most AEZs in the US, in particular in drier AEZs (e.g. AEZ7, AEZ8. AEZ9). In some AEZs like AEZ10, AEZ11, AEZ12 (humid and sub humid temperate areas with major rainfall) the difference between the irrigated and rainfed yields is not large for wheat, cereal grains, and oilseeds.

Figure 5 represents similar information for China as another example. As Figure 5 displays, the irrigation-rainfed yield gap is not large for AEZ10, AEZ11, and AEZ12 for wheat and cereal grains. However, the gap is considerable for paddy rice in all zones.

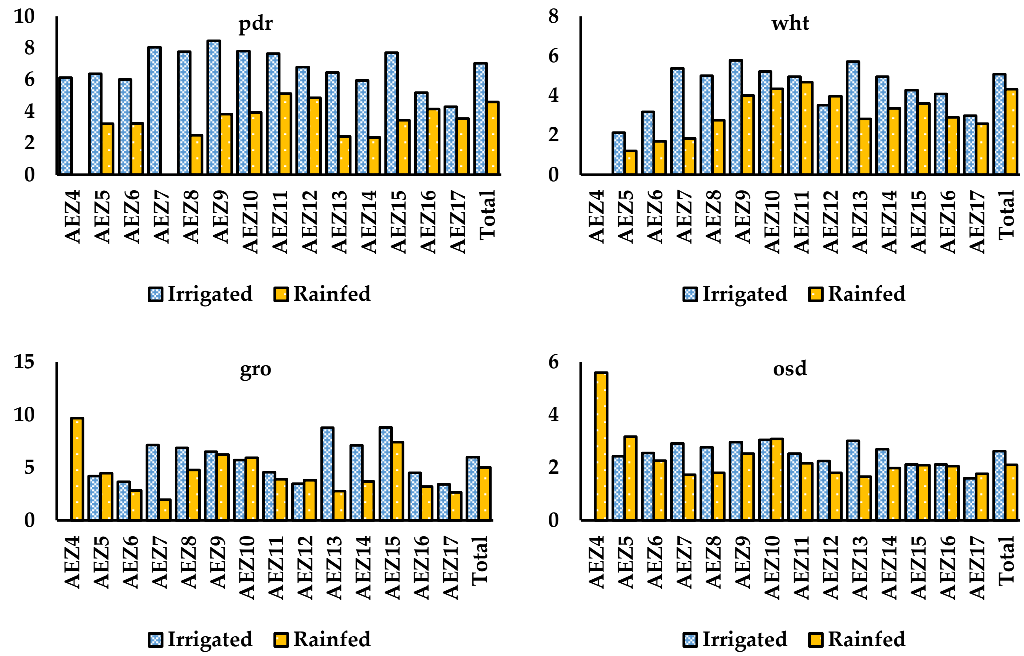

Figure 5. Crop yields by AEZ for China in 2011 (metric tons per hectare).

Source: Authors' calculations.

Figure 6 demonstrates the irrigated and rainfed yields for USA by river basin in 2011, for which we see significant differences across basins. For example, in USA, the yield of irrigated paddy rice is the highest in the California basin (RB2) and is the lowest in the Southeast basin (RB13), respectively 10.4 and 6.7 metric tons per hectare. The irrigated yield for wheat is the highest for the Columbia basin (RB5) and is the lowest for the Red Winnipeg basin (RB11), respectively 8.5 and 3.3 metric tons per hectare.

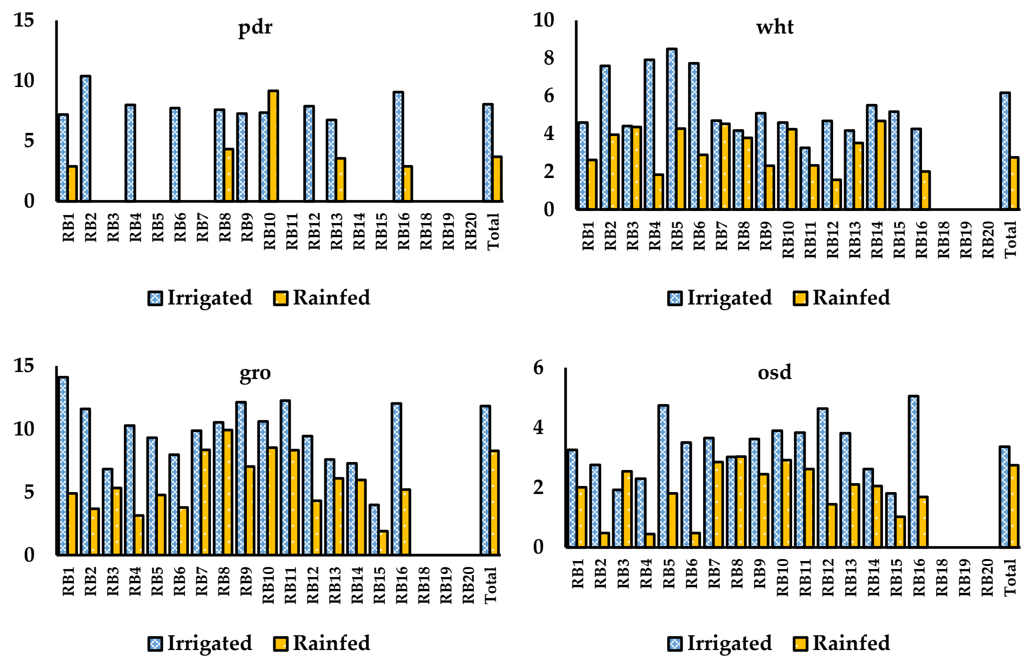

Figure 6. Crop yields by river basin for USA in 2011 (metric tons per hectare).

