Virtual water trade in the semi-arid regions of Nigeria

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Abstract. With continuous growth in the world population, the demand for water increases and hence water scarcity rises. Adequate measures have to be put in place in order to make proper utilization of the available water. Virtual water trade is defined as the water volume conveyed within the imported or exported food. Hence, the aim of this study was to determine the virtual water volume required for crops production of 25 different crops in the semi-arid regions of Nigeria for the year 2013. In addition, the water footprint, imports and exports of virtual water, the production volume of virtual water, green, blue, and grey water contributions to crops production, water balance, exports income, imports costs and value of the selected crops produced were distinguished. The study was conducted using CROPWAT 8.0 software. The result revealed that in the 7 regions of the semi-arid zone, the crops selected had total volume of virtual water produced of approximately 35.9 Gm³/yr, exports volume of virtual water was 27.5 Mm³/yr, imports volume of virtual water was 8.6 Gm³/yr, water footprint was 44.5 Gm³/yr and water balance was 8.6 Gm³/yr. Total value of the produced crops was $2.6 billion, export income $1.1 million and import cost $794.6 million. Gusau with higher percentage of green water used is preferable region to grow crops in the semi-arid regions of Nigeria, which can consequently lead to reduced cost of production and scarcity of water.

1. Introduction

With continued water scarcity especially in arid and semi-arid climate regions and due to persistent population increase, water resources are generally regarded as economic goods across all areas of the globe [1, 2]. In order to acquire the desired domestic food demand, many countries opted to import the food they consume instead of local production owing to their scarcity of water resources. However, the food imported in those water scarce countries, is virtually equal to the water importation which can be used to produce food within the nation domestically under other circumstances. According to [3], ‘Virtual Water’ is regarded as the water which is conveyed within imported food. Moreover, idea of virtual water was expanded by [4] study, which identified virtual water, as water needed to produce agricultural and industries goods. Due to their major ratio in aggregate water use, deliberations on virtual water issues are until now mainly based on food items [1]. With a prolonged increase in scarcity of water, the contribution of virtual water trade (VWT) in equating domestic water budget in numerous countries of the globe is anticipated to rise [5].

This study was focused on determining the virtual water volume required for the production of 25 different crops in Nigeria for the year 2013 considering semi-arid as the case study zone. Also, exports...
and imports of virtual water, produced virtual water volume, green, blue, and grey water contributions to crops production, water balance, exports income, imports costs, value of the selected crops produced and water footprint were also assessed. In addition, cost benefit analysis was also performed.

2. Method

2.1. Study country

Nigeria is a West African country situated in the tropical zone between the longitudes of 20°2`E to 14°30`E and latitude between 4°N to 14°N with total area of about 923,770 km². The northern and southern Nigeria are separated by a distance of 1,050 km while the optimum distance between east and west is 1,150 km. Different countries bordered Nigeria including Chad to the northeast, Cameroon to the east, Benin to the west, and Niger to the north and northwest while southern part of Nigeria is bordered by the Atlantic Ocean. Nigeria’s Land constitutes thick mangrove forests and dense rain forests at south while northeastern part of the country has close-to-desert situation [6]. Abuja is the central and the Nigeria’s capital territory, it is surrounded by 36 states that make up the country (as seen in Figure 1).
Table 1. Agro-ecological zones in Nigeria

| Zone description      | Percentage of country area (%) | Annual rainfall (mm) | Minimum (°C) | Normal (°C) | Maximum (°C) |
|-----------------------|--------------------------------|----------------------|--------------|-------------|--------------|
| Semi-arid             | 4                              | 400 - 600            | 13           | 32 - 33     | 40           |
| Dry sub-humid         | 27                             | 600 - 1000           | 12           | 21 - 31     | 49           |
| Sub-humid             | 26                             | 1000 - 1300          | 14           | 23 - 30     | 37           |
| Humid                 | 21                             | 1100 - 1400          | 18           | 26 - 30     | 37           |
| Very humid            | 14                             | 1120 - 2000          | 21           | 24 - 28     | 37           |
| Ultra humid (Flood)   | 2                              | > 2000               | 23           | 25 - 28     | 33           |
| Mountainous           | 4                              | 1400 - 2000          | 5            | 14 - 29     | 32           |
| Plateau               | 2                              | 1400 - 1500          | 14           | 20 - 24     | 36           |

2.2. Study region

Huge part of Northern Nigeria is covered by semi-arid climate including Sudan bioclimatic and Sahel savanna regions. The climate of the regions is dominated by rain bearing, tropical maritime south westerly air masses, the dry and tropical continental north-easterly [7]. In reaction to the relative intenseness of the St. Helena and the Azores-Libyan system for tropical pressure, the air masses meeting which travelled over west Africa formed humidity discontinuity known as inter-tropical discontinuity of a quasi-frontal zone [8]. Whenever the inter-tropical discontinuity migrates beyond bound of northward, the rainy season begins at any moment, while retreating at the end Southward. North and the northern Nigeria are invaded between June and September by the Inter-tropical discontinuity which is subsequently influenced by tropical maritime.

