CIÊNCIAeNATURA

UFSM
Ci. e Nat., Santa Maria v.42, e67, p. 1-24, 2020
DOI:10.5902/2179460X35060
ISSN 2179-460X

Environment Submissão 05/10/18 Aprovação 13/01/20 Publicação 09/09/20

Water footprint as a sustainable water use indicator in spring area of Pantanal biome, Brazil

Eliane Aparecida Antunes Fagundes[I], José Dantas Neto[II], Vicente Paulo Rodrigues Silva[III], Domingos Sávio Barbosa[IV], Vera Lúcia Antunes Lima[V]

ABSTRACT

Water footprint (WF) is an indicator of fresh water consumption that considers in its calculation the used water volume during the production process. The research objective was to evaluatecotton, corn and soybean crops WF at the São Lourenço-MT sub-basin area. The water consumption was quantified in Green Water Footprint (WFGreen) and Gray Water Footprint (WFGray). The WFGreen of each crop was calculated by the evapotranspiration value throughout the crop growing period. The WFGray was counted separately for a group of nine agrochemicals. In the current scenario there is sustainability in the sub-basin of the São Lourenço river, but with the agricultural current area expansion rate, in 2025 there will be no such sustainability.

Keywords: Water resources; Gray footprint; Agrochemicals; Water consumption; Sustainability

1 INTRODUCTION

Ensuring current and future generations the necessary water availability, in quality standards appropriate to their uses, should be the main objective of any public water management policy on the planet (Pizella e Souza 2007; Braga et al., 2008; et al., 2010). The planet water volume has not changed over time, but the delay between the use of water, which is often a polluting processes subject, and its purification in the atmosphere, is interpreted as if drinking water is running out, when in fact, there is a reduction in available quantities (Gleick 1998, Aldaya, Allan and Hoekstra 2010, FAO 2013).

The desired balance search, between the demanded and the offered water resources quantities in nature, requires strategies that can be used to reduce the risk factors (Vörösmarty et al., 2010), highlighting an increased efficiency of water use

[I] Universidade Federal de Campina Grande, MT- Brasil - elifagundes_@hotmail.com
[II] Universidade Federal de Campina Grande, MT- Brasil - zedantas1955@gmail.com
[III] Universidade Federal de Campina Grande, MT- Brasil - _vicente@dca.ufcg.edu.br
[IV] Universidade Federal de Mato Grosso, MT- Brasil - domingosbar@gmail.com
[V] Universidade Federal de Campina Grande, MT- Brasil - antuneslima@gmail.com

This work is licensed under a Creative Commons Attribution-NonCommercial-ShareAlike 4.0 International License.

processes as well as reducing the negative impact of activities on water quality in a region (Empinotti and Jacobi 2013). In order to quantify the multiple sustainable water manners, several indicators have emerged (Gleick 1998), which provide a numerical result, a metric dimension for specific information evaluation about the economic, environmental and social dimensions, contributing to the decision-making process. These information is obtained through the use of management tools (Böhringer and Jochem 2007, Borowski and Hare 2007).

Brazil is one of the largest soy, corn and cotton exporters in the current commodity situation. In environmental terms, inside grains, large quantities of virtual water leave the country. Virtual water refers to the indirect water trade that is product embedded, from their production site to the final destination. As there is an unequal water availability in various regions of the planet, it is necessary to use specific indicators to analyze the water resources consumption. Hoekstra and Hung (2002) and Allan (2011) have shown that by quantifying the incorporated water in the products, that the global fresh water character can be understoodand used to quantifythe consumption and trade effects of water resources. This understanding could serve as a basis for improving and adapting the management of planet freshwater resources.

The concept of Water Footprint (WF) has been used as afreshwater consumption indicator for people and products in various parts of the world (Van Oel, Krol and Hoekstra, 2009). It was created by Hoekstra (2003) and aims to show the consumption patterns and global dimensions of water use (Hoekstra et al., 2011; Vanham, Hoekstra and Bidoglio, 2013). The calculation of the total Water Footprint considers three types of Water Footprint in reference to the types of water considered by the method: Blue Water Footprint (WF_{blue}), Green Water Footprint (WF_{green}) and Gray Water Footprint (Hockstra et al., 2011; Wang et al., 2014, Marano and Fillipi 2015).

In its calculation, the method considers not only the consumed water volume from various sources, such as surface and groundwater and stored rainwater in the soil, but also the polluted water amount during the production process in a given location and period (Zeng et al., 2012). According to Chapagain et al. (2006), the total volume of fresh water used to produce goods, services or products, provides a basis for assessing impacts on freshwater systems and formulating strategies to reduce these impacts. The Water Footprint of a region is influenced by the economic development model, which is often deeplypracticed and based on the generation of wealth, which neglects the natural support life systems (Silva et al., 2013).

The world literature about people and products WF has increased very swiftly, however there are still few focused WF studies on specific river basins (UNEP, 2012, Zeng et al., 2012), especially for those carried on preserved biomes such as the Pantanal. Located in South America, the Pantanal is the largest floodplain in the world, with an area of about 250,000 square kilometers, of which, 62% is on Brazilian soil, in the states of Mato Grosso and Mato Grosso do Sul. The Pantanal extents still in the territories of Bolivia and Paraguay. It is also the second largest South American biome, surpassed only by the Amazon Bioma(Silva and Bates, 2002).

The WF assessment at the river basin level is an important step towards understanding how anthropic activities, agriculture, livestock and industry, force the natural water cycles and is presented as an integrated management tool of water resources and sustainable water uses (Zeng et al., 2012). The Pantanal is becoming increasingly threatened by major development programs. The expansion of agriculture and its agroindustry, as well as the construction of reservoirs for hydroelectric power generation in the hydrographic basins, modify the discharge pattern and sediment load of the region's rivers (Junk and Cunha 2005).

