Virtual water trade and water footprint of agricultural goods: the 1961-2016 CWASI database

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Abstract. To support national and global assessments of water use in agriculture, we build a comprehensive database of country-specific water footprint and virtual water trade (VWT) data for ~~hundreds of~~357 agricultural goods. The water footprint, indicating the water needed for the production of a good including rainwater and water ~~withdrawals~~from surface- and ground- water bodies, is expressed as a volume per unit weight of the good (or unit water footprint, uWF)

10 and is here estimated at the country scale for every year in the period 1961-2016. The uWF is also differentiated, where possible, between production and supply, referring to local production and to a weighted mean of local production and import, respectively. The VWT data, representing the amount of water needed for the production of a good and virtually exchanged with the international trade, are provided for each commodity as bilateral trade matrices, between origin and destination countries, for every year in the period 1986-2016. The database, developed within the CWASI project,

15 improves upon earlier datasets because it takes into account the annual variability of the uWF of crops, it accounts for both produced and imported goods in the definition of the uWF and it traces goods across the international trade up to the origin of goods' production. The CWASI database is available on the Zenodo repository at https://doi.org/10.5281/zenodo.3987468 (Tamea et al., 2020) and welcomes contributions and improvements from the research community to enable analyses specifically accounting for the temporal evolution of the uWF.

20 **1 Introduction**

There has been a booming interest in the concept of Water Footprint (WF) since its introduction about 15 years ago (Hoekstra & Chapagain, 2007, 2008). The water footprint offers a common approach, language and method to a wide range of analyses and multidisciplinary studies, and it is appreciated for its capability to convey environmental messages to the public. The WF identifies the freshwater needed for the production of goods along the full supply chain,

25 separating rainfall and water from surface/ground-water bodies. The WF assessment provides a quantitative framework to analyse the volume of water embedded in agricultural goods and the efficiency of water use, when the metric is computed per unit weight of the good (hereafter referred to as the unit water footprint, or uWF). The term *unit water*

footprint is here introduced to unify the current terminology which includes "water footprint", used indifferently for volumes and for volumes per unit weight, "crop water footprint" which excludes livestock products, or "virtual water content" mainly used within the context of trade (see for e.g., Hoekstra et al., 2011; Konar et al., 2011; Dalin et al., 2012; Tuninetti et al., 2015). Also the concept of virtual water, originally proposed by J. A. Allan (1998) and from which the WF originated, has been growing in popularity among both the scientific community and the general public. Virtual water is the volume of water needed to produce a certain good that is virtually traded as a factor of production when the good is exchanged among countries. Such virtual flow defines the international virtual water trade (VWT) and represents a metric that is suitable to analyse environmental aspects related to the global trade of agricultural goods, to the water management and to the agricultural policy.

Assessment of WF and VWT requires a relatively large amount of data, including production and trade data (in tonnes) and unit water footprint data (in cubic meters per tonne). The first remarkable database of uWF data has been prepared and shared by the Water Footprint Network, which published a large open-access dataset of uWF for several primary and processed agricultural goods, having crop and animal origin (Mekonnen & Hoekstra, 2010a, 2010b). This database, named WaterStat, includes average values over the period 1996-2005 and has been the basis of the water footprint assessment as presented, e.g., in Hoekstra et al. (2011). Other uWF datasets exist, which are based on spatially distributed models coupling the soil water balance with vegetation growth (see, e.g., Tuninetti et al., 2015, and references therein); such databases mostly refer to a single year or a period or to long-term averages. Other datasets, referring to blue water or to scarcity-weighted indicators, are also available from the literature related to the Life Cycle Assessment (e.g., Pfister et al., 2011; Pfister et al., 2016). The temporal variability of uWF has been seldom considered. Few examples include water scarcity indexes (e.g., Pfister & Bayer, 2014), or annual time series of uWF in the EORA database, based on assumptions about the economic growth of different production sectors (Lenzen et al., 2013). Recently, Tuninetti et al. (2017) proposed a Fast-Track method to estimate annual uWF values from WaterStat using agricultural yield data.

International trade statistics of agricultural goods are organized and shared by, e.g., the Food and Agriculture Organization (FAOSTAT) and the United Nations (UN-COMTRADE). Early publications by the Water Footprint Network (e.g., Hoekstra & Chapagain, 2011) are based on the combination of such trade databases and WaterStat to produce WF assessments. Trade data are also organized and shared as Input-Output tables, tracing supply chains across sectors and countries, whose worldwide dimension is captured by global multi-regional input-output tables (MRIO) (see Tukker & Dietzenbacher, 2013, for a review). In such a framework, some MRIO databases offer specific water-related extensions, quantifying water volumes associated to international trade (e.g., Geschke & Hadjikakou, 2017). Two

60 relevant examples are the EORA database (Lenzen et al., 2013) and EXIOBASE (Stadler et al, 2108), both including a water assessment distinguishing between green and blue water and including the temporal variability, although product categories and geographical regions are more aggregated than in the present study. Supply chains and trade of specific products, with their impact on the local environment and the water resources are also the objectives of the TRASE project developed by the Stockholm Environment Institute and the Global Canopy Programme (SEI, 2019). Such

65 project focuses on a limited set of products, although accurately investigating their supply chain and environmental effects.

Methodologies for VWT and WF assessment can be classified in two approaches: the bottom-up and the top-down approach. The *bottom-up* approach refers to a process-based analysis, with a detailed description of production

70 processes and associated water volumes. Within such approach, the uWF of each good is multiplied by the (produced or traded) quantity of such good and resulting water volumes are then summed across goods. WaterStat is the main example of a bottom-up approach The *top-down* approach aims at tracing full supply chains throughout economic sectors and different countries. Input–output analyses, frequently used in Economics for environmental assessments, belong to this approach (Duarte & Yang, 2011). Bottom-up approaches do not consider the entire supply chain of goods

75 and can be affected by truncation errors when used to assess the water footprint of final consumption (Feng et al., 2011). At the same time, bottom-up techniques can offer high commodity resolution considering the water associated to the production of a large variety of single (agricultural) products. A major problem affecting bottom-up approaches is the identification of the geographic origin of produced goods (Hubacek & Feng, 2016). In many cases, product re-export disconnects producing and consuming countries, now allowing a correct identification of dependencies and

80 externalities. In the present work, we improve the traditional bottom-up approach by identifying the origin of produced goods and reconstructing the supply chain of agricultural goods, implementing the method proposed in Kastner et al (2011). With such improvement, the VWT quantified in this study aims both at best estimating the water embodied in bilateral trade and at providing accurate estimates of the total virtual water embedded in final consumption (Feng et al., 2011; Lenzen et al., 2013).

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In this publication, we present an open-access database of virtual water trade, including the annual trade matrices (years 1986-2016) and the annual virtual water export (years 1961-2016) associated to a large number of agricultural products, as well as their unit water footprint in all countries (years 1961-2016), referring to the sum of green water (originated from rainfall) and blue water (originated from surface- and ground-water bodies). Starting from the uWF dataset in

90 Mekonnen & Hoekstra (2010a, 2010b), we extend it to provide annual statistics of uWF. Improvements also include the

differentiation between the production-side and supply-side of uWF. The new time-varying uWF are applied to the FAOSTAT datasets of agricultural production and trade. The results of this analysis constitute the CWASI database.

The database addresses several needs: (i) the need for a comprehensive database of uWF, WF and VWT, (ii) the need to
95   adopt unit water footprints that vary in time, as recently pointed out by D'Odorico et al. (2019), (iii) the need to disentangle the production-side and the supply-side uWF to coherently assess the WF of production and consumption, (iv) the need for ready-to-use detailed trade matrices, accurately tracing goods' trade and origin, suitable for network analyses. The uWF dataset may also be useful for other methodologies of WF and VWT assessments, such as those based on input-output matrices or the one proposed in the ISO standardization (ISO, 2014).
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The present database has been developed within the EU-funded CWASI project "Coping with WAter Scarcity In a globalized world" and it is shared through an online open-access repository (Tamea et al., 2020). In a relatively recent overview of the field, the research lines that originated from the concept of WF were identified (Hoekstra, 2017). These are the role of trade and globalization in goods production and consumption and how they affect local water issues, the
105   comparison of water requirements with water availability and renewability, and the supply-chain approach applied to water management. With the CWASI database we aim at contributing to these research lines and provide all researchers with an up-to-date and ready-to-use starting point for their research. The database will welcome additions and external contributions that may possibly become available in the future and will represent an open and shared source of data on water footprint and virtual water trade.

110   **2 Data and preliminary arrangements**

From FAOSTAT, the statistical database of the Food and Agriculture Organization (FAO)of the United Nations (FAOSTAT, 2018), we collected 31 years (1986-2016) of trade data of agricultural goods (FAO, 2019b). , including crop-based and animal-based commodities. Data originate from national accountings and are available as records containing the following information: reporting country (with FAO code), type of trade (import or export), partner
115   country reported within the trade record (with FAO code), year, commodity (with FAO code), unit of measure, quantity. From FAOSTAT (2018), we also collected 56 years of data on country export (1961-2016), regardless of the destination, and of agricultural production data including crop-based and animal-based commodities, containing, having this information: producing/exporting country (with FAO code), year, commodity (with FAO code), unit of measure, quantity (FAO, 2019a, 2020a, 2020b, 2020c, 2020d). From FAOSTAT (2018the same source), data of agricultural yield
120   and harvested area have were also been collected per for each considered crop, country and year in the period 1961-

2016 (FAO, 2019a). Reference unit water footprint values for every commodity and country, averaged around the year 2000 over the period (1996-2005 period), are taken from WaterStat (Mekonnen & Hoekstra, 2010a, 2010b), as well as the product fraction and the value fraction needed for the computation of the uWF of processed crops. A detailed summary of data sources has been arranged in Table 1.

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2.1 Commodities

Production and trade data collected from FAOSTAT (2018) include crops, processed crops, livestock primary, livestock processed and live animals. The commodities currently included in the CWASI database are 357 and have been identified as those whose FAO code or name or description could be associated to a WaterStat database entry

130 (commodities are listed in the Appendix, Table SIA.1). Commodities includes all products in the "Crop" production statistics of FAO, many processed crops with the exception of feed products (such as bran and cake), animals and animal-based products for most relevant species. Among all commodities, some appear in both trade and production data, some appear only in trade and some other appear only in production. Production data are only available for primary goods and for few processed goods, while trade includes primary and a larger set of processed goods. For

135 example, the flour of wheat or the bread are only available as trade data because production data only include the primary commodity (wheat). Conversely, yams or sugar cane are only available as production data because their trade is not recorded in the FAO statistics, possibly because they are not internationally exchanged as raw product. Commodities have been subdivided into 9 categories whose numbers of produced and traded commodities are specified in Figure 1. The FAOSTAT database provides for each commodity and year the amounts of goods produced (or traded)

140 in any given country (or pair of countries) expressed in tons or heads, depending on the type of product (see the details in Table 1).

