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Water Footprint Assessment of Black Tea; a Case Study from Nuwara Eliya District, Sri Lanka

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ABSTRACT

The virtual water or water footprint of a product has been defined as the total volume of water required for producing unit of product. Water footprint reflects the consumption of water in terms of three categories; green, blue and grey. It ensures efficient, equitable and sustainable water use and management throughout the production chain. This study was conducted to find the water footprint of black tea throughout the lifecycle from cultivation stage to production stage. Water footprint of tea crop growth and black tea production were calculated separately. Guidelines provided in water footprint assessment manual were used in the calculation. In tea crop growth, green water footprint and grey water footprint were calculated and in black tea production, green water footprint and blue water footprint were calculated. The study revealed that, harvesting one ton of tea leaves in tea estates require about 5,246 m^3 of rain water and the subsequent green water footprint of black tea is 12,784.55 m^3/ton. The resulted blue and grey water footprints of black tea are 65.79 m^3/ton and 73 m^3/ton respectively. The virtual water content of black tea is 12,923.34 m^3/ton/year with a higher contribution (98.9%) from green water footprint which generates economic benefits to the country that has relatively low opportunity cost compared to ground and surface waters. The volume of water required to produce black tea depends particularly on the climate at the place of production and the yields per hectare that are obtained.

KEYWORDS: Black tea, Lifecycle, Virtual water, Water footprint

INTRODUCTION

Awareness on environment has been increased due to proven adverse effects related to production of commodities. Depletion of natural resources is the major challenge when expecting higher economic performances without concerning the well-being of the environment. Water scarcity and pollution are expected to be burning issues in most of the countries as a result of increased water demand and lack of good management. Also, climate changes and global warming affect to the water scarcity. The concept of the "Water Footprint (WF)" was introduced by Hoekstra and Hung (2002) and subsequently elaborated by Chapagain and Hoekstra (2004) for efficient, equitable and sustainable water use and its management.

Further, WF is a tool to calculate the amount of water that is consumed and polluted in all processing stages of a production process. Therefore, WF is an indicator for direct and indirect gross water consumption and pollution due to production of commodities. Three types of water are considered, namely green water (WFg), blue water (WFb) and grey water (WFgr) in water footprint calculations. The green water footprint refers to the volume of rain water evaporation from lands and crop or tree plus rainwater incorporated into the harvested product. The blue water footprint refers to the volume of surface and groundwater that evaporated or incorporated in to the product. Finally, the grey water footprint of a product refers to the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standard. Summation of water footprint for the tea crop and water footprint for the production of black tea is the total water footprint for black tea.

This study was intended to account the fresh water consumption in the total life cycle of black tea production, starting from the cultivation stage and continuing on to tea processing.

MATERIALS AND METHODS

Study Area

Nuwara Eliya district is an agricultural district in the Central province of Sri Lanka. Major crops grown in the area are tea and vegetables. The district falls into wet zone with a high rainfall of above 1900 mm during South-West monsoon. The major soil type in Nuwara Eliya district is Red Yellow Podosolic.

Two tea estates from Watawala Plantations PLC which are located in Nuwara Eliya district were selected for this study. The study was carried out from January to May 2016.

Data Collection and Analysis

Climate data, tea crop and production data with fertilizer application and soil data were collected from Meteorology Department, two tea estates and Tea Research Institute (TRI) respectively. Quality of water in terms of chemical oxygen demand (COD) and nitrate nitrogen (NO_3-N) in spring water (raw water), and process waste water were tested in the laboratory. Data were collected for one year of period (May, 2015 to April, 2016).

Green water footprint of tea was calculated using CROPWAT 8.0 model. Blue and Grey water footprint of black tea were calculated following the guidelines in the Water Footprint Assessment Manual, (2011).

Water Footprint of Tea Crop

Both green and grey water footprints were calculated for the tea crop. Green water content of fresh tea leaves is the volume of rainwater incorporated to tea crop during the length of growing period. Since tea estates were not irrigated by any irrigation method, crop water requirement of the tea crop was fully obtained from the effective rainfall prevailed during the particular period of concern.

$$ET\ green = CWR \qquad [1]$$

Where;
ET green- Evapotranspiration of tea crop
CWR- Crop water requirement of Tea

Evapotranspiration green represents evapotranspiration of rain water. Evapotranspiration of a tea plant was calculated using the CROPWAT 8.0 model developed by the Food and Agriculture Organization of the United Nation (FAO, 2003). Table 1 represents supplementary data used for estimating evapotranspiration of water for tea cultivation in tea estates.

The crop water use (CWU) was calculated by accumulation of daily ET green (mm/day) over one year period and multiply by 10 according to the following equation.

$$CWUgreen = 10 \times \sum_{d=1}^{lgp} ET\ green \qquad [2]$$

Where;
CWU- Crop water use
Lgp- Length of growing period
ET green- Evapotranspiration of tea crop during the period of concern.