The objectives of the study were: (1) to evaluate cotton, corn and soybeans crops WF planted in the São Lourenço river basin area; (2) evaluate WF as a sustainabilityindicator of agricultural activities in the basin over an annual time interval.

The sub-basin chosen was from the São Lourenço river, in the state of Mato Grosso, Brazil, a Pantanal biome spring area. The average regional annual precipitation is 1700mm (INMET 2015) and all agriculture is rainfed. Thus the components were computed: green and gray water footprint.

The regionalpesticides overuse has worried the scientific community. The Ministry of Agrarian Development (MDA) and the National Agency of Sanitary Surveillance (ANVISA) affirm that Brazil is the world largest pesticides consumer and producer since 2009 and that these products marketis already four times higher than the world average (ANVISA 2012, Dellamatrice and Monteiro 2014). In the states of Mato Grosso and Mato Grosso do Sul, in the Pantanal region, Miranda et al. (2008) evaluated in their study the pesticides sediments contamination in seventeen rivers; from the 23 monitored pesticideswere detectedresidues of pyrethroids (permethrin, lambda-cyhalothrin and deltamethrin) and chlorinated (DDT). The WF assessment is an important indicator of basin sustainability as it can provide local environmental management authorities and producers the needed information to allocate monitoring and management efforts to the achieve the established objectives in the Brazilian water resources legislation.

2 MATERIAL AND METHODS

The study was carried out in the upper São Lourenço river region, southeast of Mato Grosso, Brazil, with a total area of 21,105 km^2, with 2,934 km^2 being occupied with agriculture. The annual average flow of the São Lourenço is about 317m^3 / s (ANA 2004).

The WF was calculated following the proposed methodology in the Water Footprint Assessment Manual (Hoekstra et al., 2011) being divided into Green Water Footprint and Gray Water Footprint, as the area's agriculture is dryland.

2.1 Green Water Footprint calculation

The Green Water Footprint calculation of basin planted crops (cotton, corn and soybean) was carried out from Equation 1 and involves the Crop Green Water (c_{green}) consumption and the crop productivity in the studied region.

$$WF_{gree} = \frac{C_{gree}}{p} \qquad (1)$$

Where: WF_{green} = Green Water Footprint (m^3 / t); c_{green}, = Green Water consumption (m^3 / ha); P = Productivity (t / ha);

The green water crop consumption was calculated through the daily evapotranspiration values of green water (ET_{green}), during the crop growing period (Equation 2), so that the consumption of green water represents the total rainwater evaporated by the crop during the growing period. In this study the cotton, corn and soybean ET_0reference was analyzed.

$$C_{gree} = \beta \, . \sum_{d=1}^{dpc} \, . EVT_{gree} \qquad (2)$$

where: c_{Green}, = Green water consumption (m^3 / ha); β = 10 (mm rainfall conversion factor for $m^3.ha^{-1}$); dpc = duration of the growth period in days (d); EVT_{green} = Daily water green evapotranspiration (mm / day);

The evapotranspiration sum considers the included values between the seeding and the harvest day. Each crop evapotranspiration was obtained by multiplying ET_0, based on the Pennman-Monteith equation (Allen et al., 1998) and crop K_c, according to Doorenbos and Pruitt (1976). The daily meteorological variables averages needed to estimate $ET_0$by Penman-Monteith method were obtained from the automatic region station.

2.2 Gray Water footprint calculation

The study of analyzed pollutants was defined according to the survey questionnaire applied on agronomists working in the region plus the Mato Grosso Institute of Agricultural Economics (IMEA) data. The most commonly used herbicides, fungicides and insecticides for the cotton, corn and soybean crops of the region were selected. The maximum permissible concentrations (C_{max}) of selected pollutants were obtained through legislation that deals with natural state water quality standards. In the case of Brazil, CONAMA Resolution N° 357/2005 (CONAMA 2005) was used for

Class II freshwater. European Union (UE, 2013) and INERIS (2013) legislation were also used because, according to Franke, Boyacioglu and Hoekstra (2013), these standards are current and scientifically reliable. The application rates of the main agrochemicals used, per crop area, for the 2014/2015 harvest are listed in Table 1.

Table 1 - Main agrochemicals application rate used for cotton, corn and soybean crops in the Upper São Lourenço river, MT

Agrotoxic (2)	Class (3)	TAPC ($L.ha^{-1}$) (4)
Glufosinate Ammonium	Herbicide	2,750
Difenoconazole	Fungicide	0,300
Zeta-Cypermethrin	Inseticide	0,112
Atrazine	Herbicide	4,750
Azoxystrobin	Fungicide	0,300
Methomyl	Inseticide	0,600
Glyphosate	Herbicide	1,500
Trifloxystrobin	Fungicide	0,350
Flubendiamide	Inseticide	0,045

TAPC = Commercial product application rate; CS = Substance concentration; TAPS = Substance application rate.
Source: authors

The total application rate (T_{tapl}) is the amount of chemical applied substance per year. Considering the area of 1 hectare for each crop it is shown that the pesticides listed T_{tapl} in Table 1 is equal to column 7 (Rate of application of substance $t.ha^{-1}$) times 1 ha.

The Gray Water Footprint calculation of each crop (WF_{gray}, $m^3.t$) was performed according to Equation 3:

$$PH_{cinza} = (axTQ)/(C_{max} \underset{p}{-} C_{nat}) \qquad (3)$$

being: PH_{Gray} = Gray water footprint ($m^3.t^{-1}$); α = Leaching fraction; TQ = Chemical substances application rate per hectare ($kg.ha^{-1}$); C_{max} = Maximum permissible pollutant concentration in the receiving aquatic environment ($kg.m^{-3}$); C_{nat}, = Natural pollutant concentration in the receiving aquatic environment ($kg.m^{-3}$); P = yield of the crop ($t.ha^{-1}$).

The average cotton, corn and soybean crop in the studied region in the 2014/2015 harvest was 4,044 $t.ha^{-1}$, 6,095 $t.ha^{-1}$, 3,000 $t.ha^{-1}$ respectively. The WF_{Gray} study was based on the area of one (01) cotton, corn and soybean hectare according to the cultural practices used in local farms.