Source: Authors' calculations.

Figure 7 represents irrigated and rainfed yields by river basin in China. They also confirm that the irrigated and rainfed yields vary significantly across basins. More detailed comparison is possible by considering both river basin and AEZ combinations.

5.6 Water use and distribution

The GTAP-Water Data Base also includes information on the level of water withdrawals, as shown in Table 5. Water withdrawal for irrigation is around 2,982 billion cubic meters (m^3) in 2011. As Figure 8 illustrates, India has the largest water use for irrigation at 710 billion m^3, which is around 24% of global water withdrawal for irrigation. China is the second largest irrigation water user at 434 billion m^3 which is around 14% of global irrigation water use. Another important region in terms of irrigation water withdrawal is Middle East accounting for nearly 11% of global irrigation water withdrawal. The Rest of South Asia and Rest of South East Asia regions are also large water users accounting for some 18% of global irrigation water use. USA has also a large share in irrigation water use, with a level of 181 billion m^3, or 6% of global irrigation water withdrawal.

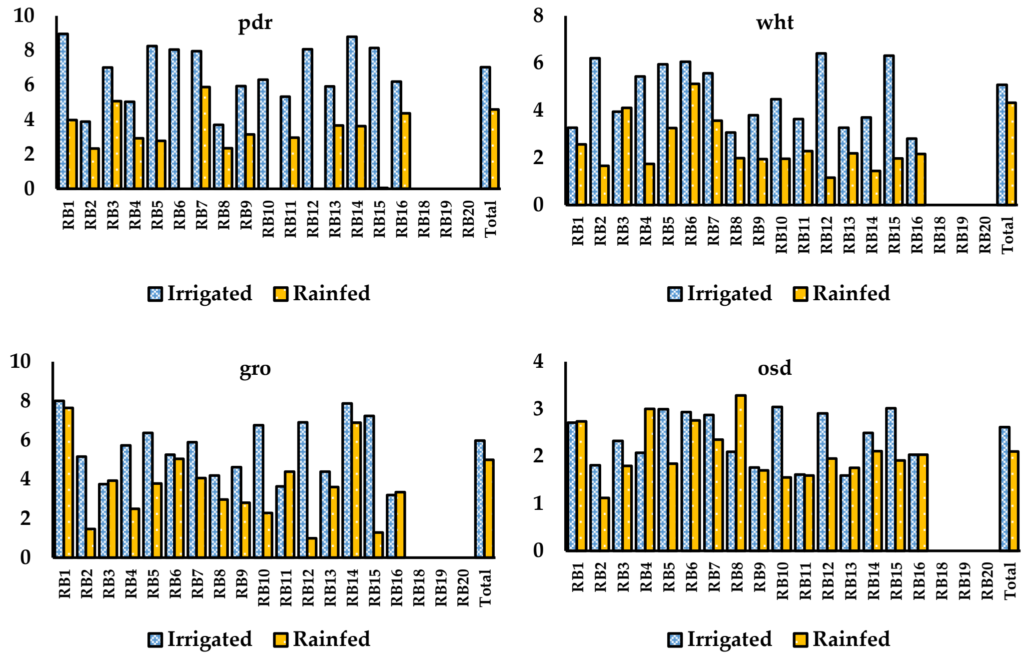

Figure 7. Crop yields by river basin for China in 2011 (metric tons per hectare).

Source: Authors' calculations.

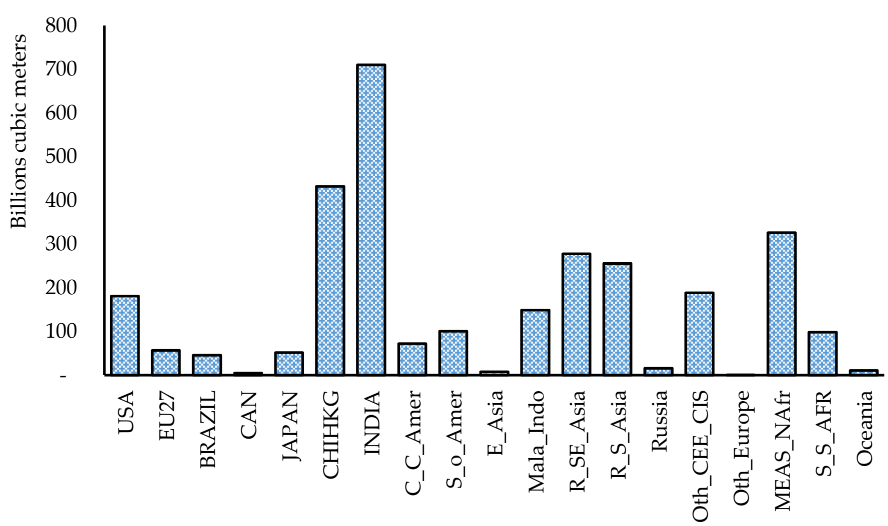

Figure 8. Irrigation water withdrawal by region in 2011

Source: Authors' calculations.

Table 5. Irrigation water withdrawal by region in 2011

Region	Water withdrawal (million m³)	Regional share (%)
USA	180,858	6.06
EU27	56,306	1.89
BRAZIL	45,635	1.53
CAN	4,796	0.16
JAPAN	51,552	1.73
CHIHKG	431,802	14.48
INDIA	709,650	23.79
C_C_Amer	71,911	2.41
S_o_Amer	100,418	3.37
E_Asia	7,873	0.26
Mala_Indo	149,105	5.00
R_SE_Asia	277,783	9.31
R_S_Asia	255,598	8.57
Russia	15,683	0.53
Oth_CEE_CIS	187,981	6.30
Oth_Europe	335	0.01
MEAS_NAfr	326,075	10.93
S_S_AFR	98,561	3.30
Oceania	10,576	0.35
World	2,982,498	100.00

Source: Authors' calculations.