2.2 Countries

The database considers all geographical/political/economical entities reporting (or reported for) at least one product and one year, either in the trade or the production data. From 1961 to 2016, agricultural goods were produced and traded

145 among 255 entities having a temporary or permanent activity (the full list is reported in the Appendix, in Table SIA.2). Not all the 255 countries were active along the whole considered period, as they underwent political-administrative changes. Examples include is the collapse of the USSR, the separation of Eritrea from Ethiopia, or the splitting of Belgium and Luxembourg, which were considered a single entity until year 2000. Despite being inactive, a country may be reported by partners as importing or exporting goods. Values reported for a country outside its range of active years

150 are associated to the corresponding larger active country or to the largest of them (e.g., a trade reported towards USSR

in 1992 is associated to the Russian Federation). ~~China has been considered as the aggregation of the~~ The following non-overlapping FAO entries~~:~~. "China, Mainland", "China, Hong Kong SAR", "China, Macao SAR", "China, Taiwan Province of", have been considered in place of the aggregate entry "China". ~~.~~ ~~There are also few~~ Two entries of unclear ~~al~~location (Neutral Zone, Unspecified)~~: they~~ are listed but values are not considered, in order to avoid the erroneous

155   accounting of trade fluxes. ~~The set of associations is detailed in Table SI.3~~ Discontinuities in the active periods~~The period of activity of~~ each country ~~is~~are listed in the Appendix, in Table A.2. ~~Supplementary Information, together with the associations adopted during country inactivity.~~

2.3 Trade matrices

The detailed trade data provided by FAO~~STAT~~ (2019b) include the international trade records reported by each

160   country. Reporting countries across the years are ~~184~~186, whereas the remaining ones (up to 255) are only reported by others. There is a total of 9 million records (i.e., trade flows per country pairs, per commodity and per year, for the commodities included in the CWASI dataset) and the number of records reported by each country is detailed in Figure 2. These records are used to reconstruct the trade matrix M for each commodity and year, having dimensions 255 x 255 and carrying the exporting countries on the rows and the importing countries on the columns. The matrix element

165    $M(i,j)$ thus identifies the trade flow from country i to country j, which is clearly different than the flow from country j to country i, i.e. $M(i,j) \neq M(j,i)$. Sub-national trade is not considered in these matrices and the terms on the diagonals are zeros.

A problem arising in the construction of trade matrices is that the same trade flow can be reported twice in the FAOSTAT database, once by the exporting country and once by the importing country. When a trade flow is reported

170   by only one of the two countries, the reported flow is used to construct the matrix (single record); this is the case for 40% records in the database. All other records are "double" (reported twice) and require a comparison between the declarations of the exporting and the importing countries, which are usually different, with a mean (absolute) relative difference, across all ~~items~~goods, countries and years, of 61%.

The choice of a value from two double records is called "reconciliation" and the method here adopted is based on the

175   identification of the most reliable reporting country among the two involved in each flow, and the use of the flow being reported by it. The reliability of countries is measured per commodity and per year with a data-based approach detailed below and adapted from Gehlhar (1996).

Country reliability

For each product, p, and year, t, two trade matrices are built, one matrix collecting all "Importer-Reported" flows and

180   the other matrix collecting the "Exporter-Reported" flows. The matrices have the same structure and dimensions, with

the exporter countries on the rows and the importing countries on the columns. Then a reliability index is calculated for each country, c, differentiating between import and export.

First, an accuracy measure (A) is defined for every flux, from country i to country j, as

$$A(i,j) = \frac{|IR(i,j) - ER(i,j)|}{max\{IR(i,j), ER(i,j)\}},$$ (1)

185 with $IR(i,j)$ being the importer-reported trade flux and $ER(i,j)$ being the exporter-reported flux. The measure is modified from Gehlhar (1996) to maintain the conceptual symmetry between import and export. The smaller is the measure and the more similar is the information reported by the importing and exporting country.

Then, the reliability of each country is measured, separately for import and export, based on the comparison between the flows reported by the country and by its trade partners. For every country, c, the reliability index for imports,

190 $RI_{imp}(c)$, and for exports, $RI_{exp}(c)$, are defined as follows:

$$RI_{imp}(c) = \frac{\sum_j^{acc} IR(j,c)}{\sum_j^{all} IR(j,c) - IR(w,c)}, \quad RI_{exp}(c) = \frac{\sum_i^{acc} ER(c,i)}{\sum_i^{all} ER(c,i) - ER(c,w)}.$$ (2)

where $IR(j,c)$ is the flux from country j to c, as reported by c (importer-reported), and $ER(c,i)$ is the flux from c to any country i, as reported by c (exporter-reported) respectively. Σ^{all} is the sum of all import or export fluxes reported by c and Σ^{acc} is the sum of acceptable fluxes only, defined as the fluxes whose accuracy A (Eq. (1)) is smaller than an

195 acceptance threshold, set to 20% as in Gehlhar (1996). $IR(w,c)$ and $ER(c,w)$ in Equation (2) are, respectively, the import from, and the export to, the worse partner w defined as the ones having the maximum (worse) flow-weighted accuracy measure (WA) defined, for import and export fluxes, as

$$WA_{imp}^c(j) = A(j,c) \cdot \frac{IR(j,c)}{\sum_j^{all} IR(j,c)}, \quad WA_{exp}^c(i) = A(c,i) \cdot \frac{ER(c,i)}{\sum_i^{all} ER(c,i)}.$$ (3)

$A(j,c)$ is the accuracy level of flux $IR(j,c)$ and $A(c,i)$ is the accuracy level of flux $ER(c,i)$; the denominators are,

200 respectively, the sum of all imports and all exports reported by country c.

Reliability indexes are calculated by country, commodity, year and flow direction (import and export). This because the reliability of a country in reporting import and export may be different, the attitude of a country to over-report or under-report may differ by products, e.g. depending on taxation, and the reliability of a country may change in time, e.g. according to socio-political factors. The direction- and commodity- averaged RI of reporting countries are shown in

205 Figure 2 with the darker (lighter) line corresponding to the newest (oldest) values. Countries more involved in trade and reporting more information (to the left) are characterized, on average, by a larger reliability, while countries less involved in trade have lower average reliability, which used to be very low in the past. Current RI values, instead, are more uniform across countries.

Having computed all reliability indexes, the "reconciled" trade matrix for each ~~item~~ good and year is built, combining

210 importer-reported and exporter-reported data. Each matrix element $M(i,j)$ is taken from the IR or ER matrix if the

importing country j or the exporting i has a larger reliability index respectively. Where the reliability indexes are equal, the country having larger acceptable fluxes is chosen.

3 Unit water footprint

215 The unit water footprint measures the amount of water required to produce a unit amount of product and it can be expressed as m^3/ton or, equivalently, as l/kg. The present work considers the sum of green water (originated from rainfall) and blue water (originated from surface- and ground-water bodies). Depending on the type of commodity, different approaches are applied for the computation of the unit water footprint. In the present work we propose a differentiation between the uWF of production (uWFp) and the uWF of supply (uWFs). The uWFp refers to locally-

220 produced crops whose water footprint depends on the crop actual evapotranspiration and crop yield, with annual estimates starting from 1961. The uWFp is a suitable indicator to assess the WF of agricultural production. The uWFs, instead, refers to the domestic supply, which relies both on local production and on international trade. Country-scale domestic supply is available for human consumption, food manufacturing, feed for livestock and as export towards other countries. The impossibility to track local production and imports into consumption and exports, within each

225 country, makes the uWFs the best indicator to be used in conjunction with consumption and export data. The uWFs is computed averaging local production and imports, after having identified the countries of origin of the goods with an appropriate procedure applicable from year 1986.

For primary crops, it has been possible to estimate both the uWFp and the uWFs. Processed crops are produced from a

230 root product which may or may not originate from local production. The absence of systematic FAO data about the production of processed crops prevents the differentiation between the unit water footprint of production and of supply. Therefore, processed crops considered in this study will have a single unit water footprint, depending on country and year, computed from the uWFs of the root product. Finally, animal-based products are here considered only with the WaterStat values, without temporal variability.

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3.1 Unit water footprint of locally-produced primary crops in time

When considering the production of primary crops, the unit water footprint of production, uWFp, is a function of the actual evapotranspiration along the growing period of the crop and the crop actual yield. Due to precipitation, evapotranspiration, and yield fluctuations, the uWFp exhibits significant spatio-temporal variability.

240 We computed the uWFp in a given year by means of the Fast-Track (FT) method, introduced and substantiated in Tuninetti et al. (2017). This method is based on the use of the WaterStat database (Mekonnen & Hoekstra, 2010a, 2010b) for expressing the spatial variations of evapotranspiration and on a ratio of agricultural yields for expressing the temporal variability of the unit water footprint, not detailed in WaterStat.

245 According to the Fast-Track method, the unit water footprint of an agricultural product p produced in country c in year t, i.e. $uWFp_{c,p,t}$, reads:

$$uWFp_{c,p,t} = \overline{uWFp_{c,p,T}} \cdot \frac{\overline{Y_{c,p,T}}}{Y_{c,p,t}}, \tag{4}$$

where $\overline{uWFp_{c,p,T}}$ is the reference unit water footprint provided by WaterStat (Mekonnen & Hoekstra, 2010a, 2010b) corresponding to an average in the period T=1996-2005, $\overline{Y_{c,p,T}}$ is the average crop yield over the same period T, and

250 $Y_{c,p,t}$ is the annual crop yield in a generic year t in the range 1961-2016. The average crop yield is obtained as an average of the annual yields in the years 1996-2005, weighted by the harvested areas across the years in country c, based on FAOSTAT data (FAO, 2019a).

The Fast-Track method keeps implicitly constant the actual evapotranspiration of crops, equal to the long-term average

255 used in the WaterStat statistics, but this hypothesis should come at no surprise. On the one hand, yield implicitly expresses many factors, including climatic conditions, water availability, soil fertility and agricultural practices among others, and yield temporal variations dominate over the variability of the water volumes used (evapotranspired) by crops. On the other hand, the uWF is less sensitive to hydro-climatic conditions than actual evapotranspiration, because it is defined as the ratio between evapotranspiration and yield, both reacting with equal signs to hydro-climatic

260 fluctuations (see, e.g., Doorenbos et al, 1979). Additional indications about the uncertainty associated to the Fast-Track method are provided in Section 5.1.