The dimensionless α factor represents the fraction of leaching or flow, defined as the fraction of applied chemicals that reach the bodies of water and can be calculated using Equation 4:

$$\alpha = \alpha_{min} + \frac{\sum_i s_i \, . \, w_1}{\sum_i w_i} . (\alpha_{max} - \alpha_{min}) \qquad (4)$$

being: α_{max} = maximum leaching fraction; α_{min} = fraction of leaching-minimum flow; Si = potential leaching-outflow; W_i = factor weight.

The minimum and maximum chemicals leaching-flow fractions in study were: minimum (α_{min} = 0.0001) and maximum (α_{max} = 0.1), according to Franke, Boyacioglu and Hoekstra (2013). By factor, the scoring for leaching potential (si) is multiplied by the weight (Wi) factor. With the help of frame 1, the scores for potential leaching flow per factor were found for the studied pesticides, which are seen in Table 2.

Frame 1 - Influencing factors the leaching and potential flow of pesticides. The state of the factor that determines the leaching and flow potential is expressed as an (S) value between 0 and 1.

Agrotoxics						
Category	Factor	Potencial	Very	Low	High	Very

			de leaching and flow potential	Low			High
			Value (S)→	0,00	0,33	0,67	1,00
					Weight (w)↓		
Chemical properties		K_{oc} (L.kg^{-1})	20	>1000	1000-200	200-50	<50
		PL (D_{T50} Days)	15	<10	10-30	30-100	>100
		PE (D_{T50} Days)	10	<10	10-30	30-100	>100
Enviromental factors	Soil	TSL	15	Clay	Silt	Loam	Sand
		TSE	10	Sand	Loam	Silt	Clay
		MO* content (dag. Kg^{-1})	10	Excelent >7,00	Nice 4,01-7,00	Medium 2,01-4,00	Low <2,00
	Weather	IP (mm)	5	Low	Moderate	High	Very High
		P (mm)	5	>600	600-1200	1200-1800	>1800
Cultural practices		PM	10	Excelent	Nice	Bad	Worst

(Adapted from Franke Boyacioglu and Hoekstra, 2013). Koc = Partition coefficient of organic carbon of the soil-water complex; PL = Persistence relevant to leaching (50% of the duration time); PE = Persistence relevant to the flow (50% of the duration time); IP = Precipitation intensity; TSL = soil texture relevant to leaching; TSE = soil texture relevant to runoff; P = Precipitation; PM = Management practices relevant to the outflow; Weight (w) of the factor. * SOURCE: Ribeiro, Guimarães and Alvarez (1999).
Source: authors

Table 2 - Values and weights, by pesticide, factors related to chemical properties, environmental factors and cultural practices, which influence leaching and flow in the study area.

Agrotoxic	K_{oc} (L. kg^{-1}) 20*	PL (days) 15*	PE (days) 10*	TSL 15*	TSE 10*	MO (dag.Kg^{-1}) 10*	IP 5*	P (mm) 5*	PM 10*
Glufosinate Ammonium	600 (0,33)	7,0 (0)	7,0 (0)	F (0,67)	F (0,33)	3,2 (0,67)	A (0,67)	1700 (0,67)	B (0,33)
Difenoconazole	>1000 (0)	130 (1)	3 (0)	F (0,67)	F (0,33)	3,2 (0,67)	A (0,67)	1700 (0,67)	B (0,33)
Zeta-	>1000	49	1	F	F	3,2	A	1700	B

Cypermethrin	(0)	(0,67)	(0)	(0,67)	(0,33)	(0,67)	(0,67)	(0,67)	(0,33)
Atrazine	100 (0,67)	75 (0,67)	- (0)	F (0,67)	F (0,33)	3,2 (0,67)	A (0,67)	1700 (0,67)	B (0,33)
Azoxystrobin	589 (0,33)	78 (0,67)	6 (0)	F (0,67)	F (0,33)	3,2 (0,67)	A (0,67)	1700 (0,67)	B (0,33)
Methomyl	660 (0,33)	1,4 (0)	8,1 (0)	F (0,67)	F (0,33)	3,2 (0,67)	A (0,67)	1700 (0,67)	B (0,33)
Glyphosate	>1000 (0)	15 (0,33)	9,0 (0)	F (0,67)	F (0,33)	3,2 (0,67)	A (0,67)	1700 (0,67)	B (0,33)
Trifloxystrobin	>1000 (0)	7,0 (0)	1,0 (0)	F (0,67)	F (0,33)	3,2 (0,67)	A (0,67)	1700 (0,67)	B (0,33)
Flubendiamide	>1000 (0)	500 (1)	6,9 (0)	F (0,67)	F (0,33)	3,2 (0,67)	A (0,67)	1700 (0,67)	B (0,33)

* Factor weight; () = Value for potential leaching and flow; F = Regarding the texture of the sandy loam soil; A = referring to the high precipitation intensity of the region; B = referring to good cultural practices relevant to the outflow

Source: authors

2.3 Green Water Footprint sustentability

The Green Water Footprint environmental sustainability of the studied area in the upper São Lourenço was related to the amount of available green water (Hoekstra et al., 2011). The availability of green water (DA_{green}) in a *x*basin at a *t*given period is defined as total evapotranspiration of rainwater (ET_{green}) minus the sum of evapotranspiration reserved for natural vegetation (ET_{amb}) and evapotranspiration of non-productive areas, according to equation 5:

$$DA_{gree}[x,t] = ET_{gree}[x,t] - ET_{envi}[x,t] - ET_{unpr} \quad \text{[volume/time]} \qquad (5)$$

being: (DA_{green}) - availability of green water in anx basin; t - a certain period; (ETgreen) - total rainwater evapotranspiration; ($ET_{environmental}$) - the sum of evapotranspiration reserved for natural vegetation; ($ET_{unproductive}$) - evapotranspiration of non-productive areas.