The database also provides water withdrawal for irrigation by crop. Crop by crop comparison helps highlight the relative importance of each crop in global water demand. For example, Table 6 shows that nearly half of global irrigation water in 2011 is used for production of paddy rice and wheat (33.2% and 15.5% respectively). The vegetable and fruits crop category, which includes a large variety of crops, uses 16.6% of global irrigation water. The next important group of crops in terms of irrigation water withdrawal is other cereal grains (gro), accounting for some 8.8% at the global level.

Allocation of water across crops is another important information. Some countries allocate a large share of irrigation water to certain crops. However, as Table 6 shows, the regional pattern of water allocation to production of crops can differ significantly. For example, in India 29.7% of irrigation water is used for the production of paddy rice and 27.5% in the production of wheat. In contrast, in China paddy rice irrigation uses 35.7% of irrigation water use; and the share of other cereal grains ("gro") is 24.2%. In Brazil, 49.1% of irrigation water is used in the production of paddy rice. Another interesting example is Japan which allocates 94.4% of irrigation water to paddy rice.

Table 6. Distribution of irrigation water across crops by region (%)

Region	pdr	wht	gro	v_f	osd	c_b	pfb	ocr	All
USA	6.1	4.2	20.7	10.2	8.2	1.2	9.4	40.0	100.0
EU27	5.6	2.3	15.1	23.7	24.0	1.2	4.1	23.9	100.0
BRAZIL	49.1	0.1	1.7	12.1	2.0	30.1	1.9	3.0	100.0
CAN		15.2	9.5	0.1	26.9		3.0	45.4	100.0
JAPAN	94.4	0.1	0.0	4.9		0.3		0.3	100.0
CHIHKG	35.7	18.3	24.2	10.5	6.1	0.5	2.9	1.7	100.0
INDIA	29.7	27.5	2.5	13.7	5.0	9.8	8.7	3.1	100.0
C_C_Amer	5.6	13.6	8.1	34.8	1.8	13.2	3.4	19.5	100.0
S_o_Amer	24.9	2.3	10.3	33.0	3.7	11.0	1.5	13.4	100.0
E_Asia	70.9	0.6	4.5	20.9	3.0		0.0	0.1	100.0
Mala_Indo	79.7		6.1	0.5	12.5	0.9		0.2	100.0
R_SE_Asia	88.1	0.3	0.8	2.6	0.1	6.9	0.2	1.0	100.0
R_S_Asia	28.9	38.4	5.8	8.7	1.0	6.6	10.4	0.2	100.0
Russia	9.4	18.0	17.0	9.0	1.1	4.1	0.1	41.4	100.0
Oth_CEE_CIS	3.7	7.5	8.2	24.5	2.1	2.4	26.4	25.2	100.0
Oth_Europe		0.0	5.1	25.1	0.4	5.2		64.2	100.0
MEAS_NAfr	5.3	13.9	7.7	48.4	6.1	2.5	2.7	13.5	100.0
S_S_AFR	41.5	4.4	6.0	16.6	5.9	15.1	2.4	8.0	100.0
Oceania	0.3	0.2	1.4	0.8	0.0	0.6	2.1	94.5	100.0
World	33.2	15.5	8.8	16.6	5.0	5.9	6.3	8.9	100.0

Source: Authors' calculations.

Water withdrawals vary across AEZs within a country due to different climates and diverse water requirements. The distribution of water use across AEZs is shown in Table 7. Globally, most of the irrigation water withdrawal occurs in AEZ7-AEZ10 which are arid or semi-arid and temperate. Note that in addition to climate conditions, water availability also affects this figure (the following paragraph will discuss the water withdrawal by river basin, emphasizing more on water supply). The share of AEZs varies by region depending on the size of the country and the composition of its AEZs. In USA, 46.8% of water use occurs in AEZ7 (arid and temperate areas), and 18.3% in AEZ8 (dry, semi-arid and temperate areas). In the EU, most of the water use is in AEZ9, AEZ10, and AEZ11, with shares of 23.1%, 45.6%, and 26.9% respectively. In India, more than 50% of water use occurs in AEZ3 and AEZ4, with an additional 30% in AEZ8 and AEZ9. In China, AEZ8, AEZ9, and AEZ12 use 21.5%, 24.2%, and 22.6% of irrigation water, respectively.

Table 7. Distribution of water use across AEZ in each region (%)

Region	AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6	AEZ7	AEZ8	AEZ9	AEZ10
USA							46.8	18.3	11.2	8.4
EU27				0.1			0.0	2.8	23.1	45.6
BRAZIL	0.1	4.0	5.6	13.2	24.4	8.3				0.0
CAN							55.9	9.7	5.6	8.7
JAPAN									0.9	31.2
CHIHKG				0.0	0.1	2.7	10.4	21.5	24.2	6.6
INDIA	0.6	7.7	36.3	15.1	1.2	0.2	4.0	18.9	15.0	0.8
C_C_Amer	10.1	6.6	6.9	10.9	11.1	7.6	21.0	7.5	13.8	4.0
S_o_Amer	6.2	1.7	2.4	5.7	13.5	6.0	14.3	8.8	6.8	15.0
E_Asia							0.0	0.3	1.8	72.7
Mala_Indo				15.2	45.7	39.1				
R_SE_Asia				25.8	47.1	25.4				0.0
R_S_Asia	9.2		0.5	6.9	11.2	1.9	48.3	10.7	2.7	5.6
Russia							24.6	36.9	14.9	11.3
Oth_CEE_CIS							33.8	35.8	14.6	7.1
Oth_Europe									0.4	44.5
MEAS_NAfr	22.6	1.4	0.2	0.2			29.6	26.4	11.6	8.0
S_S_AFR	17.2	20.8	15.6	13.8	7.1	10.9	4.4	1.7	4.0	3.0
Oceania	0.1	0.7	0.7	0.3	0.0	0.0	20.4	20.5	20.7	5.9
World	4.4	2.9	9.6	8.5	9.3	5.8	16.2	15.6	11.5	

