



QUANTITATIVE MODELING OF THE WATER FOOTPRINT AND ENERGY CONTENT OF CROP AND ANIMAL PRODUCTS CONSUMPTION IN TANZANIA

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ABSTRACT

A comprehensive understanding of the link between water footprint and energy content of crop and animal products is vitally important for the sound management of water resources. In this study, I developed a mathematical relationship between water content, and energy content of many crops and animal products by using an improved LCA approach (i.e., water footprint concept). The standard values of the water and energy content of crops and animal products were obtained from the databases of Agricultural Research Service, UNESCO Institute for water education and Food, and Agriculture Organization of the United Nations. The water footprint approach was applied to analyze the relationship between water requirement and the energy of content of crop and animal products, in which the uncertainty and sensitivity was evaluated by Monte Carlo simulation technique that is contained in the Oracle Crystal Ball Fusion Edition v11.1.1.3.00. The results revealed significant water saving due to changes in food consumption pattern (i.e., from consumption of more meat than vegetables). The production of 1kcal of crop and animal products requires about 98% of green, 4.8% blue water and 0.4% of gray water. In which changes in consumption pattern gave annual blue water saving of about 1605 Mm³ that is equivalent to 41.30m³/capita, extremely greater than the standard drinking water requirement for the whole population. Moreover, the projected results indicated, triple increase of dietary water requirement from 30.9 Mm³ in 2005 to 108



Mm³ by 2050. It was also inferred that, Tanzania has a positive virtual water balance of crop and animal products consumption with net virtual water import of 9.1 Mm³ that is the contribution margin to the water scarcity alleviation strategy. Therefore, this relationship of water footprint and energy content of crops and animal products can be used by water resource experts for sustainable freshwater and food supply.

Keywords: Water footprint, energy content, human health, crop, animal products

1. INTRODUCTION

A large quantity of crop and animal products whose production process contributes greatly to the global climate change and freshwater scarcity are produced and consumed daily (CLEVELAND, et al., 2011; VANHAM, et al., 2013; LAM, et al., 2013). The introduction of various agriculture methods including the application of pesticides and herbicides as well as the large consumption of energy intensive food staffs contributes greatly to the current environmental degradations (MUELLER, et al., 2012; GAN, et al., 2012; REEMTSMA, et al., 2013).

Agricultural production contributes about 85% of the global freshwater use and the amount of water consumption is projected to double by 2050 (PFISTER, et al., 2011). With the increased freshwater consumption, the world is placed at risk of climate change which is the global issue of environmental concern resulting in the possible deterioration of human health and quality of ecosystems (BOULAY, et al., 2011; HELLER; KEOLEIAN, 2011; KOEHLER, 2008).

Likewise, significant environmental impacts that are resultant from the animal production have been realized in many parts of the world. For example livestock raised for meat production in the U.S. contributes to 8% of global freshwater consumption and global green-house gas production of about 18% which the numbers are expected to double by 2050 (TUOMISTO; MATTOS, 2011; FAO, 2006).

Considering the environmental impacts of agricultural production, hence developing a precise link between water requirements and energy content of crop and animal products is vitally important. Among various life cycle assessment (LCA) approaches, the water footprint approach is widely applied to the assessment of water content of crop and animal products (BOULAY, et al., 2011; JIAO, et al., 2013).



Water footprint analysis is the most advanced LCA concept which characterizes freshwater requirements throughout the product life cycle stages (ZHAO, et al., 2010; STOESSEL, et al., 2012; NÚÑEZ, et al., 2013). In LCA studies more emphasis is given to the characterization of environmental impacts that resulted from freshwater unavailability, while little emphasis is given to the estimation of freshwater requirements (BOULAY, et al., 2011; RIDOUTT; PFISTER, 2010; PFISTER, et al., 2009).

