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**Grey Water Footprint (GWF) by agrochemicals: a case
study of soybean farming in the Brazilian Cerrado**

DISSERTAÇÃO DE MESTRADO

Dissertation presented to the Programa de Pós-Graduação em Engenharia Urbana e Ambiental of the Departamento de Engenharia Civil, PUC-Rio as partial fulfilment of the requirements for the degree of Mestre em Engenharia Urbana e Ambiental (opção Profissional)

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Rio de Janeiro

June 2016



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Bibliography data

Boff, Renata Facin

Grey water footprint (GWF) by agrochemicals : a case study of soybean farming in the Brazilian cerrado / Renata Facin Boff ; advisor: Celso Romanel ; co-advisor: Markus Pahlow. – 2016.

90 f. : il. color. ; 30 cm

Dissertação (mestrado)–Pontifícia Universidade Católica do Rio de Janeiro, Departamento de Engenharia Civil, Programa de Pós-Graduação em Engenharia Urbana e Ambiental, 2016.

Inclui bibliografia

1. Engenharia civil – Teses. 2. Engenharia urbana – Teses. 3. Pegada hídrica cinza. 4. Poluição da água. 5. Agrotóxicos. 6. Soja. 7. Cerrado. I. Romanel, Celso. II. Pahlow, Markus. III. Pontifícia Universidade Católica do Rio de Janeiro. Departamento de Engenharia Civil. Programa de Pós-Graduação em Engenharia Urbana e Ambiental. IV. Título.

CDD: 624

Acknowledgments

Firstly, I thank my parents Regina and João Carlos Boff for always assisting me in my decisions. This research could not be completed without their support. I am also grateful for the help of my brother, Rafael Boff, whose counselling and insights made me see beyond.

I am especially thankful for Dr. Markus Pahlow and his family, for the great support during my stay in the Netherlands. For his patience in the process of choosing a thesis topic and also for the encouragement in my decisions. I am certain that his guidance was determinant in completing this task.

I appreciate the Water Resources Department in the University of Twente for hosting me as an external student during the development of the master research, in especial professor Arjen Hoekstra for welcoming in the team.

I thank Ana Paula Schwantes and for openhearted receiving me in Enschede, sharing great moments, helping me settle and turning into a good friend.

I would like to thank my colleagues Ana Carolina João, Flavia Moretz-Sohn, Jessica Francisca Costa, Karina Marckmann and Mariana Magalhães for the good moments we shared throughout the master course at PUC-Rio.

I am also appreciative of Professor Celso Romanel for being compliant with my ideas and Paula Enoy for the kindness and readiness to help at all times.

Abstract

Boff, Renata; Romanel, Celso (Advisor); Pahlow, Markus (Co-Advisor). **Grey Water Footprint (GWF) by agrochemicals: a case study of soybean farming in the Brazilian Cerrado.** Rio de Janeiro, 2016.90p. Master Dissertation - Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

The growing world population, coupled with changes in lifestyle, result in an increasing demand for food, feed and energy crops. Brazil is increasingly producing and supplying these crops for other parts of the world. The Cerrado has become the centre of Brazil's soybean industry. The natural savannah has been replaced by crop monocultures which are associated with intensive use of synthetic fertilizers and pesticides. This study determines to which extent the application of agrochemicals in the cultivation of soybean contributes to the pollution of local river basins in the Cerrado. As a measure to quantify this impact, the grey water footprint (GWF) of soybean cultivation in a typical farm in the municipality of Correntina-BA is calculated for 5 cropping years. The most significant pollutant for all years was the pesticide 2,4-D. The GWF of soybean cultivation for the case study in the period ranged from 7,661 to 13,587 m³ per hectare and 2,441 to 7,651 m³ per tonne of soybean. The average water pollution level (WPL) associated with the production of this crop at river basin level was 48.6 %. The average water pollution level (WPL) associated with the production of this crop at river basin level was 48.6 % with values ranging from 36 % to 83 %. The calculated GWFs and WPLs show a large variation among different cropping seasons. The GWF in 2013/2014 had discrepant values, being 43.6 % higher than the value in 2010/2011. This difference is mainly due to a higher application of the pesticide, from 0.80 kg/ha to 1.42 kg/ha. The WPL in 2013/2014 reached 83 %. The results indicate that following the local trend of further intensification of large scale agriculture, the pollution of local water bodies with dissolved agrochemicals will increase to the point that it is likely to soon violate the local water quality standards.