In fact, when the Fast-Track estimates of unit water footprint were compared to the results of a complete model based on a daily soil water balance fed by year-specific hydro-climatic variables, the errors were within a 10% range (see

Tuninetti et al., 2017). The uncertainty introduced in the unit water footprint estimates with the Fast-Track method is

265 lower than the model uncertainty in the water footprint assessment (see Tuninetti et al., 2017). The Fast-Track method, initially applied to 4 crops (wheat, maize, rice and soybeans), has been here extended to a large set of primary products, including cereals, fruits, vegetables, seeds, luxury food and non edibles. The extension is justified by the fact that similar error ranges are expected in all crops, because water stress affects the evapotranspiration of different crops in a similar way, the only difference being the phases of the growing periods affected by water stress and the crop

270 ~~coefficients describing the water requirements along the growing periods. Water stress is assumed not to affect irrigated crops, implying that actual evapotranspiration matches the crop maximum evapotranspiration in irrigated conditions. Uncertainty associated to the Fast-Track method has been sparsely checked on some other crops and the range of errors found in Tuninetti et al. (2017) has been confirmed.~~

3.2 Primary-equivalent trade matrix

275 For the correct identification of countries of origin of the crops traded internationally, the reconstruction of a primary-equivalent trade matrix, M_{eq}, is necessary (Kastner et al., 2011). This is defined as

$$M_{eq} = M_p + \sum_{dp} \left(M_{dp} \cdot \frac{f_v}{f_p} \right) , \qquad (5)$$

where M_p is the trade matrix of any root-product, M_{dp} is the trade matrix of the derived products (dp) and f_p, f_v are the product fraction and value fraction which convert the derived products into a root-product equivalent quantity. The

280 summation is extended to all derived products which originate from the same root product and, in the case of a multi-step supply chain, Eq. (5) is applied iteratively until reaching a root product that is also a primary crop. The product fraction, f_p, is defined as the weight of a derived product obtained from a ton of input product. For example, a ton of nuts with shells leads to f_p (<1) tons of shelled nuts. The value fraction, f_v, is the market value of the derived product divided by the aggregated market value of all derived products resulting from a ton of input product. For example, in a

285 production process of wheat flour there are other economically valuable by-products (e.g., wheat germs to feed animals); hence, the value of wheat flour constitutes only a portion (i.e., the value fraction) of the total value generated by the process. Product fractions and value fractions used in the CWASI database are time- and space- invariant and are taken from Mekonnen & Hoekstra (2010a, 2010b), as well as the root products and the full supply chains of the considered commodities.

3.3 Supply-side unit water footprint of primary crops

The country supply of a primary crop results from the sum of local production and imports, where imports may occur from producing or non-producing countries, the latter case testifying a re-export of goods produced elsewhere. Therefore, the unit water footprint of supply, uWFs, is proportionally contributed by local production and by trade, specifying the relative contribution of every country from which the goods originated from, considering re-exports and

295 the processing of goods, if necessary. For each primary-equivalent crop and each year, we can define a column vector, S, containing the supply of all countries as rows. This vector is calculated as the sum of the production vector, P, and of the imports obtained from the bilateral trade matrix M_{eq}, where $M_{eq}(i,j)$ identifies the trade flow from i to j as

$$S = P + M'_{eq} \cdot I, \tag{6}$$

where I is a column vector of ones (i.e., a summation vector) and M'_{eq} is the trade matrix transposed. Hence, the uWFs of a country depends both on the domestic uWFp (through P) and on the uWFp of the origin countries, where the product is produced.

In order to trace the actual origin of the country's supply, namely tracing its origin back to the country where it was produced, we adopt the approach proposed by Kastner et al. (2011). First, we define a matrix R, where each element $R(i, j)$ is the quantity of supply in country i that is produced in country j. A first approximation of R can be based on reported flows only, and being equal to the sum of a diagonal matrix with elements of the P vector on the diagonal, i.e. $diag(P)$, and the transposed trade matrix, M'_{eq}. However, this approximation misses the fact that exporting countries may obtain the exported products not only from local production, but also from import. To account for this fact, a matrix of export shares, X, can be defined as

$$X = M'_{eq} \cdot diag(S^{-1}), \tag{7}$$

where $X(i, j)$ is the share of country j's supply that is exported to country i. The term $diag(S^{-1})$ denotes a diagonal matrix made up by the reciprocal elements of S. In turn, the imported and re-exported products may partly originate from local production and import, and so on, recursively. It has been shown by Miller and Blair (2009), that such procedure converges to

$$R = (I - X)^{-1} \cdot diag(P), \tag{8}$$

where the R matrix identifies where the supply of each country originates from and I is the identity matrix. For further details and exemplification, see Kastner et al. (2011).

~~The R matrix identifies where the supply of each country originates from. Therefore,~~

By knowing the uWFp of the primary crop in such countries, ~~we~~ can now define the unit water footprint of supply in country c and year t of the primary product p, i.e. $uWFs_{c,p,t}$, as

$$uWFs_{c,p,t} = \sum_{j=1}^{255} uWFp_{j,p,t} \cdot \frac{R_{p,t}(j,c)}{S_{c,p,t}}. \tag{9}$$

The evaluation of uWFs corresponds to a weighted average of the uWFp values, where the weights are the actual fractions of supply, S, traced back to their origins. Eq. (9) is valid for every primary crop p and year t, considering that trade matrices, production vectors and uWFp values change from year to year. It is worth noticing that because the trade matrices are available form 1986 only, the uWFs can be built from that year only.

3.4 Unit water footprint of processed crops in time

Processed crops are based on the processing of root products, which are available as country's supply. The time-varying unit water footprint thus depends on that of the root product and on the conversion factors, i.e. (Hoekstra, et al., 2011),

$$uWF_{c,dp,t} = uWFs_{c,p,t} \cdot \frac{f_v}{f_p}, \tag{10}$$

where $uWF_{c,dp,t}$ is the unit water footprint of the processed crop (or derived product, dp), $uWFs_{c,p,t}$ is the unit water footprint of supply of the root product from which it derives (p), c and t are country and year, respectively, f_p is the product fraction and f_v the value fraction of the processed crop (see Section 3.2). The method takes into account the temporal variability associated to both the crop production, through the Fast-Track method applied to the primary crop, and the evolution of trade, through the Kastner's method applied to the crop supply; the method does not include water inputs for processing of goods. When supply chains are formed by multiple steps, for example in the case of bread, made with flour, made in turn with wheat, Eq. (10) is applied routinely at each step. Within the CWASI dataset, the longest supply chain is made of 4 steps, leading to final products such as refined sugar or chocolate.

Equation (10) describes the unit water footprint without differentiating between production and supply. This is because the absence of FAOSTAT data of production of most processed crops (FAO 2020a) hinders the application of the Kastner's method (Sect. 3.3), thus an explicit accounting of countries of origin of trade, as in the case of primary crops. However, the trade of processed crops is implicitly taken into account in the procedure, thanks to the use of the primary-equivalent trade matrix (Eq. (5)) which serves to compute the uWFs of the primary crop.

For the very few derived products without indication of the root product (Mekonnen & Hoekstra, 2010a), an association is made which is based on logical considerations (such as "Figs dried" deriving from "Figs") or on similitudes of products. The "Sugar" products (Raw Sugar, Refined Sugar,…) were also missing the root-product, likely due to a lack of information. For these products, we have traced back the root product to the product most largely available as country supply (either "Sugar Beet" or "Sugar Cane").

3.5 Unit water footprint of animal-based commodities

Animal-based commodities are available from considered in FAOSTAT areas grouped in three categories: "Live animals", "Livestock primary", and "Livestock processed" (FAO, 2020b, 2020c, 2020d). Products of the first category are given in heads Heads unit, which have been converted in tons according to FAO conversion factors (FAO, 2013). The missing conversion values for some countries (or animal products) have been assigned with an average value by category or considering similar animals. Due to the lack of reliable data about country-specific animal diets and theirits temporal variability as well as the lack of detailed trade matrices of feed crops, we do not currently provide a time-dependent unit water footprint for the animal-based commodities. Nevertheless, we include these products in the present

355 database adopting the country-specific values provided by WaterStat (Mekonnen & Hoekstra, 2010b) and without differentiating between production and supply (i.e., $uWFp = uWFs$). These values of unit water footprint take into account the feed-animal-commodity global supply chain, considering locally-produced and imported feed (Mekonnen & Hoekstra, 2012) but are only available as time-averaged values over the period 1996-2005. Here data are generically referred to year 2000 and are arranged consistently with the rest of the CWASI database.

4 Virtual water trade and water footprint indicators

4.1 Water footprint and VWT data

The water footprint of agricultural production in a country and year is obtained by multiplying the production data (FAO, 2019a, 2020a, 2020b, 2020c, 2020d), expressed in metric tons, by the corresponding (commodity, country, year) unit water footprint, considering the unit water footprint of production, $uWFp_{c,p,t}$, in the case of primary crops. A

365 problem arises when a country was not a producer in the 1996-2005 decade, thus it does not have an associated value in the WaterStat database. In such case, the uWF in the closest producing country within a certain distance (10°) is taken; if no producing countries are found (e.g., in the case of remote islands, or small producing areas), then the global average weighted by production is used. In the case of countries having experienced political discontinuity, for example belonging to a larger country before years 1996-2005 considered in the WaterStat database (e.g., USSR), the reference

370 value of uWF required in Eq. (4) is computed as a production-weighted average of the values of countries belonging to the union and available in WaterStat. This average value is then used to reconstruct the annual uWF from 1961 up to the year of the disaggregation. After converting the agricultural production into water volumes, the overall water footprint of production is obtained by summing across all commodities. Care must be used to avoid double-accounting of water footprints of primary and derived goods. For this reason, only primary products must be considered in aggregated

375 production data. In particular, when dealing with animal-based commodities, one should avoid the inclusion of both livestock and the corresponding their products as well as the inclusion ofthe crops used to feed the livestock. Primary, or single-accounting, products to be included in the sum are indicated in the Appendix, in Supplementary Material, Table SIA.1.

380 Computation of the supply-side unit water footprint of goods enables the fast computation of the water footprint associated to the consumption of commodities, under the hypothesis that consumption (and export) shares with the country's supply the same mix of local and imported goods. The water footprint of consumption in a country and year can thusen be obtained by multiplying the consumed quantity of each good by the unit water footprint of supply,

$uWFs_{c,p,t}$ (per commodity, country and year), then summing across all commodities. In this case, there is no double-accounting issues.

The virtual water trade is obtained by multiplying trade data (FAO, 2019b), expressed in metric tons, by the unit water footprint of supply, $uWFs_{c,p,t}$ of the exporting country. Thanks to the new definition of supply-side unit water footprint, this computation allows one to take into account the origin of goods, which are traced back to their origin places countries along across the supply chain. In the few cases of goods exported from countries not having an associated uWF (less than 1% of trade links over the whole period, mainly from minor countries or remote islands), the global average uWF of supply is used, weighted by all countries' exports. Virtual water trade associated to animal-based commodities is given for year 2000 only, consistently with their unit water footprint, with the uWFp used for the conversion, not being available a uWFs for these commodities yet.