The ETamb variable is the 'green water environmental demand' and refers to the amount of green water used by natural preserved vegetation basin areas, aiming at maintaining biodiversity and sustaining communities that depend on natural ecosystems. The natural preservation area was stipulated by Law No. 12,651 of May 25, 2012, Forest Code, to preserve 35% of the Cerrado biome (Brazil 2012).

The green water scarcity level in a xbasin in tperiod is defined as the ratio of the total green water footprint in the basin to the availability of green water, equation 6:

〖EA〗_gree [x,t]=∑▒〖PH〗_gree [x,t] (6)

〖DA〗_gree [x,t]

2.4 Gray Water Footprint sustentability

The Gray Water Footprint environmental sustainability of the upper São Lourençostudied area was estimated as the consumed fraction of the effluents assimilation capacity and calculated by the ratio between the total gray water footprints (ΣWFgray) and the actual flow of the basin (Qreal) as equation 7. According to Hoekstra et al. (2011), this is a relevant local impact indicator for calculating the level of water pollution (NPA) in a basin.

NPA[x,t]=∑▒〖PH〗_gra [x,t] (7)

Q_real [x,t]

3 RESULTS

3.1 Green Water Footprint (WFGreen)

The largest Green Water Footprint (WFGreen) was soybean with 1673 m3.t-1, followed by cotton with 864 m3.t-1 and corn with 464 m3.t-1. Precipitation and climate determine evapotranspiration and therefore, influence the crops Water Footprint. According to COSTA, D.C. et al., (2018), the temporal dynamics of the water footprint indicate that cultivars with high yield potential are efficient in using the rain supply thus reducing soybean water footprint. The studied area ET0 in the 2013/2014-year crop was 3.5 mm.day-1, considered satisfactory to soybean, cotton and corn crops cultivation under rainfed conditions.

The WFGreen soybean results were consistent with values found in Indonesia, which is 1644 m3.t-1 (Bulsink, Hoekstra and Booij, 2010), but lower than those found by Ercin, Aldaya and Hoekstra (2012) in non-irrigated farms in Canada and France, whose WFGreen were 2069 m3.t-1 and 2048 m3.t-1 respectively. The global meandescribed in the Mekonnen and Hoekstra (2011) paper is 2037m3.t-1, which shows that the found soybean WFGreen in the studied region (1673 m3.t-1) is lower due to the favorable crop situations such as climatic conditions and no-till farming practices. In this system, the soil is always covered by straw, which contributes to an evaporation and soil temperature reduction and at the same time increase the organic stuff, favoring the water soil stowing (Figueiredo, Ramos and Tostes, 2008). It is noticed that the sum of these factors contributes to the fact that the regional cultivated soybeans WFGreen is smaller than the global average.

Cotton has the second highest WFGreen of this study with 864 m3.t-1 whose value is similar to the Australia, which is 870 m3.t -1 (Chapagain et al., 2006) and below countries like India (6490 m3 / t), USA (2114 m3 / t) and China (1440 m3 / t), according to Franke and Mathews (2013). The average for the global cotton water footprint is 755 m3 / t (Mekkonnen and Hoekstra, 2010).

Corn presents the lowest WFGreen, 464 m3.t-1, and this result is due to the lower life cycle of the previous variety planted in the region. The presented corn WFGreen value in this study is lower than those found in some literatures such as: Carvalho and Menezes (2014), who found corn WFGreen of 955 m3.t-1, to that found by Mekkonnen and Hoekstra (2010); which was 947 m3.t-1 and that of Soares e Campos (2013), whose result found in the semi-arid region was 709 m3.t-1.

3.2 Gray Water Footprint (WFGray)

From the leaching-flow fraction (α); of the total rate of application of the substance (Ttapl); of the pollutant load of the substance (L) and the value of the maximum permissible concentration (Cmax), the annual Gray Water Footprint (WFCa) of each pesticide used on the farm of one hectare of cotton, maize and soybean study (Table 3)

Table 3 - Annual Water footprint ash (WFca) of each pesticide used in one hectare of cotton, corn and soybean crops in the Upper São Lourenço river, MT

Culture (1)	**Agrotoxic (2)**	**α (3)**	**T_{tapl} (t) (4)**
Cotton	Glufosinate Ammonium	0,0367	$1{,}65\times10^{-3}$
	Difenoconazole	0,0694	$2{,}25\times10^{-4}$
	Zeta-Cypermethrin	0,0402	$1{,}57\times10^{-4}$
Corn	Atrazine	0,0569	$2{,}38\times10^{-3}$
	Azoxystrobin	0,0467	$6{,}00\times10^{-5}$
	Methomyl	0,0367	$1{,}94\times10^{-4}$
Soy	Glyphosate	0,0351	$1{,}44\times10^{-3}$
	Trifloxystrobin	0,0301	$1{,}05\times10^{-4}$
	Flubendiamide	0,0451	$3{,}24\times10^{-5}$

(α) = Leaching flow fraction; T_{tapl} = Total application substance rate; L = Pollutant substante rate; C_{max} = Maximum permitted concetration rate.
Source: authors