With regard to the sustainable consumption of food products, water footprint studies are booming for the fruits and vegetables (STOESSEL et al. 2012), agriculture products (CAZCARRO, et al., 2012; HELLER, et al., 2013), corn grain, stover, wheat straw and soybeans (CHIU; WU, 2012), agriculture and industrial products (HOEKSTRA; MEKONNEN, 2012; CHICO et al. 2013), roses, carnation, alstroemeria, lisianthus, statice and cut foliage flowers (MEKONNEN, et al., 2012) and animal products (TUOMISTO; MATTOS 2011).

However, no regard is given so far to assess the connection between water footprint and energy content of the crop and animal products. Usually freshwater consumption is computed by using the water GAP2 global model or the methodology that was proposed by Hoekstra et al. (BOULAY, et al., 2011; PFISTER, et al., 2011; TUOMISTO; MATTOS, 2011; PFISTER, et al., 2009; HOEKSTRA, et al., 2009).

The former involves costive software which may be only relevant for global studies while the latter is time consuming and is subject to many approximations which are caused by limitations of data. Therefore, this study utilized the scientific experimental data for gray, green and blue water footprints of crop and animal products, which was developed by Makonnen and Hoekstra further followed the methodology proposed by Hoekstra et al. in the computation of the water footprint of crop and animal products consumption (MEKONNEN; HOEKSTRA, 2010). Food energy is the most essential nutrient for the maintenance of human health (POPKIN, et al., 2010; PREMA, 2013).

Moreover, freshwater requirements and human health have varied relationships including water required for drinking, hygiene and food energy production (MOE; RHEINGANS, 2006; SAWKA, et al., 2005; GLEICK, 1996). It is important for policy makers to understand the association between food energy and



freshwater requirements from the aspect of human health and effective implementation of the integrated water resources management. With integrated water resource management the contradiction between water requirements and supply can be resolved (ROY, et al., 2012; WUTICH, et al., 2012, LIU, et al., 2013).

Tanzania as with other developing countries around the world, and the case for this study is experiencing freshwater scarcity while agricultural production is contributing about 70% of the national freshwater consumption (NBS, 2012; PACHPUTE, 2010; MAKURIRA, et al., 2009; MUTIRO, et al., 2006). The government of Tanzania is making great efforts to ensure a sustainable supply of food and water including implementation of a virtual water strategy (YANG, et al., 2012; HOEKSTRA; MEKONNEN, 2011; ZHAO, et al., 2010; URT, 1992).

These efforts evoked questions as to what extent do developing countries including Tanzania have benefited from the strategy, and how do changes in food consumption pattern affect water scarcity? These questions are important to the country's policy evaluation. Therefore, the objectives of the present study are to, (1) quantify minimum food energy and drinking water requirements for the healthy population in the country (2) assess the water footprint and energy content of the crop and animal products consumption (3) to model scenarios for the water footprint and energy change due to variations in consumption patterns and (4) determine virtual water transfers from the crop and animal products consumption in Tanzania.

2. MATERIALS AND METHODS

2.1. Approach

This study has examined the association between blue, green and gray water footprints in relation with the energy content of crop and animal products consumption in Tanzania. Water footprints analysis, blue, green and gray water requirements for the production of crop and animal products were quantified. Blue water is defined as the volume of water the ground and surface water bodies available for abstraction, green water is the volume of water evaporation from the soil while gray water refers to the volume of water needed to dilute pollutants which are released into a natural water body (HOEKSTRA; MEKONNEN, 2012; BERGER, et al., 2012; BAYART, et al., 2010).



In the present study, the gray and green water footprints were not involved in the scenario analysis and determination of the virtual water transfers since they have no significant contribution to the environmental impacts from freshwater consumption (RIDOUTT; PFISTER, 2010; PFISTER, et al., 2009; CANALS, et al., 2009). Therefore, this study utilized blue water to explore the link between freshwater and energy requirements in the context of freshwater scarcity.