4.2 The uWF index

In the Results section, the (volumetric) water footprint and the virtual water trade are summed across different commodities and the overall trends are assessed in time. However, the unit water footprint of different commodities cannot be assessed as a whole, but only for one commodity at a time. To overcome such problem, an appropriate index is constructed in analogy to some economic indices aggregating prices of different commodities, such as the Agriculture Producer-Price Index (in FAOSTAT) calculated with the Laspeyres approach. The index is built as the inverse ratio between the WF of production (in m^3) of all commodities (i) in all countries (c) in year 2000 and the WF obtained with the same quantities (year 2000) but with uWF in year t, i.e.

$$I(t) = \frac{\sum_{i,c} \ uWF(i,c,t) \cdot P(i,c,2000)}{\sum_{i,c} \ uWF(i,c,2000) \cdot P(i,c,2000)} \cdot 100. \tag{11}$$

In such way, $I(t)$ expresses the variation of uWF across all agricultural commodities, weighted by the productions in year 2000, $P(i,c,2000)$. A similar index as in Eq. (11) can also be built for trade using, e.g., the exports of each country in year 2000 as weights, thus leading to a uWF index for trade. In addition, indexes (for production or trade) referring to single categories of goods can be built by aggregating only the goods belonging to a given category.

5 Results

The importance of considering a time-dependent unit water footprint is highlighted in Figure 3, which shows the temporal trends of the global average uWF of production of some commodities. The global average is computed by weighting the uWFp of each country by the country production of such crop. The relevance of the temporal change is

evident, ranging from 4000 to 1500 m³/ton over the whole considered period. It is worth noticing that the uWF od production of other major crops are shown in Tuninetti et al. (2017).The values considered in WaterStat refer to the period T=1996-2005, highlighted by a grey shade in Figure 3. It is clear that the average value in such reference period is scarcely representative of the whole period considered in the present dataset. It is thus very important to consider the temporal variability of unit water footprint, especially in analyses spanning long periods or periods different than years 1996-2005.

The temporal variation of the uWF of production of crops is marked all over the world. If compared to the values averaged over the period 1996-2005 (as in the WaterStat database), the uWFp computed with the Fast-Track method at the beginning and at the end of the considered period are very different. Figure 4 shows the relative change of the uWFp of wheat in 1961 and 2016 with respect to the 1996-2005 average. The variation is quite uniform worldwide with improvements (decreases of uWF) in both periods which are consistent with the different duration of the two periods. Extreme variations have occurred in China (largest improvement from 1961) and in African countries, showing large improvements in time but also occasional worsening due to unstable socio-economic conditions. It should be noticed that few countries worldwide do not produce wheat or miss FAOSTAT or WaterStat data: in such cases, uWFp values from nearby countries or worldwide averages are used instead. Having a uWF, for any good, in all countries and years is a need dictated by the chance that a non-producing country is an exporter (or re-exporter) of such good and thus requiring a uWF for the conversion of the trade flow into virtual water.

A comparison between the uWF of production and supply of primary crops is very informative. Figure 5 highlights the absolute difference for wheat and soybean with red colours indicating countries where the uWFs is smaller than uWFp and green colours for the contrary. The more intense is the red colour, the more efficient is the crop import in saving global water resources because the imported crops are produced with lower uWF that the local uWF of production. This is the case for several African countries, some South-American ones and Thailand for wheat and several South-Asian countries for soybeans. On the contrary, the more intense is the green colour, and the more efficient the global production is, as compared to imports. The extreme case of non-producing (but importing) countries is highlighted by bold contours. This is observed in several Far-East countries for wheat and by most African countries for soybeans.

Considering all commodities together, the analysis of temporal evolution requires the use of a uWF index (Eq. (11)). The index built weighting by agricultural production decreases monotonically in time (Figure 6, left), being at +50% in 1961 and -7% in 2016. The trend is less marked than in Figure 3 because all goods, and not only wheat, are being considered in the index. The uWF index weighted with exports decreases even more starting with a +85% in 1961. The

difference may be interpreted in two ways, the first being that in the past times, for a given good, the production in exporting countries was more efficient than in the other (producing but not exporting) countries. The second interpretation focuses on a given country and highlights changes in the relative composition of export, with increasing shares of water-efficient goods at the expenses of water-inefficient ones. It is worth noticing that the uWF index is built with all commodities, including those not having a uWF varying in time (e.g., animal-based products, as made explicit in Figure 6, right): considering such contribution, the index temporal variation would be even more marked. The uWF indexes by category, shown in Figure 6 (right), allows one to find similarities and differences. In time, traded fruits and vegetables have improved their uWF more than global production, with large discrepancies in the past between trade-weighted and production-weighted indexes. Traded cereals, especially in the past, where produced with high efficiency, while in more recent years the average uWF of traded cereals became larger than that of the global cereal production. This fact may be due to the increased participation in the international trade of developing countries (Carr el at., 2013), countries producing cereals with lower efficiency than major exporters (eg., the USA). Seeds/oils and luxury food had intermediate periods where trade was on average more efficient than global production, while non-edible goods are currently traded with low efficiency, i.e. the trade-weighted uWF index is larger than the production-weighted one.

The time-varying uWF in the CWASI database is used to assess the temporal evolution of virtual water trade across the years, considering the contribution of different categories of goods. Figure 7 updates previous versions published in the literature (e.g., Konar el at., 2011; Carr el at., 2013; Tuninetti et al., 2017) by either introducing the temporal variability of the uWF of crop-based goods, expanding the number of considered crops and/or extending the temporal range considered. Total VWT has increased from 750 to 2400 km^3/y in the considered period (about 1000 km^3/y in 1986). Major categories are cereals, luxury food, seeds/oils and vegetables, with the relative contribution of cereals, which was very large in the 60ies, being outperformed by the other categories in the most recent years. VW volumes associated to cereals has doubled in the considered period, while volumes associated to vegetables has grown 9-fold. The growth of animal-based products is remarkable, but it should be specified that it only reflects the increased trade quantity without considering the temporal variability of uWF.

5.1 Uncertainties and limitations

Despite the large amount of information and the many improvements provided with the CWASI database, the data uncertainty and a few cautions are worth to be mentioned. The time-varying unit water footprints of crops and crop-based commodities are estimated with a simplified method (the Fast-Track method), that has been thoroughly assessed before applying it widely. For example, the Fast-Track estimates of unit water footprint were compared to the results of a complete model based on a daily soil water balance fed by year-specific hydro-climatic variables and the errors were

found to be within a 10% range (Tuninetti et al., 2017). The uncertainty introduced in the unit water footprint estimates with the Fast-Track method is also lower or comparable to the model uncertainty associated to the water footprint assessment, verified by a comparison with the WaterStat values (see Tuninetti et al., 2017).

The Fast-Track method, initially applied to 4 crops (wheat, maize, rice and soybeans), has been extended in the CWASI database to a large set of primary products, including cereals, fruits, vegetables, seeds, luxury food and non-edibles. The extension is justified by the fact that similar error ranges are expected in all crops, because water stress affects the evapotranspiration of different crops in a similar way, the only difference being the phases of the growing periods affected by water stress and the crop coefficients describing the plant water requirements. Water stress is assumed not to affect irrigated crops, implying that actual evapotranspiration matches the crop maximum evapotranspiration in irrigated conditions. Uncertainty associated to the Fast-Track method has been sparsely checked on other crops than the first 4, and the range of errors found in Tuninetti et al. (2017) has been confirmed. Considering the hypothesis of a long-term average actual evapotranspiration of crops, we suggest to use with care single-year data of uWF, as well as WF and VWT. It is precautionary to consider single-year data in a temporal perspective, such as a trend analysis, or use a multi-year average to minimize the error and avoid misinterpretations of year-specific results.

A minor point of caution is related to the supply-side uWF, which averages country's local production and import. This variable is the best estimate to be used in association to countries' export and consumption, unless more detailed information is available about the origin of country's export or consumption. If local production or import should prevail, as compared to the average country's supply, a more precise weighted average of unit water footprint will be enabled by such information.

For what concerns~~At present~~, the uWF of animal-based commodities, as well as their WF and the VWT, they are here reported for year 2000 only, referring to the average over the years 1996-2005 in the WaterStat database. Where necessary, these values have been applied to production and trade occurring in different years (see Figures 6-7) although cautions in such applications should be used. ~~is kept constant in time.~~ This limitation can be overcome when reliable data on the country-specific feed composition and diet of ~~each~~ animals ~~type~~ will be~~come~~ available along the considered time period.

6 Conclusions

The globalization of water resources through the international trade of food and agricultural goods is a remarkable global environmental change of our times, and the scientific community is devoting great effort to study it. The quantification of the volumes of water involved in the production and trade of agricultural goods is a key tool to investigate the water-food-trade nexus issues. This study presents an open-source database specifically developed for this purpose. The main outcome of this study is the time-varying unit water footprint ~~for~~in the years 1961-2016 and the virtual water trade matrices for the years 1986-2016 of hundreds of commodities ~~form~~ from the food and agricultural sector. The water footprint of production per commodity are also available annually in the period 1961-2016. The current database includes a total of almost 30~~26.8~~ million data, half of them being elements of the trade matrices. ~~Figure 8 shows the number of shared data per variable and per year.~~The introduction of a supply-side estimate of the unit water footprint brings much more detail in the water footprint accounting. This is a new concept and ~~it is~~ a key tool in the expedite and accurate accounting of the virtual water trade and ~~also~~ of the water footprint of consumption. The supply-side unit water footprint overcomes ~~It also enables the overcome of~~ previous problems related to the non-consideration of re-export and it also enables a more accurate assessment of virtual water trade, with the correct identification of countries of origin of traded goods.

~~The time-varying unit water footprints of crops and crop-based commodities are estimated with a simplified but robust method, affected by a known range of uncertainty. Single-year data should be used with care and be put in a temporal perspective or in a multi-year average, in order to minimize the error and to avoid misinterpretations of year-specific results.~~

~~At present, the uWF of animal-based commodities is kept constant in time. This limitation can be overcome when reliable data on the country-specific feed composition and diet of each animal type will be available along the considered time period.~~ ~~Despite this shortcoming, the overall~~ The open-source database presented in this work aims to help the scientific community and policy makers to quantify and investigate the complex linkages between the global food system and water resource issues. Potential applications of the CWASI dataset range from supporting national-scale policies of water management as well as agricultural policies oriented to the optimization of water use or, ultimately, to provide indications for price formation or for trade agreements based on the efficient and sustainable use of water resources worldwide. The CWASI database is shared through the Zenodo online open-access repository (Tamea et al., 2020) and it is planned to be improved and updated in the future, capitalizing contributions from the overall scientific community.

Data availability

Data are available on the Zenodo repository at https://doi.org/10.5281/zenodo.3987468 (Tamea et al., 2020).

Author contribution

ST, MT and IS analysed the data, developed the codes, and organized the dataset. All authors designed the methods and FL supervised the work, ST prepared the manuscript with contributions from all co-authors.

Competing interests

The authors declare not to have competing interests.