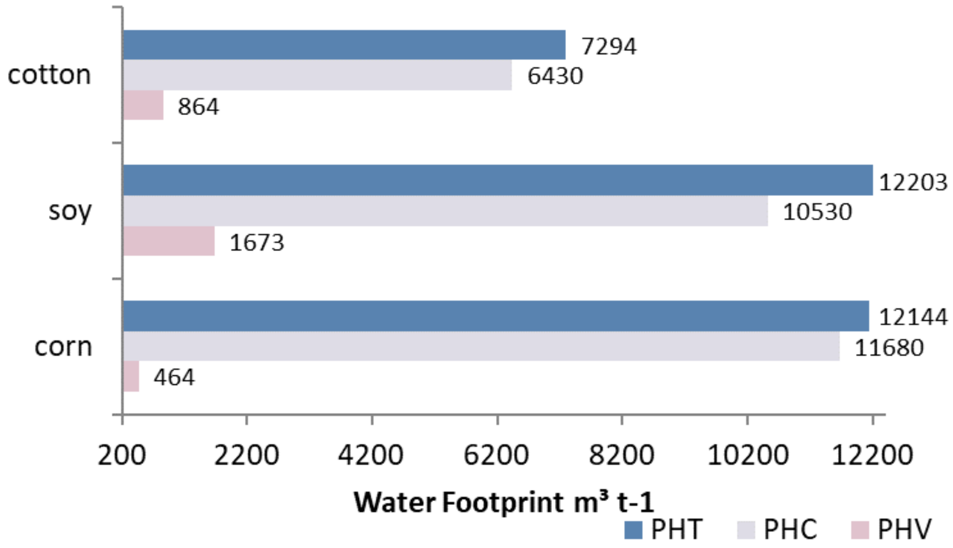
According to Table 3, the agrochemical that presents the highest WF_{Ca} in the 1 ha cotton farm was the fungicide difenoconazole with a value of 26,000 m^3. Considering that the average cotton yield in the 2013/2014 harvest was 4.044 $t.ha^{-1}$, the produced cotton Gray Water Footprint (WF_{Gray}) in the region was 6.43 x 103 $m^3.t^{-1}$ (26,000 m^3 / 4.044 t). The agrochemical that presents the highest WF_{Ca} in the cultivation of 1 ha of corn was the methomilinsecticide with a value of 71,200 m^3. Considering that the average maize productivity was 6,095 t / ha^{-1}, the gray water footprint (WF_{Gray}) of produced corn in the region was 11.68 x 103 $m^3.t^{-1}$ (71,200 m^3 / 6,095 t). Also, according to Table 4, the agrochemical that presents the highest WF_{Gray} in the agricultural holding of 1 ha of soybean was the fungicide trifloxystrobin with a value of 31,600 m^3. Considering that the average soybean yield was 3,000 $t.ha^{-1}$, the produced soybean WF_{Gray} in the region was 10.53 x 103 $m^3.t_{-1}$ (31,600 m^3 / 3,000 t).

The pesticides ranking expresses the relative position for the total volume of WF_{Gray} and can be used to select pesticides that can minimize the volume of gray water in agricultural crops. According to the type of pesticide, in the herbicide line, the lowest WF_{Ca} was for glyphosate (180m³), in the fungicide line the lowest WFCa was Azoxystrobin (296m³) and in the insecticide line was Zeta-cypermethrin with WF_{Ca} of 0.011m³ .

Figure 1 shows the WF_{Gray}, WF_{Green} and Total Water Footprint (WFT) of each crop. Very close values are observed for soybean and corn crops. The lowest WFT is from the cotton crop with 7.29x103 $m^3.t^{-1}$, although it is the crop that, in this study, presents the highest number of pesticides application. The corn crop presents the most polluting pesticide, therefore the highest WF_{Gray}, which contributes to the increase of WFT that was 1.21x104 $m^3.t^{-1}$ and the soybean crop presented the highest WFT of the three cultures with 1, 22x104 $m^3.t^{-1}$. The values between the gray and green water footprints of each crop are very different, with the WF_{Gray} value always higher than the WF_{Green}. Thus for cotton the WF_{Gray} was 7.4 times higher than WF_{Green}, for corn the WF_{Gray} was 25.2 times and for soy the WF_{Gray} was 6.3 times.

The found WFT values in this research are very above the world culture averages, according to Mekkonnen and Hoekstra (2010), which are: 4029 $m^3.t^{-1}$, 2145 $m^3.t^{-1}$, 1222 $m^3.t^{-1}$ for cotton, corn and soybean respectively. These differences are due to the methodology used by Mekkonnen and Hoekstra (2010) to find the WF_{Gray}, which did not take into account the type of pesticides used, but the nitrogen leached fraction in the nitrate form. When the WF_{Gray} was calculated using the agrochemicals Franke, Boyacioglu and Hoekstra. (2013), found in India cotton farms WF_{Gray} of 38x106 $m^3.t^{-1}$, well above that found in this research that was 6.43x103 $m^3.t^{-1}$.

Figure 1 - Total Water Footprint (WFT), Ash (WF_{gray}) and Green (WF_{green}) of cotton, corn and soybean crops in the upper São Lourenço river, MT.



Source: authors

The reduction of the Water Footprint can be achieved through the efficient use of water in the agricultural sector, through the correct use of pesticides and better utilization of rainwater, avoiding mainly the pesticides transport to surface water. Thus, even considering the same number of applications of pesticides per crop, if glyphosate herbicide, fungicide Azoxystrobin and Zeta-Cypermethrin insecticide were used, the WF_{Gray} of the analyzed crops would decrease dramatically, being 219 $m^3.t^{-1}$, 145 $m^3.t^{-1}$, 197 $m^3.t^{-1}$, for cotton, corn and soybean respectively.

3.3 Water footprint sustentability on upper São Lourenço river

The WF_{Green} sustainability calculations were estimated according to Hoekstra et al. (2011) methodology. The total upper São Lourenço River area is 21,105 km^2. The annual evapotranspiration for the crop year 2013/2014 was 1294.32 mm and the period from May to July was 274.43 mm, according to data collected on the INMET website (2015). The natural reserve for the area is 35% for the preservation of biodiversity and the unproductive area represents 1% (INPE, 2016) and refers to the urban area, occupation mosaic of the studied area and water reservoirs. The calculations showed that the ET_{green} total of the area was of 27,30x109 m_3, ET_{amb} was of 9,56x109 m^3 and ET_{improd} was of 0.27x109 m^3. The green water availability (DA_{green}) of the studied area was: 27,30x109 m^3 - 9,56x109 m^3 - 0,27x109 m^3 = 17,47x109 m^3.