As shown in Figure 2, the zones of aridity in Nigeria are classified in to four [9] they include:

- Semi-arid
- Dry sub-humid
- Moist sub-humid and
- Humid

Semi-arid zone is characterized by the highest rate of water scarcity among the four zones. Therefore, this research focused on the semi-arid zone in the northern part of Nigeria.
Figure 2. Aridity zones in Africa [9]

The semi-arid zone has 7 regions. These are; Gusau, Kano, Katsina, Maiduguri, Nguru, Potiskum, and Sokoto. A total of 25 crops were selected from regions. The crops are; Millet, Tobacco, Banana 1, Pepper, Rice, Banana 2, Winter wheat, Sorghum, Barley, Beans dry, Potato, Date palm, Soybean, Sugarcane, Vegetables fresh nes, Wheat (spring) Beans green, Cabbage, Citrus, Maize, Mango, Pulses, Sugarbeet, Tomato, and Groundnut. They were grouped into; Oilseed crops, Cereals, Fruit and Nuts, Vegetables, and other crops.

2.3. Water colours

Virtual water is classified into three types, namely; the green water, the blue water and the Grey water respectively. It is, therefore, important to differentiate them as they also differ in their characteristics [10].

**Green water**: The green water as virtual water content is defined as the volume of rain-fed water which evaporated in the process of production. This specifically concerned products from agriculture, whereby referred to the aggregate sum of rained water hoard inside soil as soil water and disappeared by evaporation from the portion at the time of crop development [11].

**Blue water**: The blue water as virtual water content is defined as the surface water volume that disappeared through evaporation owing to its production (it includes rivers, streams, lakes, and ground water). With regards to crop production, the content of blue water is established as the evaporation of soaked water from soil and water supplied evaporation from the soaked watercourse and unnatural hoarding reservoirs [12].

**Grey water**: Grey water is defined as the volume of water needed to mix the quantity of toxic waste (pollutants) ejected into the pure water scheme to a point that the perfection or pureness of the surrounding area of the water kept beyond the quality standard of water agreed [11].

2.4. Calculations

Virtual water content was calculated based on [13], Virtual water trade, Gross virtual water import and export, and Net virtual water import (water balance) were calculated on the basis of [12]. Virtual water demand was obtained by multiplying production quantity by virtual water content. Green and Blue
virtual water for CROPWAT were computed on the basis of [14] using irrigation schedule option, while water footprint was obtained by adding virtual water import to virtual water demand minus virtual water export. $E_T$ calculations were arranged by Penman Monteith equation [15]. CROPWAT 8.0 software developed by Food and Agricultural Organization of the United Nations [16] was used for the calculations of crop evapotranspiration and reference evapotranspiration.

2.5. Climate data
This study employed the use of database for providing input data to CROPWAT model called CLIMWAT 2.0 for CROPWAT developed by FAO [17]. It provides data on solar radiation, temperatures, sunshine hours, wind speed and relative humidity. The software is accessible through FAO’s website. The CLIMWAT database contains data for over 100 countries including the used data for Nigeria.

2.6. Crop parameters
CROPWAT/CLIMWAT database(s) provided the crop parameters including crop coefficient in the initial, middle, and late stages, and also root depth while planting dates were adopted from FAO crop calendar. FAOSTAT database was used as the source of crop yield data and can be accessible through FAO’s website [18]. Owing to lack of the data, the regional cultivated lands considering the country’s population distributions were obtained by generating an equation.

2.7. Calculations procedure
The step by step procedure of the virtual water trade calculated in the semi-arid regions of Nigeria were summarized in Figure 3 below

![Figure 3](image-url)

Figure 3. The overall virtual water trade procedure
3. Results and Discussions
The results of this study were obtained and presented in accordance with the procedure and the methodology applied. As revealed in the results shown in Table 2, crops produced in Kano constitute the highest virtual water content, thus, its production required more water than any region in the semi-arid zone. Maiduguri is the second largest crops production region in terms of water consumption. Sokoto followed as third, then Potiskum, Gusau, Katsina, and Nguru is the least water consumption region.

Comparing the volume of virtual water between exports and imports in the semi-arid regions of Nigeria in 2013, it can be seen that virtual water imports volume is 292 million m$^3$/yr which is by far larger than that of exports which is 919.6 thousand m$^3$/yr, from region with least volume of virtual water (Nguru). Being a region with highest crop virtual water content, and with 3.1 billion m$^3$/yr and 9.3 million m$^3$/yr, Kano also has the largest virtual water volume for both imports and exports (as in Table 2).