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Figures

	Cereals	Fruits	Vegetables	Seeds&Oils	Meat	Diary & Eggs	Lux-foods	Non-edible	Live animals
Trade (290)	24	59	58	30	36	23	36	13	11
Production (214)	14	53	49	19	29	7	16	16	11

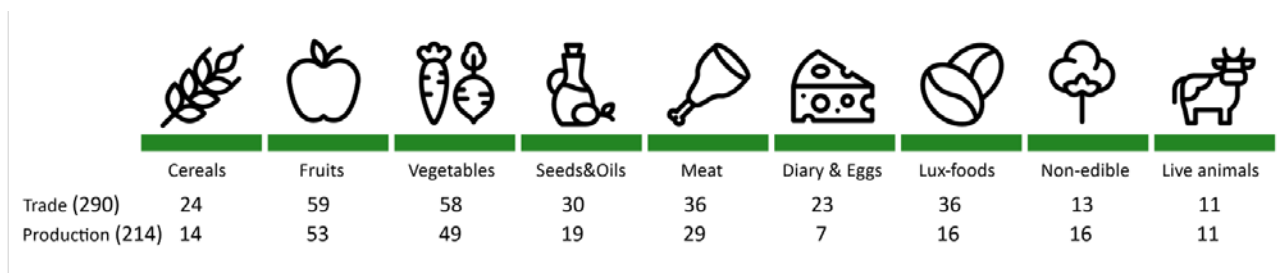



Figure 1: Commodities considered in the analysis, split into 9 categories: number of commodities in the trade and production dataset. Icons from Flaticon.com.

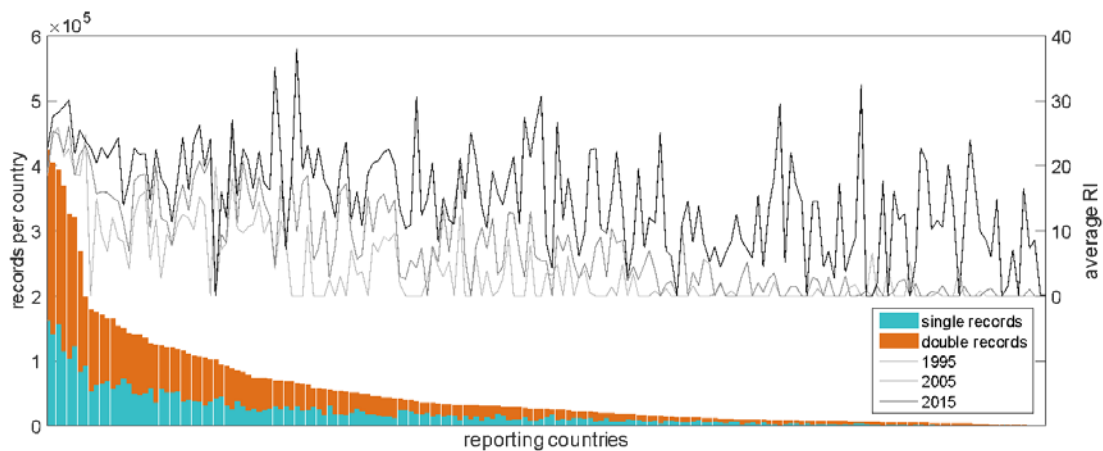



Figure 2: Number of single and double records per reporting country (including all partners, all ~~goods~~items and all years). Right axis indicates the country-specific Reliability Index averaged over all ~~goods~~items in 3 separate years.

640

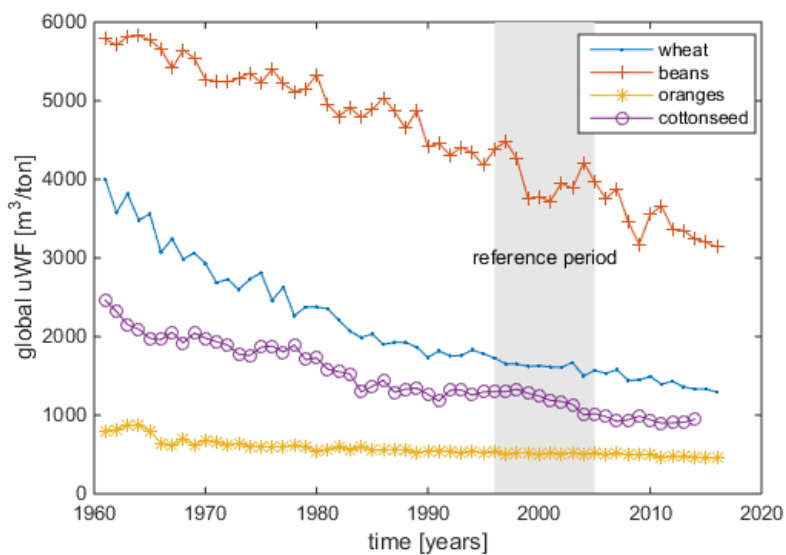



Figure 3: Production-weighted global uWFs along the period 1961-2016 for wheat, beans, oranges and cotton.

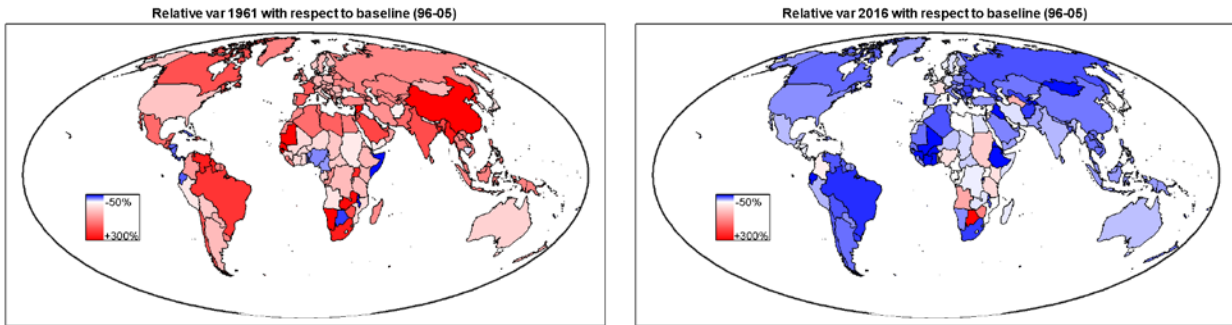



Figure 4: Relative change (in m3/ton) in the uWFp of wheat in 1961 (left) and 2016 (right) with respect to the average in 1996-2005, using identical color ranges: red/blue colors identify higher/lower values and color intensity scales with change values. (Maps created with Matlab® R14 software, Mapping Toolbox v.2.0.3).

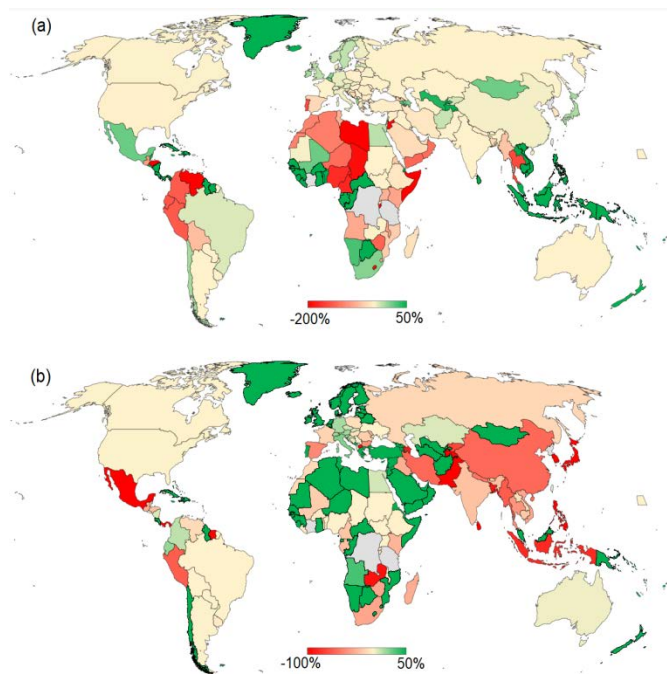



Figure 5: Percentage difference between the uWF of production and supply of wheat (a) and soybean (b) in year 2016, calculated as the difference between uWFs and uWFp, normalized by uWFs. Bold green countries do not produce the crop; hence they only have a supply-side uWF. (Maps created with Microsoft Power Map for Excel, © Microsoft).

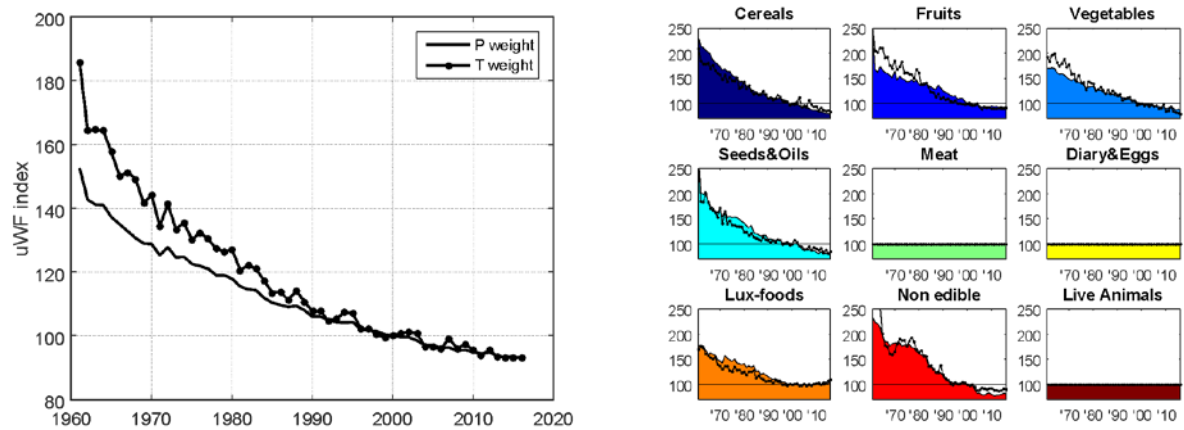



Figure 6: Temporal variability of uWF indexes weighted with agricultural production (solid) and export (with dots) in year 2000, aggregated across all goods (left), and (right) split into the 9 categories of goods.