Table 7 (continued). Distribution of water across AEZ in each region (%)

Region	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16	AEZ17	AEZ18	ALL
USA	8.4	5.6	1.0	0.2	0.0	0.0			100
EU27	26.9	1.4	0.0	0.0	0.1	0.0			100
BRAZIL	0.0	44.4							100
CAN	1.5		8.4	4.0	5.6	0.5			100
JAPAN	42.4	24.2			1.3				100
CHIHKG	10.2	22.6	1.1	0.2	0.4	0.1	0.0		100
INDIA	0.2	0.1	0.0	0.0	0.0	0.0			100
C_C_Amer	0.1	0.2	0.0	0.0	0.0				100
S_o_Amer	2.9	12.7	1.0	1.9	0.7	0.4			100
E_Asia	19.3		0.0	0.9	4.9				100
Mala_Indo									100
R_SE_Asia	1.1	0.5			0.0	0.0			100
R_S_Asia	1.8	0.7	0.4	0.2	0.0	0.0			100
Russia	0.2		2.2	3.6	6.2	0.1			100
Oth_CEE_CIS	0.2	0.0	4.1	4.1	0.2	0.0			100
Oth_Europe				22.0	31.3	1.7			100
MEAS_NAfr									100
S_S_AFR	1.4	0.1							100
Oceania	13.0	16.8			0.0	0.8	0.0		100
World	3.8	5.4	0.6	0.4	0.2	0.0	0.0		100

Source: Authors' calculations.

Table 8. Distribution of water across river basins in each region (%)

Region	RB1	RB2	RB3	RB4	RB5	RB6	RB7	RB8	RB9	RB10	RB11
USA	10.6	19.2	0.0	7.5	11.1	4.0	0.4	10.4	22.0	0.2	0.3
EU27	0.1	0.1	11.7	0.0	0.3	4.9	43.6	0.0	21.5	3.5	0.0
BRAZIL	0.2		14.3		14.6	22.8	3.7	35.1	9.4		
CAN	1.7	0.3	3.8	5.5	79.3	0.0	9.4				
JAPAN	83.4	16.6									
CHIHKG	0.9	0.2	18.9	0.0	16.8	10.1	22.9	0.0	0.7	1.2	0.0
INDIA	0.8	2.7	1.4	1.3	1.4	41.4	7.9	2.1	18.5	8.1	0.0
C_C_Amer	5.7	10.1	1.0	35.6		9.7	26.2	6.2	5.7		
S_o_Amer	6.6	18.0	0.7	12.7	15.7	12.1	9.7	10.9	6.4	0.3	4.5
E_Asia	1.5	0.2	64.9	20.4	1.8		11.0				
Mala_Indo	0.5	1.8	82.3		1.7	13.8					
R_SE_Asia	0.0	0.3	20.7	18.8	30.2	20.1	10.0				
R_S_Asia	2.1	7.3	10.0	67.9	4.2	0.1	7.4	1.0			
Russia	1.5	0.1	40.1	0.8	0.0	0.0	7.8		2.4	3.0	34.9
Oth_CEE_CIS	36.9	0.0	7.5	4.6	0.7	8.9	0.0	3.3	1.9	17.1	7.7
Oth_Europe	44.0	4.5	24.9	26.5							
MEAS_NAfr	11.3	0.2	4.4	19.1	11.4	2.6	0.5	19.2	27.1	4.3	
S_S_AFR	0.3	0.0	3.8	10.4	0.0	1.7	2.8	20.8	13.7	15.3	0.4
Oceania	1.3	8.3	61.9	24.5			1.0	3.0			

Table 8 (continue). Distribution of water across river basins in each region (%)

Region	RB12	RB13	RB14	RB15	RB16	RB17	RB18	RB19	RB20	ALL
USA	3.2	2.4	0.2	0.0	7.9	0.4				100
EU27	0.2	0.2	0.8	0.2	1.0	12.0				100
BRAZIL										100
CAN										100
JAPAN										100
CHIHKG	0.3	0.6	9.8	7.0	8.4	2.0				100
INDIA	3.4	6.9	3.1	0.0	1.0					100
C_C_Amer										100
S_o_Amer	2.3									100
E_Asia										100
Mala_Indo										100
R_SE_Asia										100
R_S_Asia										100
Russia	2.0	1.7	5.7							100
Oth_CEE_CIS	0.6	0.2	8.2	1.1	1.3					100
Oth_Europe										100
MEAS_NAfr										100
S_S_AFR	2.7	1.1	4.0	5.8	1.2	1.9	1.1	7.9	5.0	100
Oceania										100

Source: Authors' calculations.

While water withdrawal shares by AEZ are useful indicators, looking at river basin shares reveals more information about supply side interactions and water availability. Table 8 illustrates water withdrawal for irrigation by river basin for the 19 region aggregation of the database in 2011. Some river basins are more important in supplying water for irrigation around the world. For example, water withdrawal in the Ganges (RB6) in India is around 294 billion m^3 and contributes to 41.4% of irrigation water use in India, and around 10% of global irrigation water use. In China, the Huang He basin (RB7) provides 22.9% of water withdrawal for irrigation. In the EU, 43.6% of irrigation water use comes from the Iberia West Atlantic (RB7). In USA, the Missouri basin (RB9) contributes to 22.0% of irrigation water use.