Despite the presence of Maiduguri as a region with second highest virtual water content, it is the third with respect to crops’ virtual water volume for both exports with 4.4 million and imports with 1.4 billion m$^3$/yr (Table 2). The gross virtual water exports average volume between the 7 study regions can be calculated from table 2 as approximately 3.9 Mm$^3$/yr for 2013 while for imports as 1.2 Gm$^3$/yr.

Table 2. Exports, imports, and gross virtual water content for semi-arid regions of Nigeria

| Regions Name | GVWC (m$^3$/ton) | GVWI (m$^3$/yr) | GVWE (m$^3$/yr) |
|--------------|-----------------|-----------------|-----------------|
| Gusau        | 104,668         | 674,802,864     | 2,724,064       |
| Kano         | 127,859         | 3,078,763,708   | 9,345,039       |
| Katsina      | 102,012         | 1,601,627,723   | 5,473,175       |
| Maiduguri    | 127,205         | 1,443,513,905   | 4,400,463       |
| Nguru        | 91,966          | 292,021,873     | 919,609         |
| Potiskum     | 105,082         | 363,234,270     | 1,078,763       |
| Sokoto       | 118,895         | 1,159,193,397   | 3,513,415       |
| Total        | 777,686         | 8,613,157,740   | 27,454,527      |

In view of the obtained results in Figure 4, the virtual water volumes of both imports and exports are comparably smaller than volume of virtual water produced in each region which provides more than two-third of the total virtual water volume of imports, exports and productions.
Amongst the semi-arid regions of Nigeria, Kano is by far the largest Green water region with 3.6 Gm$^3$/yr (Table 3). With a difference of over 2 billion cubic meters of water in comparison to Kano, Gusau has second highest Green water availability. Katsina is the third, followed by Maiduguri, Sokoto, Potiskum, and Nguru with 251 Mm$^3$/yr was found to be the highest Green water scarce region (As seen in Table 3 and Fig. 5).

For Bluewater, the region with the largest consumption was Kano which happens to be the biggest consumer of crops virtual water with approximately 9 Gm$^3$/yr. Katsina was the next in Bluewater consumption followed by Maiduguri, Sokoto, Gusau, Potiskum and Nguru with 945 Mm$^3$/yr the lowest Green water region had the lowest Bluewater demand (As seen in Table 3 and Fig. 5).

In crops production, Grey water was less significance. Owing to that, less than 0.01% of Greywater was used for the entire produced selected crops. Kano region with 609.8 thousand m$^3$/yr was found to be the highest virtual water volume of Greywater, followed by Gusau, Sokoto, Maiduguri, Katsina, Potiskum, and Nguru with 9.7 thousand m$^3$/yr was the region with fewest amount of Grey water (as shown in Table 3).
Based on the obtained results, highest virtual water contributing to crops production in the semi-arid regions of Nigeria in 2013 was Bluewater due to semi-arid nature of the climate of the study regions (Fig. 6). The overall Blue and Green water contributions for all the regions were 74% and 26%, respectively (Fig. 6), while contributions of Blue water for each region were Katsina 81%, Nguru 79%, Maiduguri 79%, Sokoto 74%, Kano 72%, Potiskum 68% and Gusau 58%. However, Green water contributions were 19%, 21%, 21%, 26%, 28%, 32% and 42%, respectively. Grey water remained 0% throughout the regions as can be seen in Figure 6.

**Figure 5.** Contributions of Grey, Blue and Green water in the study regions
Positives water balance (NVWI) were obtained for all the regions. This signifies that there were less exports than imports as shown in Table 4. It is obvious from Table 4 that the total volume of virtual water demand in the study regions could be calculated to be 81% of the water footprint while

**Figure 6.** Regional and zonal percentage contributions of green, blue, and grey water
the water balance to be 19%. Kano with 15.6 Gm³/yr was the region with a maximum volume of virtual water used and Nguru with 1.5 Gm³/yr was the minimum (Table 4).

By visual inspection of table 4, it can be distinguished that import cost is higher than export income and all together lower than production value. Kano region had the highest production value, which stood at $842 million that could be largely owing to its production superiority. Katsina with $511.9 million reclaimed the second position, Maiduguri $375.5 million, Sokoto $326.7 million, Gusau $292.2 million, Potiskum $109.9 million, and the least in production value was Nguru $100.1 million. Furthermore, Kano with $261.5 million also led in import cost, followed behind by Katsina, Maiduguri, Sokoto, Gusau, Potiskum, and lastly Nguru $31.1 million. The export income goes in a similar manner with $364.3, $221.4, $162.4, $141.3, $126.4, $47.5, and $43.2 thousands, respectively. The total exports income $1.1 million, import cost $794.6 million and production value was $2.6 billion. (Table 4).