The green water footprint of growing a crop or tree (WF green, m^3/ton) is calculated by using the procedure of Water Footprint Assessment Manual (Hoekstra *et al.*, 2011).

Table 1. Supplementary Data for running CROPWAT 8.0 model

Supplementary data	Source of data
Altitude, Latitude Longitude, Minimum and Maximum temperature, Humidity, Wind speed, Sunshine hours, and the Rainfall from January 2015 to December 2015.	Talawakele Agro climatic Station
Crop coefficient (Kc) and critical depletion fraction	FAO Irrigation and Drainage Paper No.56
Average rooting depth of tea plant	Observed at the field level
Crop heights of tea plant	Observed at the field level
Infiltration rate	Version 2.X of the Minnesota Storm water Manual.
Yield data	Yield record of estate.

$$WF\ green = \frac{CWU\ green}{Y} \qquad [3]$$

Where,
WF green- Green Water Footprint
CWU green- Green Crop Water Use
Y- Yield

The grey water footprint of black tea was calculated for tea crop cultivation. The grey component in the water footprint of growing a tea crop (WF grey m^3/ton) was calculated by using the guidelines of the Water Footprint Assessment Manual (Hoekstra *et al.*, 2011).

$$\text{WF grey} = \frac{(\alpha \times \text{AR})/(\text{C}_{\text{max}} - \text{C}_{\text{nat}})}{\text{Yield}} \qquad [4]$$

Where;
AR- Chemical application rate (kg/ha)
α- Leaching-run-off fraction
C_{max}- Maximum acceptable concentration (kg/m^3)
C_{nat}- Natural concentration for the pollutant considered (kg/m^3)
Y- Crop yield (ton/ha)

To represent an estate, three water samples were taken from stream that was located in the tea field. Water samples were collected before and after fertilizer application. Natural concentration of nitrate-nitrogen (NO_3^--N) and COD were measured to calculate grey water footprint for tea crop.

Water Footprint for Black Tea Production

The water footprint of a product is defined as the total volume of fresh water that is used directly or indirectly to produce the product. The direct water footprint was only calculated in this study.

Virtual water content in black tea is the water footprint for black tea production and for tea crop. Water consumption in each processing step was measured using separate water meters during the research period.

$$WFblue = \frac{Q}{Y\ black\ tea} \quad [4]$$

Where;
Q- Quantity of spring water consumed (m^3)
Y black tea- Quantity of black tea produced (ton)

The green water content in the processed tea (black tea) was calculated incorporating the product fraction values. After each processing step, the weight of the remaining product is smaller than the original weight. Product fraction (pf) in a certain processing step is the ratio of the weight of the resulting product to the weight of the original product. The green water content of the resulting product (expressed in m^3/ton) is larger than the green water content of the original product. It can be found by dividing the virtual water content of the original product by the product fraction (Chapagain and Hoekstra, 2007).

RESULTS AND DISCUSSION

Table 2 shows different variables required for the CROPWAT 8.0 model in order to produce value of green water evapotranspiration (ETgreen) for tea crop.

Results revealed that, evapotranspiration (ETgreen) was 996.7 mm/year for tea crop from CROPWAT 8.0 model. This means, each year needs a water layer of 996.7 mm over the whole area on which the tea crop is grown. The annual average land productivity of tea estates is 1.9 tons per hectare from yield records. Since, upcountry tea cultivation is only depending on the rain water and not irrigated, water footprint of tea crop solely depend on green water footprint. Blue water foot print or amount of water utilized for tea cultivation the means of irrigation either surface water or ground water is not relevant and it remains to be zero for up country tea cultivation. Further, the study revealed that the amount of rainfall receiving is adequate to fulfill the water demand of tea crop in Nuwara Eliya district.

Crop water use green was 9,967 m^3/ha for the tea cultivation in tea estates from calculations. The WF of the fresh tea leaves (tea crop) of the tea estates in the period from May 2015 to April 2016 was calculated as 5,245.79 m^3/ton/year. It means 5,245.79 m^3 water amount was used to produce 1ton of fresh tea leaves.

However, the WF (crop) value calculated for the tea cultivation in the study area was higher than value reported by Chapagain and Hoekstra, 2007. According to Chapagain and Hoekstra report, WF (crop) values for the tea cultivation in Sri Lanka was around 3,174 m^3/ton. Crops with high land productivity have a smaller water footprint than crops with low land productivity. Average annual yield per hectare in the studied tea estates was lower than the average annual land productivity of tea estates in Sri Lanka which Chapagain and Hoekstra reported in year 2007. Therefore, it is recommended to adopt suitable crop and land management practices in the tea estates in order to improve the land productivity.