2.1.1. Water footprint and energy value connection

Water footprint analysis method was used to evaluate the water footprint of crop and animal products consumption in Tanzania. The energy value and water footprint of crop (340) and animal (145) products were computed based on the experimental data published by the U.S. Agricultural Research Service, UNESCO Institute for water education and Food and Agriculture Organization of the United Nations (FAO, 2012; USDA, 2011; MEKONNEN; HOEKSTRA, 2010).

The uncertainty between water footprint and energy content of crop and animal products was considered by Monte Carlos' simulation performed in the Oracle Crystal Ball Fusion Edition v11.1.1.3.00. The food energy value and water footprint of crop and animal products consumption is presented by Equation 1 and 2.

$$E_c^f = \sum_{i=1}^n (Q_i \times \varepsilon_i) \quad (1)$$

$$W_c^f = \sum_{i=1}^n (Q_i \times \omega_i) \quad (2)$$

Where E_c^f represents total food (Gcal), W_c^f presents water footprint of products (Mm³), Q is the quantity of products (Mkg), ε is energy content of the products (kcal/kg), ω is the water content of products (m³/kg), i is the product type and n is the number of products.

2.1.2. Water footprint and energy value scenario analysis

Household changes in consumption of the crop and animal products have significant reduction of water and carbon footprint (RIDOUTT, et al., 2012; STOESSEL, et al., 2012; CAZCARRO, et al., 2012).

The scenario analysis was performed to model water footprint and energy change resulted from the variations in consumption pattern of crop and animal



products. Crop and animal products (485) consumed in Tanzania were grouped into seven classes including cereals, vegetable and melons, fruits and nuts, oil seed crops, beverage and other crops, and meat, milk and eggs according to the products' energy content and the corresponding water footprint. Four strategically selected percentage values were selected to test best policy options for implementation based on freshwater saving and conservation of minimum food energy requirements (Figure 1).

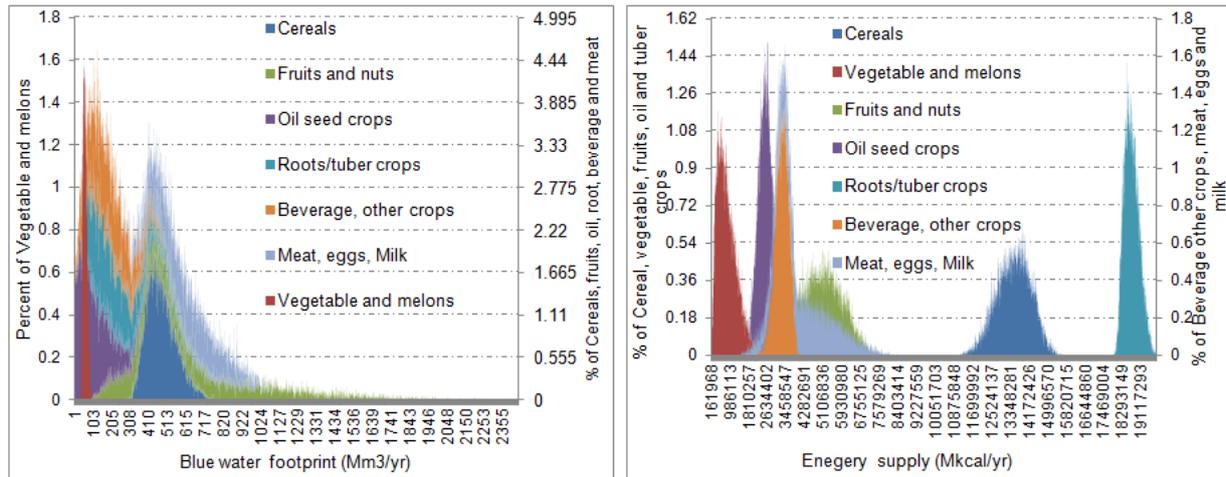


Figure 1: Water footprint and food energy of crop and animal products

2.1.3. Virtual water transfers of crop and animal products

The knowledge about water footprint and virtual water strategy is vital for effective implementation of the national water policy. Whereby, water footprint refers to the water embodied into the products while virtual water is the volume of freshwater that is used to produce goods and services consumed by inhabitants of certain area (YANG, et al., 2012; ZHAO, et al., 2010).