Table 4. Export income, import cost, virtual water demand, water footprint, water balance, and production value of the semi-arid regions of Nigeria for the year 2013

| Regions Name | VWD (m³/yr) | NVWI (m³/yr) | WP (m³/yr) | Production Value ($) | Import Cost ($) | Export Income ($) |
|--------------|-------------|--------------|------------|---------------------|----------------|------------------|
| Gusau        | 3,622,385,651 | 672,078,800  | 4,294,464,451 | 292,209,166         | 90,761,786    | 126,448          |
| Kano         | 12,521,544,086 | 3,069,418,670 | 15,590,962,756 | 842,028,048         | 261,539,746   | 364,333          |
| Katsina      | 6,523,754,007  | 1,596,154,548 | 8,119,908,555  | 511,886,141         | 158,995,364   | 221,399          |
| Maiduguri    | 5,869,013,385  | 1,439,113,442 | 7,308,126,827  | 375,456,645         | 116,619,529   | 162,381          |
| Nguru        | 1,196,000,272  | 291,102,264   | 1,487,102,536  | 100,100,560         | 31,091,845    | 43,247           |
| Potiskum     | 1,459,134,481  | 362,155,507   | 1,821,289,989  | 109,901,608         | 34,135,493    | 47,483           |
| Sokoto       | 4,712,629,262  | 1,155,679,982 | 5,868,309,244  | 326,694,329         | 101,473,382   | 141,259          |
| Total        | 35,904,461,145 | 8,585,703,212 | 44,490,164,357 | 2,558,276,497       | 794,617,145   | 1,106,550        |

4. Conclusions

(1) In each region of the semi-arid zone of Nigeria for the year 2013, the virtual water content of crops varied due to the difference in climatological parameters. For some crops, high water requirements were observed but they possessed less virtual water content due to their large crop yield.

(2) It was deduced based on the results obtained that the virtual water trade volume could be categorized in to unregulated and regulated circumstances. The unregulated circumstances are the meteorological parameters, which cannot be altered including wind speed temperatures (Max. and Min.), solar radiation sunshine hours and relative humidity. Quantities of exports and imports and the types of crops constituted the regulated circumstance.

(3) With continued improvement in the modern techniques for agricultural productions, Nigeria may be self-sufficient in the years to come in terms of food production. As of 2013, only about 19% of the food consumed were imported through virtual water trade and the production was averagely 81% of virtual water consumed. Due to large population of Nigeria, despite the immense contributions in food productions, within the semi-arid zone of the country about $794.6 million was spent for food importation and received internal income of $1.1 million but domestically produced food crops that amount to approximately $2.6 billion. With improvement in food production sector, income generation will rise and expenditure through food importation will decline and subsequently, result in developmental growth.

(4) With persistent release of toxic waste in to the atmosphere, the global warming continues to linger, thus results in ascendance of water scarcity and drying of surface water. Hence, in order not to deplete the water resources, regions necessitating the minimum blue water for cultivation of the crops
should be given due consideration. Consequently, Gusau is the preferable region to grow crops among the seven study regions, due to its minimum blue water used and higher percentage of green water, which reduced cost of blue water provision.

5. Recommendations
The following recommendations were drawn upon completion of this study. These are;
• Similar researches should be conducted apart from the semi-arid regions of Nigeria, in order to widen the scope and to determine how the degree of aridity influences exports, imports and productions of virtual water in Nigeria.
• More studies should be conducted before and after the year of this study (2013) to ascertain the influence of weather and population on virtual water trade in Nigeria.
• Number of crops should be increase from the 25 most populous crops in this study to all crops that are imported, exported, produced and consumed in Nigeria.
• Studies should also be conducted on livestock products to compare and ascertain the virtual water trade in both food crops and livestocks in Nigeria.
• In consideration of the conclusion drawn by this study, where the majority of water used was found to be blue water owing to insufficiency of rainfall to supply for green water, the available blue water in the regions may be exhausted eventually due to continued crop productions. This could thereby expose people living in the areas to unnecessary hardship. Therefore, in such regions, crop productions should be reduced to the barest minimum. For the vulnerable people whom their survival is dependent on farming, a means of empowering and supporting them should devise by government through enrolling them in to skills acquisition programs, issuance of loans to start trade, and bulks of other initiatives that can meet their daily needs. By so doing, the dwellers will continue enjoy living without hindrance in the regions by utilizing the little available water in the regions for consumptions and other day-to-day activities.
• As tremendous growth in population continues to be experienced in Nigeria, food demand also rises. The current production capacity should be enhanced and improved through modern sophisticated means such as advanced farming machines and equipments, in order to have self-reliant country in terms of crop productions and the citizens could be benefited by channeling the funds needed for food imports to other infrastructural works.

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