660

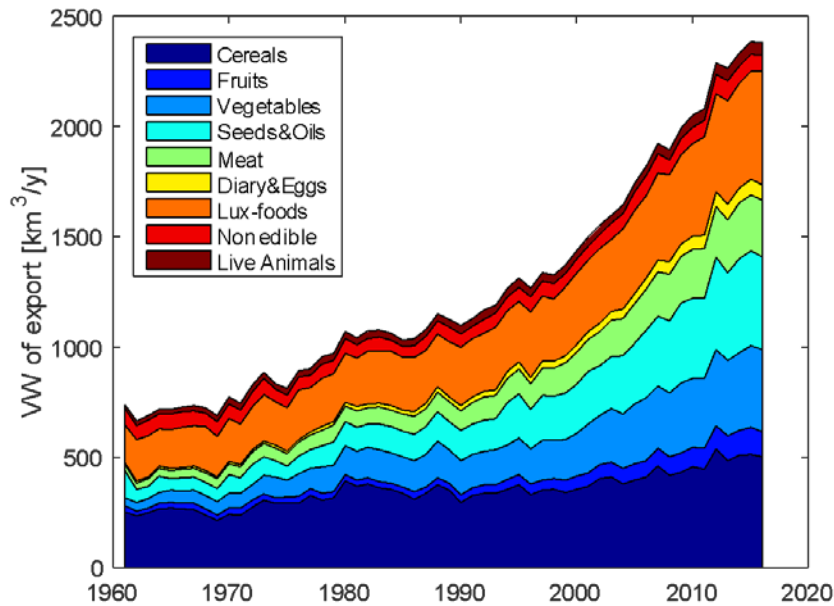



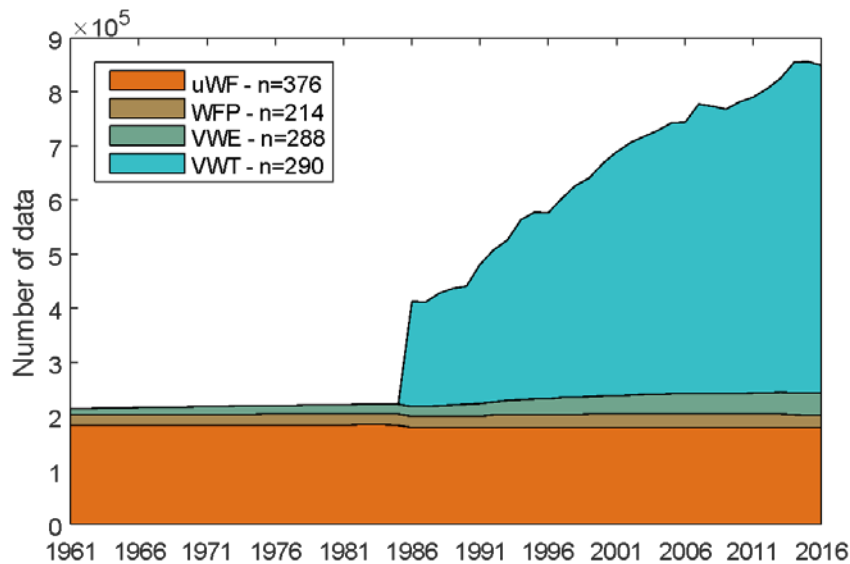
Figure 7: Global virtual water trade (as derived from export data) from 1961 to 2016 considering the 9 categories of goods from Figure 2.

Tables

Table 1: data sources used to prepare the CWASI database.

Variable	Years	URL	Reference	Access date
Crop production, yield and harvested areas	1961-2016	*http://www.fao.org/faostat/en/#data/QC*	FAOSTAT (2019a)	10/2019
Production of processed crops	1961-2016	*http://www.fao.org/faostat/en/#data/QD*	FAOSTAT (2020a)	01/2020
Detailed trade matrices	1986-2016	*http://www.fao.org/faostat/en/#data/TM*	FAOSTAT (2019b)	10/2019
Animal-based primary production	2000	*http://www.fao.org/faostat/en/#data/QL*	FAOSTAT (2020b)	03/2020
Animal-based processed production	2000	*http://www.fao.org/faostat/en/#data/QP*	FAOSTAT (2020c)	03/2020
Live animals	2000	*http://www.fao.org/faostat/en/#data/QA*	FAOSTAT (2020d)	03/2020
Reference uWF of crop-based products	2000 (average)	*https://waterfootprint.org/en/resources/waterstat/product-water-footprint-statistics/*	Mekonnen & Hoekstra (2010a)	03/2020
Reference uWF of animal-based products	2000 (average)	*https://waterfootprint.org/en/resources/waterstat/product-water-footprint-statistics/*	Mekonnen & Hoekstra (2010b)	03/2020

Appendix A: Commodities and countries in the CWASI database

Commodities included in the CWASI database are listed in Table A.1, which includes the commodity name, the FAO code, the presence of production data (1: yes, 0: no), the presence of trade data (1: yes, 0: no) and the associated category. Countries considered in the CWASI database are listed in Table A.2, which include the country name, the FAO code, the position in the CWASI vectors/matrices, the indication of reporting (1) or non-reporting (0) countries, and the presence of discontinuities in the considered period.

Table A.1 List of commodities in the CWASI database

Commodity name	FAO code	in Production	in Trade	Category
Wheat	15	1	1	Cereals
Flour of Wheat	16	0	1	Cereals
Macaroni	18	0	1	Cereals
Bread	20	0	1	Cereals
Bulgur	21	0	1	Cereals
Rice, paddy	27	1	1	Cereals
Rice - total (Rice milled equivalent)	30	0	1	Cereals
Beverages, fermented rice	39	0	1	Lux-foods
Barley	44	1	1	Cereals
Barley Pearled	46	0	1	Cereals
Malt	49	0	1	Cereals
Beer of Barley	51	0	1	Lux-foods
Maize	56	1	1	Cereals
Germ, maize	57	0	1	Cereals
Flour of Maize	58	0	1	Cereals
Maize oil	60	0	1	Seeds & Oils
Rye	71	1	1	Cereals
Oats	75	1	1	Cereals
Oats Rolled	76	0	1	Cereals
Millet	79	1	1	Cereals
Sorghum	83	1	1	Cereals
Buckwheat	89	1	1	Cereals
Quinoa	92	1	0	Cereals
Fonio	94	1	1	Cereals
Triticale	97	1	1	Cereals
Canary seed	101	1	1	Non edible
Mixed grain	103	1	1	Cereals
Cereals, nes	108	1	0	Cereals
Flour, cereals	111	0	1	Cereals
Cereal preparations, nes	113	0	1	Cereals
Potatoes	116	1	1	Vegetables
Potatoes Flour	117	0	1	Vegetables
Frozen Potatoes	118	0	1	Vegetables
Sweet potatoes	122	1	1	Vegetables
Cassava	125	1	1	Vegetables
Cassava Dried	128	0	1	Vegetables
Cassava Starch	129	0	1	Vegetables

Yautia (cocoyam)	135	1	0	Vegetables
Taro (cocoyam)	136	1	0	Vegetables
Yams	137	1	0	Vegetables
Roots and Tubers, nes	149	1	1	Vegetables
Flour of Roots and Tubers	150	0	1	Vegetables
Sugar cane	156	1	0	Vegetables
Sugar beet	157	1	1	Vegetables
Maple Sugar and Syrups	160	0	1	Lux-foods
Sugar crops, nes	161	1	1	Lux-foods
Sugar Refined	164	0	1	Lux-foods
Molasses	165	0	1	Lux-foods
Other Fructose and Syrup	166	0	1	Lux-foods
Sugar, nes	167	0	1	Lux-foods
Sugar flavoured	171	0	1	Lux-foods
Glucose and Dextrose	172	0	1	Lux-foods
Beans, dry	176	1	1	Vegetables
Broad beans, horse beans, dry	181	1	1	Vegetables
Peas, dry	187	1	1	Vegetables
Chick peas	191	1	1	Vegetables
Cow peas, dry	195	1	0	Vegetables
Pigeon peas	197	1	0	Vegetables
Lentils	201	1	1	Vegetables
Bambara beans	203	1	1	Vegetables
Vetches	205	1	1	Vegetables
Lupins	210	1	0	Vegetables
Pulses, nes	211	1	0	Vegetables
Flour of Pulses	212	0	1	Vegetables
Brazil nuts, with shell	216	1	0	Fruits
Cashew nuts, with shell	217	1	1	Fruits
Chestnuts	220	1	1	Fruits
Almonds, with shell	221	1	0	Fruits
Walnuts, with shell	222	1	1	Fruits
Pistachios	223	1	1	Fruits
Kolanuts	224	1	1	Fruits
Hazelnuts, with shell	225	1	0	Fruits
Arecanuts	226	1	0	Fruits
Almonds Shelled	231	0	1	Fruits
Walnuts Shelled	232	0	1	Fruits
Hazelnuts Shelled	233	0	1	Fruits
Nuts, nes	234	1	1	Fruits
Soybeans	236	1	1	Vegetables
Soybean oil	237	0	1	Seeds & Oils
Cake of Soybeans	238	0	1	Vegetables
Soya Sauce	239	0	1	Vegetables
Soya Paste	240	0	1	Vegetables
Groundnuts, with shell	242	1	0	Vegetables
Groundnuts Shelled	243	0	1	Vegetables
Groundnut oil	244	0	1	Seeds & Oils
Cake, groundnuts	245	0	1	Vegetables
Coconuts	249	1	1	Fruits
Copra	251	0	1	Fruits
Coconut (copra) oil	252	0	1	Seeds & Oils
Cake, copra	253	0	1	Fruits

Oil, palm fruit	254	1	0	Fruits
Palm kernels	256	1	0	Fruits
Palm oil	257	1	1	Seeds & Oils
Palm kernel oil	258	0	1	Seeds & Oils
Cake of Palm Kernel	259	0	1	Fruits
Olives	260	1	1	Fruits
Olives Preserved	262	0	1	Fruits
Karite Nuts (Sheanuts)	263	1	0	Fruits
Castor oil seed	265	1	0	Seeds & Oils
Oil of Castor Beans	266	0	1	Seeds & Oils
Sunflower seed	267	1	1	Seeds & Oils
Sunflower oil	268	0	1	Seeds & Oils
Sunflower Cake	269	0	1	Seeds & Oils
Rapeseed	270	1	1	Seeds & Oils
Rapeseed oil	271	0	1	Seeds & Oils
Cake of Rapeseed	272	0	1	Seeds & Oils
Tung nuts	275	1	0	Seeds & Oils
Jojoba seed	277	1	0	Seeds & Oils
Safflower seed	280	1	0	Seeds & Oils
Sesame seed	289	1	1	Seeds & Oils
Sesame oil	290	0	1	Seeds & Oils
Mustard seed	292	1	1	Seeds & Oils
Poppy seed	296	1	1	Seeds & Oils
Melonseed	299	1	0	Seeds & Oils
Tallowtree seed	305	1	0	Seeds & Oils
Kapok fruit	310	1	0	Seeds & Oils
Kapokseed in shell	311	1	1	Seeds & Oils
Seed cotton	328	1	0	Seeds & Oils
Cottonseed	329	1	1	Seeds & Oils
Cake of Cottonseed	332	0	1	Seeds & Oils
Linseed	333	1	1	Seeds & Oils
Linseed oil	334	0	1	Seeds & Oils
Cake of Linseed	335	0	1	Seeds & Oils
Hempseed	336	1	0	Seeds & Oils
Oilseeds, Nes	339	1	1	Seeds & Oils
Cabbages and other brassicas	358	1	1	Vegetables
Artichokes	366	1	1	Vegetables
Asparagus	367	1	1	Vegetables
Lettuce and chicory	372	1	1	Vegetables
Spinach	373	1	1	Vegetables
Cassava leaves	378	1	0	Vegetables
Tomatoes	388	1	1	Vegetables
Juice of Tomatoes	390	0	1	Vegetables
Paste of Tomatoes	391	0	1	Vegetables
Tomato Peeled	392	0	1	Vegetables
Cauliflowers and broccoli	393	1	1	Vegetables
Pumpkins, squash and gourds	394	1	1	Vegetables
Cucumbers and gherkins	397	1	1	Vegetables
Eggplant-baseds (aubergines)	399	1	1	Vegetables
Chillies and peppers, green	401	1	1	Vegetables
Onions (inc. shallots), green	402	1	1	Vegetables
Onions, dry	403	1	1	Vegetables
Garlic	406	1	1	Vegetables