Table 2. Different variables used to produce ET green by using CROPWAT 8.0 models

Variable	Sub variable	Value
Climate data	Minimum Temperature (°C)	14.10
	Maximum Temperature (°C)	24.90
	Humidity (%)	81.00
	Wind speed (km/day)	89.00
	Sunshine hours	5.40
	Evapotranspiration (mm/day)	3.24
	Rainfall mm)	2137.60
	Effective rainfall (mm)	1368.60
Crop data	Crop coefficient	1.15
	Growth stage (days)	364
	Rooting depth(m)	1.20
	Critical depletion fraction	0.45
	Crop height (m)	2.00
		83.00
Soil data- Clay loam	Total available soil moisture (mm/m)	
	Maximum rain infiltration rate(mm/day)	37.00
	Initial soil moisture depletion (%)	45.00
	Initial available soil moisture (mm/m)	45.60

Water footprint for black tea production

Figure 1 shows the calculation of the green water footprint (m^3/ton) for black tea production. The weight reduction occurs in two steps in black tea production. These are withering and rolling and drying (oxidizing). In calculations, a remaining fraction after withering and rolling of 0.53 (ton of withered and rolled tea per ton of fresh leaves) and a remaining fraction after firing of 0.72 (ton of black tea per ton of rolled leaves) were taken from field measurements. From the total product 7% of tea is rejected as refused tea and then the total green water content in black tea was 12784.55 m^3/ton.

Further, blue water footprint of black tea production was 65.79 m^3/ton. Water is obtained from the springs and used in humidifying and roller washing in the studied tea factories. The blue water footprint of black tea depends on the method of tea processing for example use of boilers in tea drying will result a higher blue water footprint in tea processing. The resulted quantity of blue water consumption is very low compared to green water content conveyed from the fresh tea leaves. Further, leaks were detected in the water distribution line which carries water into humidifiers and roller washing at the site. Therefore, there is a potential to reduce blue water component in the black tea product.

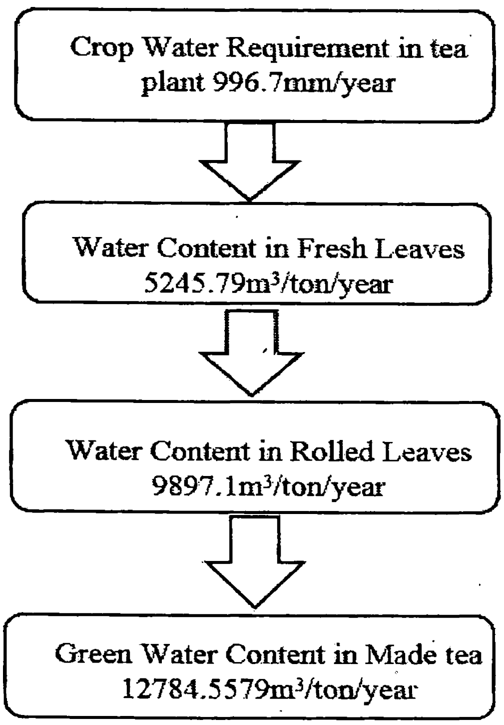

Figure 1. The Calculation of the Green Water Footprint for Black Tea Production

Grey Water Footprint of Tea Production

Previous studies identified that, nitrate is the major pollutant in agrochemicals which subjected for leaching in crop production systems (Deurer *et al.*, 2011) and therefore in this study, nitrogen fertilizer application rate was considered based on the fertilizer application rates to the tea estates.

Annual nitrogen application rate (6.8 kg/ha) was calculated based on replacement ratio. Due to the difficulty of measuring nitrate leaching, most of the grey water footprint calculations in the literature were based on assuming that, 10% of the nitrogen applied as fertilizer is lost through leaching.

Annual grey water footprint of tea cultivation was 73 m^3/ton for tea cultivation. It means 73 m^3 volume of water required to dilute the pollution load generated during the tea cultivation.

The virtual water content of black tea produced by the study area is 12,923.34 m^3/ton/year which is a higher value compared to the values available in the literature. This might be due to the lower land productivity in the tea plantations and incorporation of both blue and grey water footprints into the present calculation.

The studied sites manufacture black tea for the export and it has positive impacts on the economy of the Sri Lanka and it generates economic benefits to the country with the use of rainwater mainly that has relatively low opportunity cost (if compared to ground and surface water).

CONCLUSIONS

The study showed that the virtual water content of black tea is 12,923.34 m^3/ton/year from the data obtained for the period of May, 2015 to April, 2016 and measurements carried out during the six months of research period. Annually, Sri Lanka exports 12,923.34 m^3 of water whenever one ton of black tea is exported. The export of tea has positive impacts on the economy of the Sri Lanka and it generates economic benefits to the country with the use of rainwater mainly that has relatively low opportunity cost. As a large fraction of water footprint goes to the green water footprint (98.9%) and other small fraction goes to the blue and grey water footprint (1.1%).

Although rainwater appropriated for tea production will often have no alternative use (e.g. production of another crop or natural forest) that will provide higher economic return, the economic value of rainwater should be included in the price of black tea.

The volume of water required to produce black tea depends particularly on the climate at the place of production and the yields per hectare that are obtained. The latter partly depends on the climatic conditions, but also on soil conditions and management practice. Further, water consumption during the production process greatly depends on the employees' attitudes.

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