Table 9. Share of water in value added of irrigated crops by crop and region (%)

	pdr	wht	gro	v_f	Osd	c_b	pfb	ocr	all crops
USA	11.7	22.4	16.4	21.4	16.3	15.4	15.0	16.5	19.6
EU27	5.2	11.8	6.1	7.5	6.3	3.3	2.6	5.9	6.8
BRAZIL	7.0	17.0	7.4	5.3	10.4	5.2	8.3	11.5	9.9
CAN		14.9	12.5	11.8	9.2			9.5	11.9
JAPAN	16.9	3.2	1.8	1.9		1.7		1.9	10.7
CHIHKG	17.9	15.0	9.4	12.2	7.6	16.5	10.0	5.0	14.2
INDIA	24.9	22.2	15.4	27.8	22.3	29.7	23.2	11.0	24.1
C_C_Amer	8.5	26.2	5.5	25.9	3.3	18.2	18.3	3.1	19.1
S_o_Amer	20.7	7.4	23.7	17.4	16.9	21.2	28.8	20.6	19.4
E_Asia	13.1	39.0		13.8	11.0			6.3	12.9
Mala_Indo	15.3		8.0	5.3	23.6	27.2		24.6	16.4
R_SE_Asia	13.8		6.4	14.4	41.6	16.9	28.4	8.2	13.7
R_S_Asia	23.5	37.4	32.4	33.4	38.9	36.6	33.7	29.7	31.7
Russia	19.5	24.9	19.9	5.3	13.6	16.0	25.1	17.5	18.6
Oth_CEE_CIS	17.4	13.4	18.3	14.6	11.6	8.9	14.2	13.9	14.5
Oth_Europe		21.7	13.1	19.6	32.1			2.4	18.2
MEAS_NAfr	10.7	8.9	9.1	9.3	10.2	8.8	9.8	6.8	9.3
S_S_AFR	6.2	11.0	3.1	5.6	4.2	8.5	7.3	1.5	5.9
Oceania	14.6	16.8	17.6	17.4	17.5	18.4	12.2	13.5	15.8
World	17.5	18.9	11.1	14.9	15.1	21.2	16.5	11.0	15.6

Source: Authors' calculations.

5.7 Water rents

The database represents water rents in production of crops by river basin and AEZ. According to our calculations, the share of water value added in regional

GDP is small. It maxes out at around 2% for the Rest of South Asia and 1.1% for India, but it is less than 0.3% for other regions. Table 9 demonstrates the share of water in total value added (labor, capital, water, land) of irrigated crops. According to this table, 15.6% of global value added generated by irrigated crops comes from water.

Globally, the water contribution to value added for irrigated sugar cane, wheat, and paddy rice is higher than other crops and generates, respectively, 21.2%, 18.9%, and 17.5% of their value added. The water share in value added of wheat is also very high in East Asia (39%). Similarly, water's share of value added is also high in the production of oil seeds in Rest of South East Asia (41.6%) and in Other Europe (32.1%).

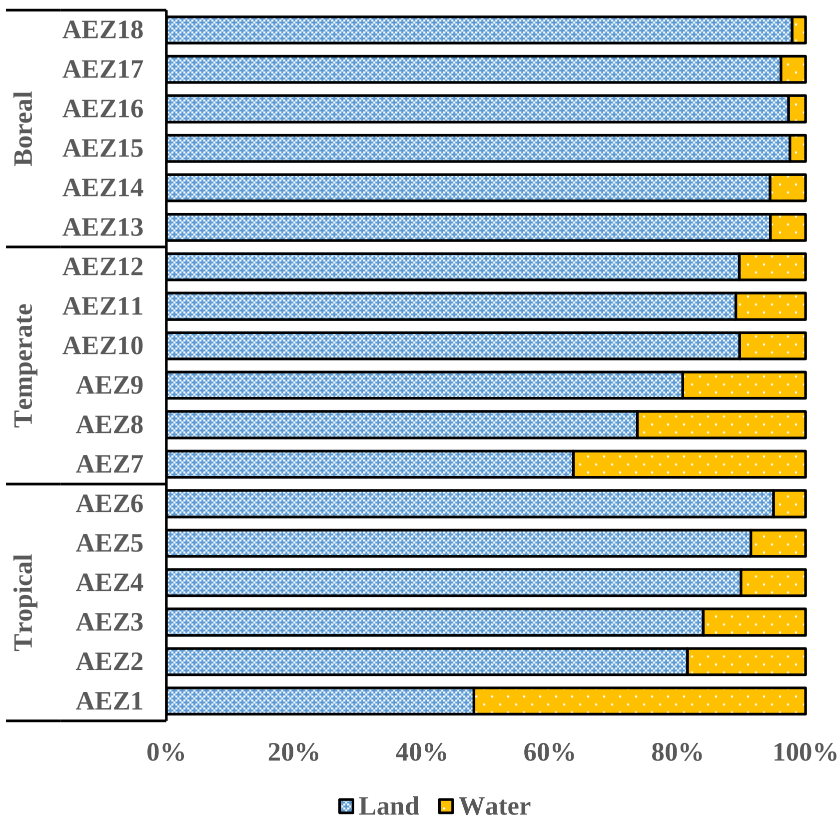

Figure 9. Water-Land value added distribution in 2011 by AEZ

Source: Authors' calculations.

The aggregate (across all crops) share of water in irrigated crop value added also varies by region. Water's contribution to value added is relatively high in Rest of South Asia (31.7%), India (24.1%), and USA (19.6%). While the share of water in value added of irrigated crops is relatively low in the EU (6.8%) and Sub-Saharan (5.9%).