Leeks, other alliaceous vegetables	407	1	1	Vegetables
Beans, green	414	1	1	Vegetables
Peas, green	417	1	1	Vegetables
Vegetables, leguminous nes	420	1	0	Vegetables
String beans	423	1	0	Vegetables
Carrots and turnips	426	1	1	Vegetables
Okra	430	1	0	Vegetables
Maize, green	446	1	1	Vegetables
Sweet Corn Frozen	447	0	1	Vegetables
Mushrooms and truffles	449	1	1	Vegetables
Chicory roots	459	1	0	Vegetables
Veg.Prod.Fresh Or Dried	460	0	1	Vegetables
Carobs	461	1	0	Vegetables
Vegetables fresh nes	463	1	1	Vegetables
Vegetables, dried nes	464	0	1	Vegetables
Vegetables Preserved Nes	472	0	1	Vegetables
Vegetable Frozen	473	0	1	Vegetables
Bananas	486	1	1	Fruits
Plantains	489	1	1	Fruits
Oranges	490	1	1	Fruits
Orange juice, single strength	491	0	1	Fruits
Tangerines, mandarins, clem.	495	1	1	Fruits
Lemons and limes	497	1	1	Fruits
Grapefruit (inc. pomelos)	507	1	1	Fruits
Juice of Grapefruit	509	0	1	Fruits
Citrus fruit, nes	512	1	0	Fruits
Citrus juice, single strength	513	0	1	Fruits
Apples	515	1	1	Fruits
Pears	521	1	1	Fruits
Quinces	523	1	1	Fruits
Apricots	526	1	1	Fruits
Dry Apricots	527	0	1	Fruits
Sour cherries	530	1	1	Fruits
Cherries	531	1	1	Fruits
Peaches and nectarines	534	1	1	Fruits
Plums and sloes	536	1	1	Fruits
Plums Dried (Prunes)	537	0	1	Fruits
Stone fruit, nes	541	1	0	Fruits
Fruit, pome nes	542	1	0	Fruits
Strawberries	544	1	1	Fruits
Raspberries	547	1	0	Fruits
Gooseberries	549	1	1	Fruits
Currants	550	1	1	Fruits
Blueberries	552	1	1	Fruits
Cranberries	554	1	1	Fruits
Berries Nes	558	1	0	Fruits
Grapes	560	1	1	Fruits
Raisins	561	0	1	Fruits
Grape Juice	562	0	1	Fruits
Wine	564	0	1	Lux-foods
Vermouths and Similar	565	0	1	Lux-foods
Watermelons	567	1	1	Fruits
Other melons (inc.cantaloupes)	568	1	1	Fruits

Figs	569	1	1	Fruits
Mangoes, mangosteens, guavas	571	1	1	Fruits
Avocados	572	1	1	Fruits
Pineapples	574	1	1	Fruits
Juice of Pineapples	576	0	1	Fruits
Dates	577	1	1	Fruits
Persimmons	587	1	1	Fruits
Cashew apple	591	1	1	Fruits
Kiwi fruit	592	1	1	Fruits
Papayas	600	1	1	Fruits
Fruit, tropical fresh nes	603	1	1	Fruits
Fruit Fresh Nes	619	1	1	Fruits
Fruit, dried nes	620	0	1	Fruits
Fruit Juice Nes	622	0	1	Fruits
Coffee, green	656	1	1	Lux-foods
Coffee Roasted	657	0	1	Lux-foods
Cocoa beans	661	1	1	Lux-foods
Cocoa Paste	662	0	1	Lux-foods
Cocoa Butter	664	0	1	Lux-foods
Cocoapowder and Cake	665	0	1	Lux-foods
Chocolate Prsnes	666	0	1	Lux-foods
Tea	667	1	1	Lux-foods
Maté	671	1	1	Lux-foods
Hops	677	1	1	Lux-foods
Pepper (Piper spp.)	687	1	1	Lux-foods
Chillies and peppers, dry	689	1	1	Lux-foods
Vanilla	692	1	1	Lux-foods
Cinnamon (canella)	693	1	1	Lux-foods
Cloves	698	1	1	Lux-foods
Nutmeg, mace and cardamoms	702	1	1	Lux-foods
Anise, badian, fennel, corian.	711	1	1	Lux-foods
Ginger	720	1	1	Lux-foods
Spices, nes	723	1	1	Lux-foods
Peppermint	748	1	1	Lux-foods
Cotton lint	767	1	1	Non edible
Cotton Carded,Combed	768	0	1	Non edible
Cotton Waste	769	0	1	Non edible
Cotton Linter	770	0	1	Non edible
Flax fibre and tow	773	1	1	Non edible
Flax Tow Waste	774	0	1	Non edible
Hemp Tow Waste	777	1	0	Non edible
Kapok fibre	778	1	1	Non edible
Jute	780	1	1	Non edible
Other Bastfibres	782	1	0	Non edible
Ramie	788	1	0	Non edible
Sisal	789	1	0	Non edible
Agave Fibres Nes	800	1	0	Non edible
Manila Fibre (Abaca)	809	1	1	Non edible
Coir	813	1	0	Non edible
Fibre Crops Nes	821	1	0	Non edible
Tobacco, unmanufactured	826	1	1	Non edible
Natural rubber	836	1	1	Non edible
Gums, natural	839	1	0	Non edible

Cattle	866	0	1	Live animals
Cattle meat	867	1	1	Meat
Offals of cattle, edible	868	0	1	Meat
Fat, cattle	869	0	1	Meat
Meat-Cattle, boneless	870	0	1	Meat
Sausage Beef and Veal	874	0	1	Meat
Meat, beef, preparations	875	0	1	Meat
Cow milk, whole, fresh	882	1	1	Diary & Eggs
Cream fresh	885	0	1	Diary & Eggs
Butter Cow Milk	886	0	1	Diary & Eggs
Milk Skm of Cows	888	0	1	Diary & Eggs
Milk Whole Cond	889	0	1	Diary & Eggs
Whey Condensed	890	0	1	Diary & Eggs
Yoghurt, concentrated or not	892	0	1	Diary & Eggs
Butterm.,Curdl,Acid.Milk	893	0	1	Diary & Eggs
Milk, whole evaporated	894	0	1	Diary & Eggs
Milk Whole Dried	897	0	1	Diary & Eggs
Milk Skimmed Dry	898	0	1	Diary & Eggs
Whey, dry	900	0	1	Diary & Eggs
Cheese of Whole Cow Milk	901	0	1	Diary & Eggs
Processed Cheese	907	0	1	Diary & Eggs
Prod.of Nat.Milk Constit	909	0	1	Diary & Eggs
Ice cream and edible ice	910	0	1	Diary & Eggs
Meat indigenous, cattle	944	1	0	Meat
Buffaloes	946	0	1	Live animals
Meat, buffalo	947	1	0	Meat
Milk, whole fresh buffalo	951	1	0	Diary & Eggs
Ghee, of buffalo milk	953	0	1	Diary & Eggs
Meat indigenous, buffalo	972	1	0	Meat
Sheep	976	0	1	Live animals
Sheep meat	977	1	1	Meat
Offals of Sheep,Edible	978	0	1	Meat
Milk, whole fresh sheep	982	1	1	Diary & Eggs
Cheese of Sheep Milk	984	0	1	Diary & Eggs
Meat indigenous, sheep	1012	1	0	Meat
Goats	1016	0	1	Live animals
Goat meat	1017	1	1	Meat
Offals of Goats, Edible	1018	0	1	Meat
Milk, whole fresh goat	1020	1	0	Diary & Eggs
Meat indigenous, goat	1032	1	0	Meat
Pigs	1034	0	1	Live animals
Pig meat	1035	1	1	Meat
Offals of Pigs, Edible	1036	0	1	Meat
Fat of Pigs	1037	0	1	Meat
Meat, pork	1038	0	1	Meat
Bacon and Ham	1039	0	1	Meat
Sausages of Pig Meat	1041	0	1	Meat
Prep of Pig Meat	1042	0	1	Meat
Lard	1043	0	1	Meat
Meat indigenous, pig	1055	1	0	Meat
Chickens	1057	0	1	Live animals
Meat, chicken	1058	1	1	Meat
Offals, liver chicken	1059	0	1	Meat

Fat, liver prepared (foie gras)	1060	0	1	Meat
Meat, chicken, canned	1061	0	1	Meat
Hen eggs, in shell	1062	1	1	Diary & Eggs
Eggs Liquid	1063	0	1	Diary & Eggs
Eggs Dried	1064	0	1	Diary & Eggs
Ducks	1068	0	1	Live animals
Duck meat	1069	1	1	Meat
Meat indigenous, duck	1070	1	0	Meat
Goose and guinea fowl meat	1073	1	1	Meat
Offals, liver geese	1074	0	1	Meat
Offals, liver duck	1075	0	1	Meat
Meat indigenous, geese	1077	1	0	Meat
Turkeys	1079	0	1	Live animals
Turkey meat	1080	1	1	Meat
Meat indigenous, bird nes	1084	1	0	Meat
Meat indigenous, turkey	1087	1	0	Meat
Meat, bird nes	1089	1	0	Meat
Other bird eggs,in shell	1091	1	1	Diary & Eggs
Meat indigenous, chicken	1094	1	0	Meat
Horses	1096	0	1	Live animals
Horse meat	1097	1	1	Meat
Asses	1107	0	1	Live animals
Meat, ass	1108	1	1	Meat
Mules	1110	0	1	Live animals
Meat, mule	1111	1	0	Meat
Meat indigenous, horse	1120	1	0	Meat
Meat indigenous, ass	1122	1	0	Meat
Meat indigenous, mule	1124	1	0	Meat
Milk, whole fresh camel	1130	1	0	Diary & Eggs
Meat, game	1163	1	1	Meat
Meat, dried nes	1164	0	1	Meat
Meat, nes	1166	1	1	Meat
Offals, nes	1167	1	0	Meat
Oils, fats of animal nes	1168	0	1	Meat
Meal, meat	1173	0	1	Meat
Tallow	1225	0	1	Meat