Keywords

Grey water footprint; water pollution; agrochemicals; soybean; Cerrado.

Resumo

Boff, Renata; Romanel, Celso (Orientador); Pahlow, Markus (Co-Orientador). **Pegada hídrica cinza por agroquímicos: um estudo de caso de cultivo de soja no Cerrado brasileiro.** Rio de Janeiro, 2016. 90p. Dissertação de Mestrado - Departamento de Engenharia Civil, Pontifícia Universidade Católica do Rio de Janeiro.

O crescimento da população mundial junto de mudanças no estilo de vida resulta em uma crescente demanda por culturas de alimentos e energia. O Brasil tem aumentado cada vez mais a produção e o fornecimento destas culturas para outras partes do mundo. O Cerrado tornou-se o centro da indústria de soja do Brasil. A savana natural foi substituída pelo cultivo de monoculturas que estão associadas ao uso intensivo de fertilizantes e pesticidas sintéticos. Este estudo determina em que medida a aplicação de agroquímicos no cultivo de soja contribui para a poluição dos corpos hídricos no Cerrado. Como medida para quantificar este impacto, a pegada hídrica cinza (GWF) do cultivo da soja em uma fazenda típica no município de Correntina-BA foi calculada para 5 anos de cultivo. O poluente mais significativo para todos os anos foi o pesticida 2,4-D. O GWF do cultivo da soja para o estudo de caso no período variou de 7.661 a 13.587 m³ por hectare e 2.441 a 7.651 m³ por tonelada de soja. O valor médio do nível de poluição da água (WPL) associado com a produção desta cultura na bacia hidrográfica foi de 48,6% com valores que variaram de 36% a 83%. Os valores de GWF e WPL calculados mostram uma grande variação entre os diferentes períodos. O GWF em 2013/2014 teve valores discrepantes sendo 43,6 % maior do que os valores em 2010/2011. A diferença é devida principalmente a uma maior aplicação do pesticida, de 0,80 kg/ha para 1,42 kg/ha. O WPL em 2013/2014 chegou a 83 %. Os resultados indicam que com a tendência de crescimento da agricultura de grande escala na região a poluição por agrotóxicos dissolvidos dos corpos hídricos se intensificará a tal ponto que é provável que viole em breve o padrão de qualidade de água local.

Palavras-chave

Pegada hídrica cinza; poluição da água; agrotóxicos; soja; Cerrado.

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List of acronyms and abbreviations

2, 4-D - 2,4 Dichlorophenoxyacetic Acid
ABRASCO - Brazilian Association of Collective Health
ANA - National Water Agency
ANDA - National Association for the Promotion of Fertilizers
ANVISA - National Health Surveillance Agency
BOD - Biochemical Oxygen Demand
CETESB - Environmental Company of the State of São Paulo
Conama - National Environmental Council
DWPA - Diffuse Water Pollution from Agriculture
FAO - Food and Agriculture Organization
GM - Genetic Modified
GWF - Grey Water Footprint
HidroWeb - Hydrological System of Information
IBGE - Brazilian Institute of Geography and Statistics
INMET - National Institute of Meteorology
INPEV - Processing Institute of Empty Containers
IAP - Raw Water Quality Index for Purposes of Public Supply
IB - Bathing index
IET - Trophic State Index
IQA - Water Quality Index
IVA - Index of Marine Life Protection
JMP - Joint Monitoring Programme
MAPA - Ministry of Agriculture, Livestock and Supply
MMA - Ministry of Environment
MS - Ministry of Health
PARA - Pesticide Residue Analysis in Food Programme
PNQA - National Water Quality Programme
RNQA - National Network of Water Quality
SINDAG - National Union of Pesticides Industries
SISAGUA - Surveillance System of Information on Water Quality for Human Consumption