The GTAP-Water is designed to represent the heterogeneity in the production of crops. One source of heterogeneity is the climate zones. Figure 9 illustrates the global value share of water in water-land composites by AEZ in total irrigated crop production. This figure illustrates that the share of water in the value added of water-land is relatively high in AEZ1 and AEZ7, which are arid zones. Moving from AEZ1 to AEZ6, we observe a declining share of water. Note that from AEZ1 to AEZ6 regions experience increasing humidity and moisture. For boreal zones, the share of water in water-land value added is relatively low compared to tropical and temperate zones.

6. Some applications

Having irrigation water explicitly expressed at the river-basin level in both value and physical terms in an economy-wide database such as GTAP can significantly increase the applicability of CGE models in developing research on crucial subjects such as: water scarcity and its impacts on food security, land use change, and trade; the interaction of water, land, energy, food, and climate; economy-wide impact of water conservation practices and policies; and many more.

An important advantage of the water-augmented GTAP database is to allow different degrees of substitution between water and other inputs in production functions. For example, within agricultural sectors the substitutability between water and land can be specified separately among crop productions. This type of modeling flexibility permits irrigated production of certain crops to be completely shut down in water-scarce locations, when there is major competition for water. Another advantage of differentiating watersheds within a region is the ability to examine demand for and supply of water that are typically relevant at the local scale. With the assistance of hydrological models, the assessment of water balance at each river basin or sub-basin can be improved, which enables more precise economic implications. Otherwise, assumptions and structures are required to overcome the absence of biophysical information on water supply. Two papers were developed on this advantage of the water-augmented GTAP database.

In the first paper, Taheripour et al. (2013a) examines the substitution between irrigated and rainfed croplands in response to an expansion in biofuel production in US. The authors show that if irrigated cropland cannot be expanded due to water scarcity, an expansion in biofuel production generates larger induced land use emissions. They conclude that to correctly estimate biofuels induced land use emissions, it is necessary to take into account the role of irrigation in crop production and the fact that irrigated cropland cannot be expanded in many regions across the world due to water scarcity.

The second paper examines the impact of water scarcity on the pattern of bilateral trade (Liu et al., 2014). The authors show that the changes in the crop mix induced by restricting irrigation water supply are quite heterogeneous across production units (i.e. RB-AEZs). When aggregated to the regional level, these differences explain the imbalance between food production and consumption across regions, which subsequently determines the flow of bilateral trade. The standard regional model ignoring sub-national difference in the productivity of land and water is incapable of capturing the competition for endowments within a region, leaving room for significant errors. However, incorporating these details can be demanding. This raises the question of to what extent and in what circumstances these data and modeling efforts should be made.

Starting with the elaborate global GTAP-BIO-W model, Liu et al. (2016) addresses this question by assessing the trade-offs between model accuracy and affordability. Three most commonly practiced simplifications in the water modeling literature are examined: (1) tackling global questions at a national level model; (2) collapsing irrigated and rainfed crop production into a single activity; and (3) removing river basin boundaries within a country. The authors show that if the research question is concerned with national-scale crop output and welfare, it might be sufficient to employ the standard national-level. However, when the interest is focused on the spatial distribution of input and output within a region, preserving hydrological boundaries and sectoral detail in the model brings considerable value to the analysis.

In another paper, Taheripour et al. (2016) use the water-augmented GTAP database and the GTAP-BIO-W model to study the economy-wide impacts of improvements in Water Use Efficiency (WUE) in irrigation in South Asia. This paper argues that with no improvement in WUE, this region will face major water challenges in the future. However, since WUE in irrigation is extremely low in this region, the economies of this region could cut a portion of their electricity subsidies (which are currently very high in the region) and invest the released subsidies for improvements in WUE. They would observe major economic benefits, and improve their food security. The paper examines the land use consequences of this mitigation option by RB-AEZ across South Asia by country.

South Asia is not the only region which will face water scarcity in irrigation in the future, according to the existing literature (Rosegrant et al., 2013). Haqiqi et al. (2016) have examined the economic impacts of future water scarcity at the global scale by country using the water-augmented GTAP database in combination with the ENVISAGE model. The authors collapse the river basin and AEZ dimensions to the national level and quantify the economic impacts of water scarcity by country. An additional feature of the water-enhanced ENVISAGE model is that it attempts to incorporate economy-wide water use, using the additional components of FAO's AQUASTAT database.

7. Conclusion

Introducing water into an economy-wide database such as GTAP, which has been widely used by many economic modelers across the world, could help investigators to extend their research agendas by focusing on the role and importance of water in economic activities. As a first step in this this direction, we have modified the GTAP-Power Data Base Version 9, the power-extended version of the standard GTAP Data Base, in two ways: 1) divided the crop sectors into irrigated and rainfed categories, and 2) explicitly included irrigation water use into the cost structure of irrigated crops. We have used the most recently available state-of-the-art databases to accomplish this task. The new database includes water for irrigation as an endowment, which is used by irrigated crops sectors. Unlike the standard GTAP Data Base, the new database represents water and land endowments by RB-AEZ in each country. This spatial disaggregation represents the heterogeneity of land and water within each country. The new database includes harvested area, crop production, and land cover items including forest, pasture and cropland in physical units, also at the RB-AEZ level. We hope that this database, and its successors, will advance the state of the art in combining bio-physical data with economic models.

The current version of the GTAP-Water Data Base has several limitations—first and foremost that the data is currently limited to water for irrigation—that need to be addressed in future extensions. Without specifying priorities or the degree of difficulty, the planned extensions include:

- Development of economy-wide uses of water to be able to assess the overall regional competition for water resources. As in agriculture, the extension of the water database to other uses will be constrained by the limited information on water pricing and market functioning.
- Distinguish water by source—surface and groundwater. Data for this is again sparse.