The blue, virtual water transfers of Tanzania for 2005 was computed based on the export and import data of crop and animal products provided by FAO food balance sheet and experimental data for blue, gray and green water footprint provided by UNESCO Institute for water education (FAO, 2012; MEKONNEN; HOEKSTRA, 2010). Net-virtual water import is given by Equation 3.

$$W_v^f = \sum_{i=1}^n (Q_{imp} \times \omega_i) - \sum_{i=1}^n (Q_{exp} \times \omega_i) \quad (3)$$



Where W_v^f represents net virtual transfers of the product (Mm^3), Q is products import and export (Mkg), ω is water footprint of the product (m^3/kg) and i is the product type.

2.1.4. Dietary water and food energy requirement

All people have equal rights of access to safe drinking water and food in a quantity that meet their basic needs despite of the ages, development and economic situations (SAWKA, et al., 2005).

According to WHO (2012) about 605 million people in the world is expected to live without access to safe drinking water in 2015 accompanied by millions of people at risk of suffering from water related diseases. For Tanzanian, the total drinking water and food energy requirements in 2005 and projections for 2050 for healthy population was modeled using standardized data by World Health Organization and the population pyramid of Tanzania (POPKIN, et al., 2010; U.S. CENSUS BUREAU, 2003; FAO, 2001).

The drinking water and food energy requirements are given by Equation 4 and 5.

$$W_r^d = \sum_{i=1}^m (p_i \times \omega_i) + \sum_{j=1}^f (p_j \times \omega_j) \quad (4)$$

$$E_r^f = \sum_{i=1}^m (p_i \times \varepsilon_i) + \sum_{j=1}^f (p_j \times \varepsilon_j) \quad (5)$$

Where W_r^d and E_r^f are the drinking water requirement (Mm^3) and total food energy requirements (Gcal), p represents population (M), ω is the standard drinking water requirement (m^3), ε is standard food energy requirement (kcal), m & f represents male and female, i, j are ages (0, 1, 2,3, 80+ years).

3. RESULTS

3.1. Water footprint and energy value connection

The energy supply of crops and animal products consumption in Tanzania is determined by availability of green water than the blue and gray water. A kilocalorie of the product consumption is produced by 98.8% of green water, 4.8% blue water and 0.4% of gray water. The energy intensity of the blue water used for crop and



animal products was found to be 28055 kcal/m³ for cereals, 14433 kcal/m³ for vegetable and melons 7102 kcal/m³ for fruits and nuts, 21149 kcal/m³ for oil seed crops, 79365 kcal/m³ for root/tuber crops, 16693 kcal/m³ for beverage and other crops, 6973 kcal/m³ for meat, eggs and milk (Figure 2).