According to the IBGE (2015) in the 2013/2014 harvest, 202,000ha of soybeans, 61,000ha of cotton and 87,030ha of Corn were planted in the field, totaling a total area of 350,030ha, or 3500,03 Km^2. Considering the crop yields in the area as well as WF_{Green} of each crop, theneeded water volume to supply the entire WF_{Green} in the São Lourenço Alto basin is obtained according to Table 4.

Table 4. Volume of water needed to supply PHV in the high São Lourenço-MT river, in the 2013/2014 harvest.

CULTURE	**AP (ha) (1)**	**PT. (t/ha) (2)**	**PD. (t) (3)=(1x2)**	**PHV (m^3/t) (4)**	**V (m^3) (5)=(3x4)**
Cotton	61.000	4,044	246.684,0	864	213.134.976
Corn	87.030	6,095	530.447,9	464	246.127.872
Soy	202.000	3,000	606.000,0	1675	1.019.056.000
∑ Green Water Footprint volume in watershed					1,47x10^9

AP = Planted area; PT = Productivity; PD = Production; WFgreen = Green Water Footprint; V = water required to supply the WFgreen in the watershed.
Source: authors

The green water (EA_{green}) scarcity level in upper São Lourenço sub-basin is defined as the ratio between the total volume of water used in green water footprints in the microbasin and the availability of green water found was (1.47x109 m^3 / 17.47x109 m^3) x100 = 8.4%. This result indicates that there was still green water sustainability in the studied area.

The increase in the area for agricultural production in the upper São Lourenço sub-basin has grown over time and, if the national average is followed, the planted area will increase around 15% in the 2025year, with a planted area of 70150 ha of cotton, 100084 ha of corn and 232300 ha of soy respectively. In this scenario of increased planted area for the 2024/2025 harvest, the green water scarcity level

(EA$_{green}$) in the upper São Lourenço sub-basin would be (1,88x109 m3 / 17,47x109 m3) x100 = 10,8 %. These data show that, even with all planted cropsarea increase, if the same planting system continues, the area will maintain green water sustainability.

In the months of May to July, the green water availability tends to decrease what could increase the green water shortage level in that period and the sustainability of the area may be compromised. In the spring area, this concern should be throughout the year, since the area is in a recovery phase and needs reserved land for biodiversity preservation, where ecosystems depend on the availability of green water for this preservation. A reforestation is being carried out in the spring area of the sub-basin of the São Lourenço river, but this area still presents great vulnerability, since the planting of crops still happens very close to the springs.

The WF$_{Gray}$ was evaluated using the most commonly used pesticides of each crop studied (Table 5). Although the pesticide that presented the highest contamination rate was metomil, an insecticide used mainly in maize, the fungicide Trifloxystrobin, used in soybean, was responsible for the largest Gray Water Footprint in the microbasin as a whole, since soybeans had a cultivated area much larger than corn. This Gray Water Footprint of 6.38x109m^3 encompassed all the gray water footprints of other pesticides, so this volume will be used to calculate the WF$_{Gray}$'s sustainability in the microbasin.

Table 5. Gray water footprint of the most polluting pesticides used in cotton, corn and soybean crops in the Upper São Lourenço Sub-Basin, MT, in the 2013/2014 harvest.

CULTURE	**AGROTÓXIC**	**WFgray (m^3/ha) (1)**	**AP (ha) (2)**	**WFgray m (m**
Cotton	Difenoconazole	26.000	61.000	1,59x10^{9}
Corn	Methomyl	71.200	87.030	6,20x10^{9}
Soy	Trifloxystrobin	31.600	202.000	6,38x10^{9}

WFgray = Footprint Gray of the pesticide; AP = Planted area; WFgray m = Gray Footprint of the agrotoxic in the microbasin;
Source: authors

The water pollution level (NPA) in the upper São Lourenço sub-basin, defined as the fraction of the effluent assimilation capacity, consumed and calculated by the largest ratio between the Gray Water Footprint and the actual flow of a basin (Q_{real}), which according to Gonçalves et al. (2011), is 317 m³ / s. Thus the NPA of the microbasin = (6.38x109m^3 / 10.00 x109m^3) x100 = 63.8%. Therefore, in the São Lourenço high basin 63.8% of the annual average volume is used to assimilate the effluents from agrochemicals. Even so, for the planted area level of the 2013/2014 harvest, there is still sustainability. In a scenario of increased planted area to the 2024/2025 harvest, the water pollution level (NPA) in the upper sub-basin of São Lourenço would be = (10.18x109 m^3 / 10.00x109 m^3) x100 = 101.8%. A water pollution level of 100% indicates that waste assimilation capacity has been fully utilized. When the level of pollution exceeds 100%, the water quality standards in their natural state are violated (Hoekstra et al., 2011).

Therefore, with the increase of the planted area of all crops, especially soybeans, and using the same pesticides, the annual volume of water in the sub-basin of São Lourenço will be used to assimilate pesticidesdilution, which characterizes an unsustainability the expansion of the agricultural area of the region in a 2024/2025 scenario.

The Water Footprint environmental sustainability is not only focused on numbers, but mainly on critical points that violate the qualitative and quantitative water resources patterns in the studied area and during a certain period. Soil and water quality plus the biodiversity downstream impact are also important concerns, as well as concerns about the health of agricultural workers and animals using water for consumption.

In addition to WF_{Gray}, special attention is given to pesticide containers handling and application equipment. The equipment washin rivers should be avoided, as it presents great toxicity to surface waters, directly affecting ecosystems biodiversity.

The great agricultural expansion in areas near the Mato Grosso wetland altered the soil cover, which may present alterations in the local hydrology, such as springs decreases mainly due to the high level of mechanization used in the area, making the soil more compacted. Proper land use management helps prevent negative consequences for the ecosystem such as soil erosion and degradation, thus avoiding the loss of biodiversity and the region's natural resources.