- Additional spatial disaggregation of water basins—we are currently using the IMPACT-Water river basin boundaries developed by IFPRI. Many of these could be further divided into sub-basins.
- Incorporate water transfers across river basins.
- We use the latest available data, some of which date back to 2000. Some of the databases are currently being updated and we plan to revise our water use estimates as the new data becomes available.

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Appendix A

Table A.1. Description of Agro-Ecological Zones (AEZs)

Length of growing period in days	Moisture regime	Climate zone		
		Tropical	Temperate	Boreal
0-59	Arid	AEZ1	AEZ7	AEZ13
60-119	Dry semi-arid	AEZ2	AEZ8	AEZ14
120-179	Moist semi-arid	AEZ3	AEZ9	AEZ15
180-239	Sub-humid	AEZ4	AEZ10	AEZ16
240-299	Humid	AEZ5	AEZ11	AEZ17
>300 days	Humid; year-round growing season	AEZ6	AEZ12	AEZ18

Source: Lee et al., (2005)

Table A.2. Description of 19 aggregated regions

Region	Description
USA	United States
EU27	European Union 27
BRAZIL	Brazil
CAN	Canada
JAPAN	Japan
CHIHKG	China and Hong Kong
INDIA	India
C_C_Amer	Central and Caribbean Americas
S_o_Amer	South and Other Americas
E_Asia	East Asia
Mala_Indo	Malaysia and Indonesia
R_SE_Asia	Rest of South East Asia
R_S_Asia	Rest of South Asia
Russia	Russia
Oth_CEE_CIS	Other East Europe and Rest of Former Soviet Union
Oth_Europe	Rest of European Countries
MEAS_NAfr	Middle Eastern and North Africa
S_S_AFR	Sub Saharan Africa
Oceania	Oceania countries

Notes: Mapping from 140 GTAP regions to the above 19 regions is available in the supplementary materials.

Table A.3. River basins in 19 region aggregation

Basins	USA	EU27	BRAZIL	CAN	JAPAN	CHN&HK	INDIA
RB1	Arkansas	Baltic	Amazon	Canada Arctic Atlantic	Japan	Amur	Brahmaputra
RB2	California	Britain	North South Amri. Coast	Central Canada Slave Basin	Others	Brahmaputra	Brahmari
RB3	Canada Arctic Atlantic	Danube	Northeast Brazil	Columbia	NA	Chang Jiang	Cauvery
RB4	Colorado	Dnieper	Orinoco	Great Lakes	NA	Ganges	Chotanagpui
RB5	Columbia	Elbe	Parana	Red Winnipeg	NA	Hai He	Easten Ghats
RB6	Great Basin	Iberia East Med	San Francisco	US Northeast	NA	Huai He	Ganges
RB7	Great Lakes	Iberia West Atlantic	Toc	MacKenzie	NA	Huang He	Godavari
RB8	Mississippi	Ireland	Uruguay	Pacific Namer North	NA	Indus	India East Coast
RB9	Missouri	Italy	Others	Others	NA	Langcang Jiang	Indus
RB10	Ohio	Loire Bordeaux	NA	NA	NA	Lower Mongolia	Krishna
RB11	Red Winnipeg	North Euro Russia	NA	NA	NA	North Korea Peninsula	Langcang Jiang
RB12	Rio Grande	Oder	NA	NA	NA	Ob	Luni
RB13	Southeast US	Rhine	NA	NA	NA	SE Asia Coast	Mahi Tapti
RB14	US Northeast	Rhone	NA	NA	NA	Songhua	Sahyada
RB15	Upper Mexico	Scandinavia	NA	NA	NA	Yili He	Thai Myan Malay
RB16	Western Gulf Mex	Seine	NA	NA	NA	Zhu Jiang	Others
RB17	Pacific Namer North	Others	NA	NA	NA	Mekong	NA
RB18	Others	NA	NA	NA	NA	Others	NA
RB19	NA	NA	NA	NA	NA	NA	NA
RB20	NA	NA	NA	NA	NA	NA	NA

Table A.3 (continued). River basins in 19 region aggregation

Basins	Central America	South America	East Asia	MLYS & IDN	R. Southeast Asia	R. South Asia
RB1	Carribean	Amazon	Amur	Borneo	Borneo	Amudarja
RB2	Central Amri.	Chile Coast	North Korea Peninsula	Indonesia East	Langcang Jiang	Brahmaputra
RB3	Cuba	Northeast South Amri.	South Korea Peninsula	Indonesia West	Mekong	Ganges
RB4	Middle Mexico	Northwest South Amri.	Lower Mongolia	Papau Oceania	Philippines	Indus
RB5	Northwest South Amri.	Orinoco	Upper Mongolia	Thai Myan Malay	SE Asia Coast	Sri Lanka
RB6	Rio Grande	Parana	Others	Others	Thai Myan Malay	Thai Myan Malay
RB7	Upper Mexico	Peru coastal	NA	NA	Others	Western Asia Iran
RB8	Yucatan	Rio colorado	NA	NA	NA	Others
RB9	Others	Salada Tierra	NA	NA	NA	NA
RB10	NA	Tierra	NA	NA	NA	NA
RB11	NA	Uruguay	NA	NA	NA	NA
RB12	NA	Others	NA	NA	NA	NA
RB13	NA	NA	NA	NA	NA	NA
RB14	NA	NA	NA	NA	NA	NA
RB15	NA	NA	NA	NA	NA	NA
RB16	NA	NA	NA	NA	NA	NA
RB17	NA	NA	NA	NA	NA	NA
RB18	NA	NA	NA	NA	NA	NA
RB19	NA	NA	NA	NA	NA	NA
RB20	NA	NA	NA	NA	NA	NA