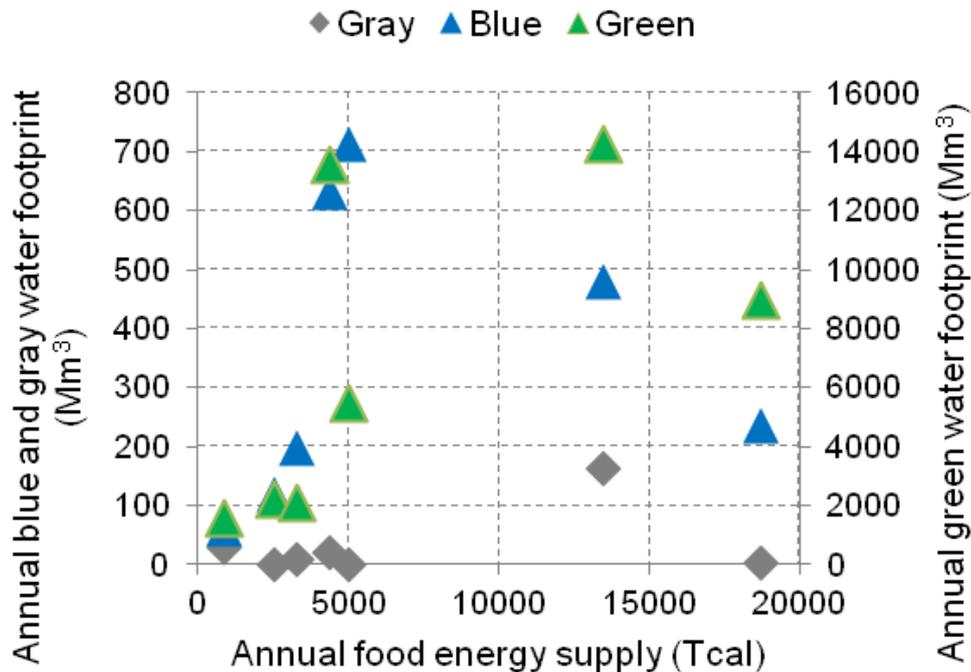


Figure 2: Blue, Green and gray water footprint of food and their energy value

Figure 2 above represent three water types i.e. blue, green and gray which are essential for generation of the unit value of food energy.

3.2. Drinking water and food energy requirement

Further environmental impacts especially on human health are expected due to triple increase of freshwater and food energy requirement in Tanzania by 2050 (Figure 3). Dietary drinking water requirements are predicted to be 108 Mm³ by 2050 compared to 30.9 Mm³ in 2005, while energy requirement expected to be 91566 Tcal by 2050 compared to 27903 Tcal in 2005. This study also realized food energy supply by crop and animal products to be relatively higher than required food energy in Tanzania though the country is experiencing water and food insecurity (Figure 3).



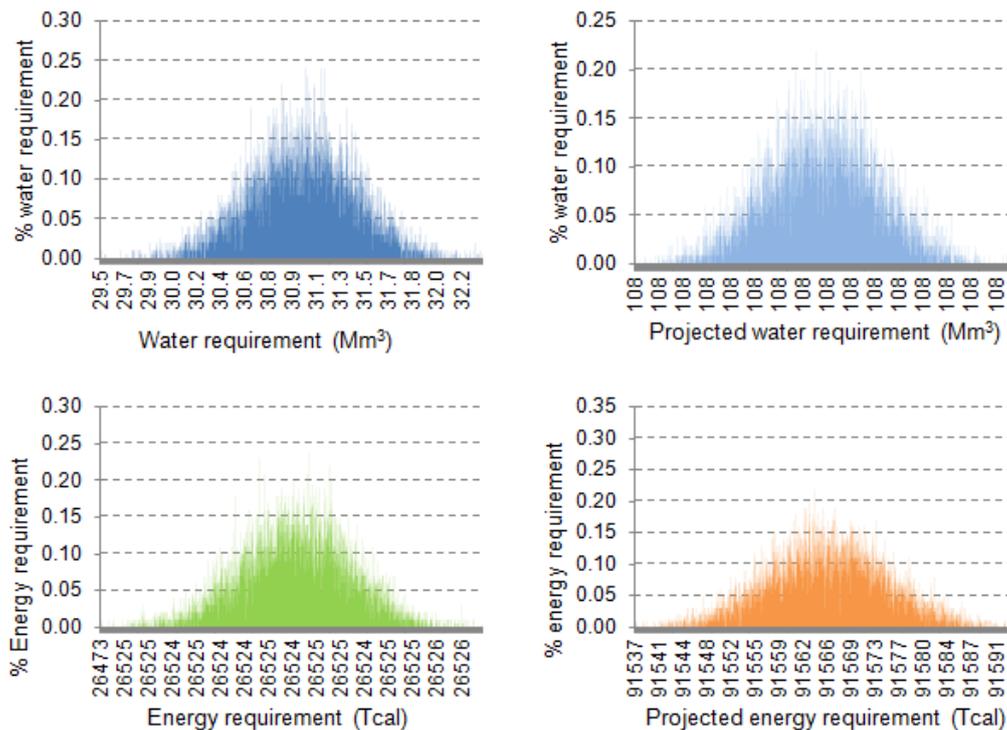


Figure 3: Status of water and food energy requirements in Tanzania for 2005 - 2050

3.3. Virtual water transfers of crop and animal products

Tanzania had a positive virtual water balance, with a net virtual water import of 9.1 Mm³ in 2005. The gross virtual water import was 107.8 Mm³ with most virtual water import from oil seed and other crops while gross virtual water export was about 61.71 Mm³ with more exports on fruits and nuts (Table 1).