680 **Table A.2 List of countries in the CWASI database**

Country name	FAO code	position	reporting	discontinuities
'Afghanistan'	2	1	1	
'Albania'	3	2	1	
'Algeria'	4	3	1	
'American Samoa'	5	4	0	
'Andorra'	6	5	0	
'Angola'	7	6	0	
'Anguilla'	258	7	0	
'Antarctica'	30	8	0	
'Antigua and Barbuda'	8	9	1	

'Argentina'	9	10	1	
'Armenia'	1	11	1	active from 1992
'Aruba'	22	12	1	
'Australia'	10	13	1	
'Austria'	11	14	1	
'Azerbaijan'	52	15	1	active from 1992
'Bahamas'	12	16	1	
'Bahrain'	13	17	1	
'Bangladesh'	16	18	1	
'Barbados'	14	19	1	
'Belarus'	57	20	1	active from 1992
'Belgium'	255	21	1	active from 2000
'Belgium-Luxembourg'	15	22	1	inactive from 2000
'Belize'	23	23	1	
'Benin'	53	24	1	
'Bermuda'	17	25	1	
'Bhutan'	18	26	1	
'Bolivia, Plurinational State of'	19	27	1	
'Bosnia and Herzegovina'	80	28	1	active from 1992
'Botswana'	20	29	1	
'Bouvet Island'	31	30	0	
'Brazil'	21	31	1	
'British Indian Ocean Territory'	24	32	0	
'British Virgin Islands'	239	33	0	
'Brunei Darussalam'	26	34	1	
'Bulgaria'	27	35	1	
'Burkina Faso'	233	36	1	
'Burundi'	29	37	1	
'Cambodia'	115	38	1	
'Cameroon'	32	39	1	
'Canada'	33	40	1	
'Canton and Enderbury Islands'	34	41	0	
'Cape Verde'	35	42	1	
'Cayman Islands'	36	43	0	
'Central African Republic'	37	44	1	
'Chad'	39	45	0	
'Chile'	40	46	1	
'China, Hong Kong SAR'	96	47	1	
'China, Macao SAR'	128	48	1	
'China, Mainland'	41	49	1	
'China, Taiwan Province of'	214	50	1	
'Christmas Island'	42	51	0	
'Cocos Islands (Keeling)'	43	52	0	
'Colombia'	44	53	1	
'Comoros'	45	54	1	
'Congo'	46	55	1	
'Congo, Democratic Republic of the'	250	56	1	
'Cook Islands'	47	57	1	
'Costa Rica'	48	58	1	
'Cote de Ivoire'	107	59	1	
'Croatia'	98	60	1	active from 1992
'Cuba'	49	61	1	
'Cyprus'	50	62	1	

'Czech Republic'	167	63	1	active from 1993
'Czechoslovakia'	51	64	1	inactive from 1993
'Denmark'	54	65	1	
'Djibouti'	72	66	1	
'Dominica'	55	67	1	
'Dominican Republic'	56	68	1	
'Ecuador'	58	69	1	
'Egypt'	59	70	1	
'El Salvador'	60	71	1	
'Equatorial Guinea'	61	72	0	
'Eritrea'	178	73	0	active from 1993
'Estonia'	63	74	1	active from 1992
'Ethiopia'	238	75	1	active from 1993
'Falkland Islands (Malvinas)'	65	76	0	
'Faroe Islands'	64	77	1	
'Fiji'	66	78	1	
'Finland'	67	79	1	
'France'	68	80	1	
'French Guiana'	69	81	1	
'French Polynesia'	70	82	1	
'French Southern and Antarctic Territories'	71	83	0	
'Gabon'	74	84	1	
'Gambia'	75	85	1	
'Georgia'	73	86	1	active from 1992
'Germany'	79	87	1	
'Ethiopia PDR'	62	88	1	inactive from 1993
'Neutral Zone'	152	89	0	all zeros
'Ghana'	81	90	1	
'Gibraltar'	82	91	0	
'Greece'	84	92	1	
'Greenland'	85	93	1	
'Grenada'	86	94	1	
'Guadeloupe'	87	95	1	
'Guam'	88	96	0	
'Guatemala'	89	97	1	
'Guinea'	90	98	1	
'Guinea-Bissau'	175	99	0	
'Guyana'	91	100	1	
'Haiti'	93	101	0	
'Heard and McDonald Islands'	92	102	0	
'Holy See'	94	103	0	
'Honduras'	95	104	1	
'Hungary'	97	105	1	
'Iceland'	99	106	1	
'India'	100	107	1	
'Indonesia'	101	108	1	
'Iran, Islamic Republic of'	102	109	1	
'Iraq'	103	110	0	
'Ireland'	104	111	1	
'Israel'	105	112	1	
'Italy'	106	113	1	
'Jamaica'	109	114	1	
'Japan'	110	115	1	

'Johnston Island'		111	116	0	
'Jordan'		112	117	1	
'Kazakhstan'		108	118	1	active from 1992
'Kenya'		114	119	1	
'Kiribati'		83	120	1	
'Korea, Democratic Peoples Republic of'		116	121	0	
'Korea, Republic of'		117	122	1	
'Kuwait'		118	123	1	
'Kyrgyzstan'		113	124	1	active from 1992
'Lao Peoples Democratic Republic'		120	125	0	
'Latvia'		119	126	1	active from 1992
'Lebanon'		121	127	1	
'Lesotho'		122	128	0	
'Liberia'		123	129	0	
'Libya'		124	130	1	
'Liechtenstein'		125	131	0	
'Lithuania'		126	132	1	active from 1992
'Luxembourg'		256	133	1	active from 2000
'Macedonia, The former Yugoslav Republic of'		154	134	1	active from 1992
'Madagascar'		129	135	1	
'Malawi'		130	136	1	
'Malaysia'		131	137	1	
'Maldives'		132	138	1	
'Mali'		133	139	1	
'Malta'		134	140	1	
'Marshall Islands'		127	141	0	
'Martinique'		135	142	1	
'Mauritania'		136	143	1	
'Mauritius'		137	144	1	
'Mayotte'		270	145	0	
'Mexico'		138	146	1	
'Micronesia, Federated States of'		145	147	0	
'Midway Island'		139	148	0	
'Moldova, Republic of'		146	149	1	active from 1992
'Monaco'		140	150	0	
'Mongolia'		141	151	1	
'Montenegro'		273	152	1	active from 2006
'Montserrat'		142	153	1	
'Morocco'		143	154	1	
'Mozambique'		144	155	0	
'Myanmar'		28	156	0	
'Namibia'		147	157	1	
'Nauru'		148	158	0	
'Nepal'		149	159	1	
'Netherlands'		150	160	1	
'Netherlands Antilles'		151	161	1	
'New Caledonia'		153	162	1	
'New Zealand'		156	163	1	
'Nicaragua'		157	164	1	
'Niger'		158	165	1	
'Nigeria'		159	166	1	
'Niue'		160	167	0	
'Norfolk Island'		161	168	0	

'Northern Mariana Islands'	163	169	0	
'Norway'	162	170	1	
'Occupied Palestinian Territory'	299	171	0	
'Oman'	221	172	1	
'Pacific Islands Trust Territory'	164	173	0	
'Pakistan'	165	174	1	
'Palau'	180	175	0	
'Panama'	166	176	1	
'Papua New Guinea'	168	177	1	
'Paraguay'	169	178	1	
'Peru'	170	179	1	
'Philippines'	171	180	1	
'Pitcairn Islands'	172	181	0	
'Poland'	173	182	1	
'Portugal'	174	183	1	
'Puerto Rico'	177	184	0	
'Qatar'	179	185	1	
'Reunion'	182	186	1	
'Romania'	183	187	1	
'Russian Federation'	185	188	1	active from 1992
'Rwanda'	184	189	1	
'Saint Helena, Ascension and Tristan da Cunha'	187	190	0	
'Saint Kitts and Nevis'	188	191	1	
'Saint Lucia'	189	192	1	
'Saint Pierre and Miquelon'	190	193	0	
'Saint Vincent and the Grenadines'	191	194	1	
'Samoa'	244	195	0	
'San Marino'	192	196	0	
'Sao Tome and Principe'	193	197	1	
'Saudi Arabia'	194	198	1	
'Senegal'	195	199	1	
'Serbia'	272	200	1	active from 2006
'Serbia and Montenegro'	186	201	1	active from 1992 to 2005
'Seychelles'	196	202	1	
'Sierra Leone'	197	203	1	
'Singapore'	200	204	1	
'Slovakia'	199	205	1	active from 1993
'Slovenia'	198	206	1	active from 1992
'Solomon Islands'	25	207	1	
'Somalia'	201	208	0	
'South Africa'	202	209	1	
'South Georgia and the South Sandwich Islands'	271	210	0	
'Spain'	203	211	1	
'Sri Lanka'	38	212	1	
'Sudan (former)'	206	213	1	inactive from 2012
'Suriname'	207	214	1	
'Svalbard and Jan Mayen Islands'	260	215	0	
'Swaziland'	209	216	1	
'Sweden'	210	217	1	
'Switzerland'	211	218	1	
'Syrian Arab Republic'	212	219	1	
'Tajikistan'	208	220	0	active from 1992
'Tanzania, United Republic of'	215	221	1	

'Thailand'	216	222	1	
'Timor-Leste'	176	223	0	
'Togo'	217	224	1	
'Tokelau'	218	225	0	
'Tonga'	219	226	1	
'Trinidad and Tobago'	220	227	1	
'Tunisia'	222	228	1	
'Turkey'	223	229	1	
'Turkmenistan'	213	230	0	active from 1992
'Turks and Caicos Islands'	224	231	0	
'Tuvalu'	227	232	1	
'Uganda'	226	233	1	
'Ukraine'	230	234	1	active from 1992
'United Arab Emirates'	225	235	1	
'United Kingdom'	229	236	1	
'United States Minor Is.'	232	237	0	
'United States Of America'	231	238	1	
'United States Virgin Islands'	240	239	0	
'Unspecified'	252	240	0	all zeros
'Uruguay'	234	241	1	
'Ussr'	228	242	1	inactive from 1992
'Uzbekistan'	235	243	0	active from 1992
'Vanuatu'	155	244	1	
'Venezuela, Bolivarian Republic of'	236	245	1	
'Viet Nam'	237	246	0	
'Wake Island'	242	247	0	
'Wallis and Futuna Islands'	243	248	0	
'Western Sahara'	205	249	0	
'Yemen'	249	250	1	
'Sudan'	276	251	0	active from 2012
'South Sudan'	277	252	0	active from 2012
'Yugoslav SFR'	248	253	1	inactive from 1992
'Zambia'	251	254	1	
'Zimbabwe'	181	255	1	
'China'	351	NaN	0	