4 CONCLUSIONS

The Water Footprint values of cotton, maize and soybean crops were high when compared to other regions of the world, but they contributed to a regionalized assessment of water use by these crops and provided subsidies for the analysis of the use of water resources in the area studied from the upper São Lourenço, MT.

The knowledge of the Gray Water Footprint of the pesticides used in this study admits the choice of chemical products that minimize the volume of gray water. Thus, the Water Footprint presents itself as a useful source of management being a tool that can be used to minimize the risk of contamination of fresh water by agrochemicals used in agricultural crops.

The Green and Gray Water Footprint presented as an indicator that makes it possible to analyze the sustainability of the agriculture of the studied area. In the current scenario and even in a future scenario there is green water sustainability, however with the expansion of the agricultural area, at the current rate, in the year 2025, the entire annual volume of water in the upper São Lourenço sub-basin will be used to assimilate the dilution of agrochemicals, which characterizes the area's unsustainability.

REFERENCES

ALDAYA, M.M; ALLAN, A.A; HOEKSTRA, A.Y. **Strategic importance of green water in green water international crop trade.** Ecological Economics. 2010; v 69, n. 4, p 887-894.

ALLAN, J. A. - **Virtual Water: Tackling the threat to our planet's most precious resource.** Nova York,. Ed. I.B.Tauris. 2011.

ALLEN, R.G.; PEREIRA, L.S.; RAES, D.; SMITH, M. **Crop evapotranspiration: guidelines for computing crop water requirements.** FAO. Irrigationand Drainage Paper 56. Rome. 1998.

ANA- AGÊNCIA NACIONAL DE ÁGUAS. ***S*trategic action program for the integrated management of the Pantanal and the Upper Paraguay River Basin.** *ANA/GEF/PNUMA/ OEA.* Brasília. DF. 2004.

ANVISA - Agência Nacional de Vigilância Sanitária (ANVISA). **Seminário de mercado de agrotóxico e regulação [internet].** 2012. Brasília. [cited 2015 dez 14]. Available from: //portal.anvisa.gov.br.

BAYART, J.B.; BULLE, C.; DESCHÊNES L.; MARGNI, M.; PFISTER, S.; VINCE F.; KOEHLER. A. **A framework for assessing off-stream freshwater use in LCA.** The International Journal of Life Cycle Assesssmen*t. 2010.* v 5. n 5.p 439-453.

BOROWSKI, I.; HARE, M. **Exploring the gap between water managers and researchers.** Difficulties of model-based tools to support practical water management. Water Resources Management. 2007. v 21, n 7. p 1049-1074.

BRAGA, B.P.F.; FLEXA, R.; PENA,D.S.; KELMAN, J. **Federal pact and water management.** Estudos avançados. São Paulo. 2008. v 22, n 63, p 1-26.

BRASIL – Lei Federal nº 12.651, de 25 de maio de 2012. **Dispõe sobre a vegetação nativa e dá outras providências.** Brasília. [internet] 2012. [cited 2015 nov 05] Available from: http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm.

BULSINK, F; HOEKSTRA, A.Y.; BOOIJ, M.J. **The water footprint of Indonesian provinces related to the consumption of crop products.** Hydrology and Earth System Science. 2010. v 14. p 119–128.

CARVALHO, A.L.; MENEZES, R.S. **Pegadas hídricas em sistemas agropecuários na região semiárida do Nordeste do Brasil.** Revista Agro@ambiente on-line, 2014. v 8, n 1, p 142-148.

CHAPAGAIN, A. K.; HOEKSTRA, A. Y.; SAVENIJE, H. H. G.; GAUTAM, R. **The Water Footprint of cotton consumption- An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries.** Ecological Economics. 2006. v 60, n 1, p 186-203.

CONAMA. Conselho Nacional do Meio Ambiente. Resolução nº 357, de 17 de março de 2005**. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e padrões de lançamento de efluentes, e dá outras providências.** [internet]. 2005 [cited 2016 sep 06]. Available from: http://www.mma.gov.br/conama.

COSTA, D.C.; MARTORANO, L.G.; MORAES, J.R.S.C.; LISBOA, L.S.S.; STOFF, R. **Dinâmica temporal da pegada hídrica de soja em polo de grãos no oeste do Pará, Amazônia.** Revista Ambiente & Água. Taubaté. 2018. v 13. n 5.

DELLAMATRICE, P. M.; MONTEIRO, R. T. R. 2014. **Principais aspectos da poluição de rios brasileiros por pesticidas.** Revista Brasileira de Engenharia Agrícola e Ambienta**l.** 2014. v 18, n 12, p 1296-1301.

DOORENBOS, J.; PRUITT, W. O. **Las necesidades de agua de los cultivos.** Roma: FAO. Estudios FAO. Riego e Drenaje, 24. 1976.

EMPINOTTI, V.; JACOBI, P. R. **Novas práticas de governança de água.** O uso da pegada hídrica e a transformação das relações entre o setor privado, organizações ambientais e agências internacionais de desenvolvimento**.** Desenvolvimento e Meio Ambiente**.** Curitiba. 2013. v 27. p 23-36.

ERCIN, A.E.; ALDAYA, M.M.; HOEKSTRA, A.Y. **The water footprint of soy milk and burger and equivalent animal products.** Ecological Indicators. 2012. v 18. p 392-402.

FAO. FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. **The State of Food Insecurity in the World: the multiple dimensions of food security.** Rome, [internet] 2013. [cited 2015 apr 20] Available from: http://www.fao.org/docrep/018/i3434e/i3434e.pdf.

FIGUEIREDO, C.C.; RAMOS, M.L.G.; TOSTES, R. **Propriedades físicas e matéria orgânica de um latossolo vermelho sob sistemas de manejo e cerrado nativo.** Bioscience Journal. Uberlândia. 2008. v 24, n 3, p 24-30.