Freshwater intensity of crop, animal and their derived products consumption is 18 kg/m³ for cereals, 10 kg/m³ for vegetables and melons, 4 kg/m³ for fruits and nuts, 1 kg/m³ for oil seed and crops, 3 kg/m³ for beverage and other crops, 3 kg/m³ for meat, eggs and milk and no blue water use by root/tuber crops.

Table 1: Average Virtual Water Transfer of Crops and Animal Products in Tanzania

Product class	Products (MKg)		Virtual water (Mm ³)		Net-virtual water import (Mm ³)
	Import	Export	Import	Export	
Cereals	650	129	34.32	7.41	26.90
Vegetables & melons	5	8	0.38	0.56	- 0.18
Fruits & nuts	19	34	1.90	76.4	-74.49
Oil seed & other crops	267	46	61.71	2.83	58.87
Root/tuber crops	0	5	0.0	0.08	- 0.08
Beverage & other crops	13	86	3.31	10.95	- 7.64
Meat, eggs & milk	20	2	6.26	0.63	5.62



3.4. Water footprint and energy value scenario analysis

Modeling scenarios helps to capture the relationship between food nutrition values and freshwater requirements to produce specific crop and animal products which have big contributions to country’s status of water scarcity. Significant variations in freshwater saving and energy supply were obtained through changes in consumption pattern and virtual water import/export strategy (Figure 4).

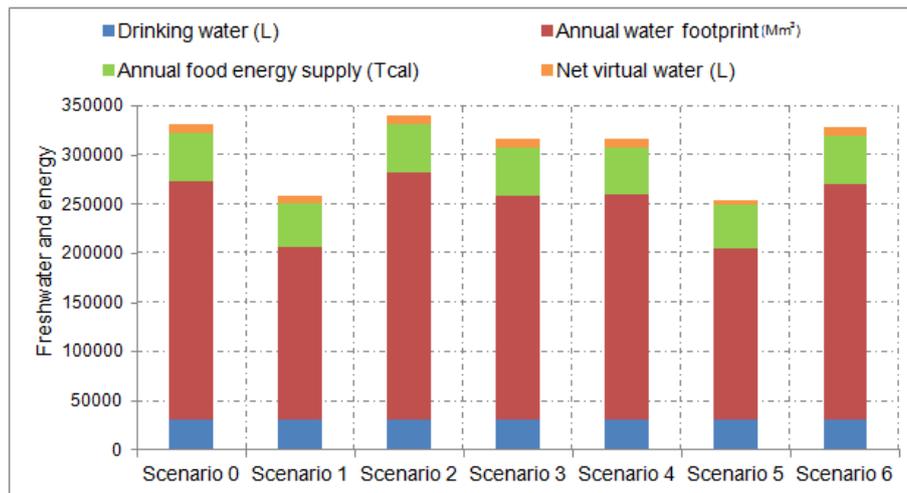


Figure 4: Scenario analysis to model freshwater change caused by variations in consumption pattern

Dietary change from calorie and meat intensive to standardized consumption demonstrated possible annual freshwater and food energy saving of about 1605 Mm³ and 6630Tcal respectively (Table 2).