Table A.3 (continued). River basins in 19 region aggregation

Basins	Russia	E-Europe-RFSU	R. Europe	M-East-N-Afri	SSA	Oceania
RB1	Amur	Amudarja	Rhine	Arabian Peninsula	Central Afri. West Coast	Central Australia
RB2	Baltic	Amur	Rhone	Black Sea	Congo	Eastern Australia Tasmania
RB3	Black Sea	Baltic	Scandinavia	Eastern Med	East Afri. Coast	Murray Australia
RB4	Dnieper	Black Sea	Others	Nile	Horn of Afri,	New Zealand
RB5	Lower Mongolia	Danube	NA	North Afri. Coast	Kalahari	Papau Oceania
RB6	North Euro Russia	Dnieper	NA	Northwest Afri. Coastal	Lake Chad Basin	Sahara
RB7	Ob	Eastern Med	NA	Sahara	Limpopo	Western Australia
RB8	Scandinavia	Iberia East Med	NA	Tigris Euphrates	Madagascar	Others
RB9	Upper Mongolia	Lake Balkhash	NA	Western Asia Iran	Niger	NA
RB10	Ural	Lower Mongolia	NA	Others	Nile	NA
RB11	Volga	Ob	NA	NA	Northwest Afri,	NA
RB12	Western Asia Iran	Syrdarja	NA	NA	Orange	NA
RB13	Yenisey	Tigris Euphrates	NA	NA	Sahara	NA
RB14	Siberia Other	Upper Mongolia	NA	NA	Senegal	NA
RB15	Others	Ural	NA	NA	South Afri. Coast	NA
RB16	NA	Volga	NA	NA	Southeast Afri. Coast	NA
RB17	NA	Western Asia Iran	NA	NA	Volta	NA
RB18	NA	Yenisey	NA	NA	West Afri. Coastal	NA
RB19	NA	Yili He	NA	NA	Zambezi	NA
RB20	NA	Others	NA	NA	Others	NA

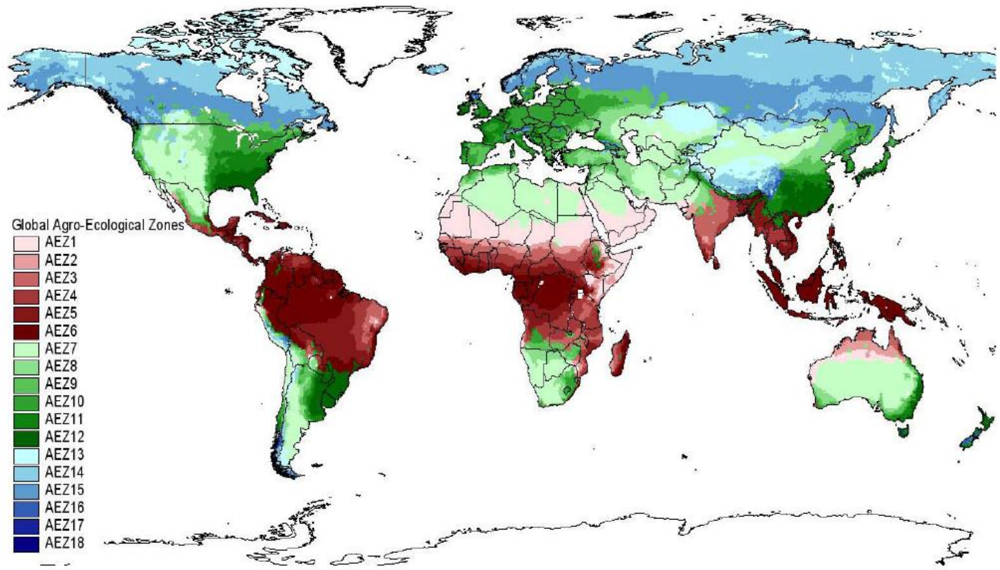

Figure A.1. Global map of 18 AEZs.

Source: Lee et al., (2005)

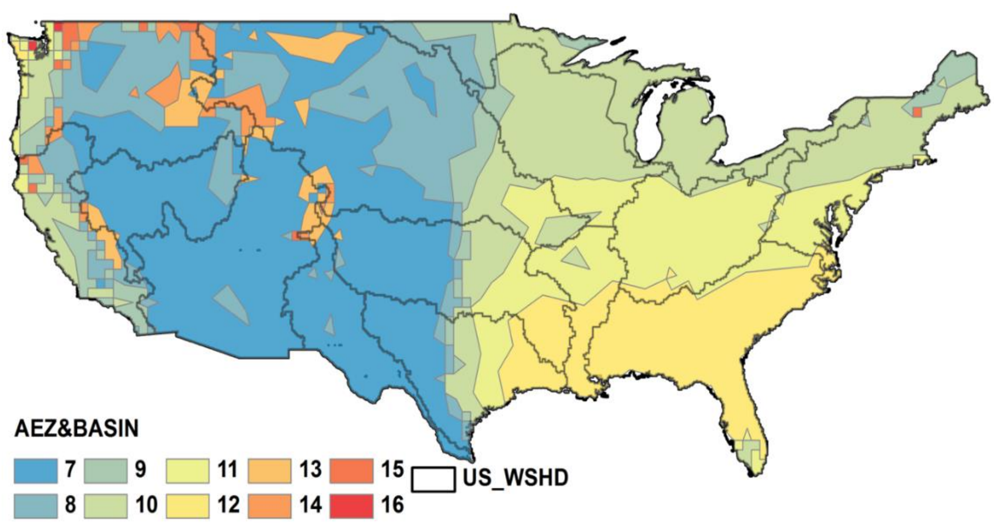

Figure A.2. Map of US by RB-AEZ.

Source: Authors