FRANKE, N.; MATHEWS, R. **C&A's water footprint strategy: Cotton clothing supply chain. Water Footprint Network.** Enschede, Netherlands & C&A Foundation, Zug, Switzerland. 2013.

FRANKE, N.A.; BOYACIOGLU, H.; HOEKSTRA, A.Y. **Grey Water Footprint Accounting: Tier 1 Supporting.Value of Water.** Research Report Series, n 65. UNESCO-IHE, Institute for Water Education. Delft. The Netherlands. 2013.

GLEICK, P.H. **Water in crisis: parths to sustainable water use.** Ecological Applications. 1998. v 8, n. 3, p 571-579.

HOEKSTRA, A. Y. **Virtual water trade: Proceedings of the International Expert Meeting on Virtual Water Trade, Value of Water.** Research Report Series, n12, UNESCO-IHE, Institute for Water Education. Delft, The Netherlands. 2003.

HOEKSTRA, A. Y., HUNG, P. Q. **Virtual water trade: a quantification of virtual water flows between nations in relation to international crop trade.** Value of Water. Research Report Series, n. 11, UNESCO-IHE, Institute for Water Education. Delft, The Netherlands. 2002.

HOEKSTRA, A.; CHAPAGAIN, A.; ALDAYA, M.; MEKONNEN, M**. Water footprint assessment manual.Setting the Global Standard.** WaterFootprint Network. 2011.

IBGE. INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. 2013. Ministério do Planejamento, Orçamento e Gestão. Cidades. [internet] 2013. [cited 2015 feb 15]. Available from:http://www.cidades.ibge.gov.br/xtras/temas.phplang=&codmun=510267&idtema=137&search=mato-grosso|campo-verde|producao-agricola-municipal-lavoura-temporaria.

INERIS – Portail Substances Chimiques. – [internet] 2013. [cited 2015 nov 06] Available from: //www.ineris.fr/substances/fr/page/9.

INMET – Instituto Nacional de Metereologia [internet]. [cited 2015 nov 11]. Available from: http://www.inmet.gov.br/portal/index.php?r=bdmep/bdmep.

INPE – Instituto Nacional de Pesquisas Espaciais [internet]. [cited 2016 mar 02]. Available from: http://www.dpi.inpe.br/tccerrado/.

JUNK, W. J.; CUNHA, C. N. **Pantanal: a large South American.** wetland at a crossroads. Ecological Engineering. 2005. v 24, n 4, p 391-401.

MARANO, R.P.; FILIPPI, R.A. **Water footprint in paddy rice systems. Its determination in the provinces of Santa Fe and Entre Ríos, Argentina.** Ecological Indicators**.** 2015. v 56, p 229–236.

MEKONNEN, M.M.; HOEKSTRA, A.Y. **The green, blue and grey Water Footprint of crops and derived crop products.** Hydrology and Earth System Sciences**.** 2011. v 15, p 1577–1600.

MIRANDA, K.; CUNHA, M.; DORES, E.; CALHEIROS, D. F. **Pesticide residues in river sediments from the Pantanal Wetland, Brazil.** Journal of Environmental Science and Health. Part B. 2008. v 43, p 717-722.

PIZELLA, D.G.;SOUZA, M.P. **Environmental sustainability analysis of the Brazilian Superficial waterfreshes.** Engenharia Sanitária e Ambiental. 2007. v 12,n 2, p 139-148.

RIBEIRO, A. C.; GUIMARÃES, P. T. G.; ALVAREZ V., V. H. (Ed). **Recomendação para o uso de corretivos e fertilizantes em Minas Gerais: 5 Aproximação.** Viçosa: Comissão de Fertilidade do Solo do Estado de Minas Gerais. 1999.

SILVA, J. M.; BATES, J. M. **Biogeographic patterns and conservation in the South American Cerrado: A tropical savanna hotspot.** Bioscience. 2002. v 52. p 225-233.

SILVA, V. P. R. MARACAJÁ, K.F.B.; ARAÚJO, L.E. DANTAS NETO, J.; ALEIXO, D.O.; CAMPOS, J.H.B.C. **Pegada hídrica de indivíduos com diferentes hábitos alimentares.** Revista Ambiente e Água – An Interdisciplinary Journal of Applied Science. 2013. v 8, n 1, p 250-262.

SOARES, R.B.; CAMPOS, K.C. **Uso e disponibilidade hídrica no semiárido do Brasil.** Revista de Política Agrícola. 2013. n 3. p 48-58.

UE - Directive 2013/39/EU of the European Parliament and of the Council amending Directives 2000/60/EC and 2008/105/EC as regards priority substances in the field of water policy. **European Union, Brussels.** Belgium [internet]. 2013. [cited 2015 out 17] Available from: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:226:0001:0017:EN:PDF.

UNEP - Measuring Water use in a Green Economy [internet]. 2012 [cited 2015 mar 18] Available from: http://waterfootprint.org/media/downloads/UNEP-2012-MeasuringWaterUse_1.pdf.

VAN OEL, P.R.; KROL, M.S.; HOEKSTRA, A.Y. **A river basin as a common-pool resource: a case study for the Jaguaribe basin in the semi-arid Northeast of Brazil.** International Journal of River Basin Management. 2009. v 7. n 4, p 345–353.

VANHAM, D.; HOEKSTRA, A. Y.; BIDOGLIO, G. **Potential watersaving through changes in European diets.** Environment International. 2013. v 61. p 45–56.

WANG, Y. B.; WU, P. T.; ENGEL, B. A.; SUN, S. K. **Applicationof water footprint combined with unified virtual crop pattern toevaluate crop water productivity in grain production in China.** Science of The Total Environment. 2014. v 497–498. p 1–9.

ZENG, Z.; LIU, P; KONEMAN, P.H.; ZARATE, E.; HOEKSTRA, A.Y. **Assessing water footprint at river basin level: a case study for the Heihe River Basin in northwest China.** Hydrology and Earth System Sciences. 2012. v 16. p 271–278.