Table 2. Summary of the Scenario Analysis Results

No.	Description of the scenario performance	Water saving (Mm ³)	Energy saving (Tcal)	Net virtual water transfer (Mm ³)
0	The actual food consumption baseline for comparison of freshwater change.	baseline	baseline	baseline
1	25% replacement of animal products consumption with vegetable products.	679	3605	9.0
2	50% replacement of bovine meat consumption with poultry products.	89*	247	7.5
3	50% replacement of bovine meat with vegetable and poultry products consumption.	154	189*	9.2
4	50% replacement of meat consumption with vegetable products.	144	63	9.1
5	100% replacement of animal products consumption with vegetable products.	688	3506	3.8
6	25% replacement of wheat and rice consumption with fruits.	28	602*	9.0

*More freshwater and energy required due to pattern change, transfer refers to import/export



4. DISCUSSION

Understanding the connection between freshwater and energy content of food consumption is essential for sustainable water resources management. Comparing blue water footprint with gray and green water footprint, green water of crop and animal products consumption is the greatest but no significant competition to its uses. The absolute increase in the consumption of the products will change freshwater scarcity due to increased blue water requirements for the agriculture.

With consideration of the energy intensity of food class, more emphasis should be placed on consumption of products with high energy yields including root/tuber crops (79365 kcal/m³), cereals (28055 kcal/m³), oil seed crops (21149 kcal/m³) and discourage excessive consumption of meat, eggs and milk (6973 kcal/m³) which has intensive water requirements with low energy yield (Figure 2). The same strategy was proposed by Cazcarro and Chóliz (2012) to reduce blue water requirements for agriculture production.

The observed changes in consumption pattern of crop and animal products in Tanzania resulted into annual freshwater saving of 1605 Mm³ which is about 41.307 m³/capita and greater than drinking water requirement; with energy saving of 6630 Tcal equivalent to 170 Mcal/capita. Similar results with freshwater saving achieved (RENAULT; WALLENDER, 2000) scenario analysis study case of California.

Government efforts to discourage consumption of animal products and more emphasis on vegetables are the best policy options for sustainable freshwater supply (Table 1). Change in consumption from bovine meat to poultry products results into increased water requirement for the food energy which is to be discouraged. While increasing consumption of fruits to replace rice has significant freshwater saving with conservation of the food energy needed. This signifies household's dietary shift in Tanzania provides an opportunity for freshwater scarcity reduction with adequate supply of food.

Tanzania similar to other countries of the world alleviates freshwater scarcity through virtual water transfer of crop and animal products. There is partial implementation of virtual water strategy indicated by importation of both water intensive animal products (3 kg/m³) and oil seed crops (1 kg/m³) and less water intensive cereal products (18kg/m³) to compensate freshwater and food energy



scarcity. The importation of relatively water intensive products including fruit and nuts (4 kg/m^3), beverage and other crops (3 kg/m^3) was observed, similar results with Ma et al., (2006) the case of China. The condition of freshwater scarcity and nutrients supply would be more severe in the absence of virtual water transfers within and outside Tanzania.

Moreover, predicted increase in water and energy requirement for healthy Tanzanian population for 2050 will ultimately affect freshwater needed for various utilizations including agriculture, hydropower, domestic and industry. This indicates human population to be an essential variable to be controlled to sustainable water and food supply. The results comprehended with ESOMAR (2011) and Kinabo (2003) who argued economic development of the developing and developed countries to be accompanied with dietary change in consumption pattern to more meat than traditional food, which is currently observed in Tanzania compared to few years ago.

5. CONCLUSION

The association between freshwater and food energy content of crop and animal products consumption in Tanzania has been evaluated. The blue, green and gray water types are all vitally important for the adequate food energy supply though with varied contributions to environmental impacts caused by freshwater consumptive uses in which knowledge about blue water requirement is most important.

Population dietary change in consumption pattern from animal products towards consumption of vegetables and effective application of virtual water strategy via importation of freshwater intensive products and exportation of less water intensive products were observed to have significant freshwater saving ultimately leading into reduced water scarcity in Tanzania. This calls the need for immediate investigation of the concerned policies to exploit more benefits of the dietary shifts and practicing virtual water strategy in the country.

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