SISNAMA - National Environmental System

SNIRH - National Information System of Water Resources

UF - Federal Unit

UN - United Nations

UNICEF - United Nations Children's Emergency Fund

UNESCO - United Nations Educational, Scientific and Cultural Organization

UNEP - United Nations Environment Programme

USDA - United States Department of Agriculture

WF - Water Footprint

WHO - World Health Organization

WPL - Water Pollution Level

WWAP - World Water Assessment Programme

When the last tree has been cut down, the last fish caught, the last river poisoned, only then will we realize that one cannot eat money.

Native american saying

Introduction

Brazilian soybean production is particularly of interest given the country's increasingly important role in the international trade of agricultural products in recent decades. Global soybean production rose from 143 to 227 Mtons between 2000 and 2010 among major producers. By 2010, Brazil had become the second largest producer of soybean in the world with 68.5 Mtons produced and is anticipated to be the world's leading soybean producer in 2014 (LATHUILLIÈRE *et al.*, 2014 *apud* FAOSTAT, 2013; USDA-FAS, 2014).

The current increase in the crop production in Brazil has been concentrated in the Cerrado, the second-largest biome in South America. The region has experienced excessive and continuous expansion of agriculture over the last 20 to 30 years, whereby the natural savannah has been replaced by monocultures of soybean, sugar cane, corn, coffee and cotton (cash crops), as well as by energy plantations and pastures. The accelerated expansion of agricultural activities has led to a significant increase in crop yields and economic wealth in the region over a short time, but it has also contributed to environmental problems associated with soil degradation, water shortages, pesticide contamination and increasing costs to control pests and diseases (HUNKE *et al.*, 2015).

The production of major export monocultures such as soybeans, has been associated to an intensive use of synthetic fertilizers and pesticides. The use of both pesticides and fertilizers in agriculture production is linked to a variety of human health and environmental problems, including forms of cancer, poisoning of fisheries and global warming (JORGENSEN & KUYKENDALL, 2008).

In this study, as a measure to quantify the pressure that excessive nutrients and pesticides puts on freshwater resources, the grey water footprint (GWF) is used. More broadly, the water footprint is an indicator of human appropriation of freshwater resources that measures both the direct and indirect "water use" of consumers and producers.

The term “water use” refers to two different components: consumptive water use and degenerative water use. The GWF is measured as the volume of water required to assimilate pollution. To express the effect of the GWF in the water quality of the local river basin, the concept of water pollution level (WPL) is used. The WPL is defined as the GWF in a river basin divided by the river basin runoff. Thus, the WPL shows the fraction of the waste assimilation capacity in a river basin that has been actually consumed and is insufficient to take up the actual pollution, resulting in a violation of water quality standards (MEKONNEN & HOEKSTRA, 2015).

The main objective of this study is to understand in which extent the usage of agrochemicals in soybean cultivation in the Cerrado contributes to the pollution of local river basins. In this context, a case study of a typical soybean cultivation farm was carried out. The intermediate objectives of this research include answering the following questions:

1. What is the GWF of a typical soybean cropping system in the Brazilian Cerrado (per hectare and per tonne of the crop)?
2. Which pollutant determines the grey water footprint? Does the determining pollutant vary temporally?
3. What is the magnitude of the WPL level related to soybean cultivation in the local river basin?

This study is divided into 7 chapters. Following the introduction, comes chapter 2 which presents the highlights of the soybeans market both worldwide and with focus in the Brazilian reality. In this chapter, we also present information on land use change focusing in the expansion of soybeans in the Brazilian Cerrado and the importance of this biome is also exposed.

In chapter 3, the focus is on the concerns related to the usage of agrochemicals. Initially an overview of the pesticides and fertilizers market development is presented, followed by the main environmental and health alarms related to the use of this substances and an outline of the Brazilian regulations on the use of agrochemicals.

The emphasis of chapter 4 is on water quality. A brief overview of the increasing freshwater demand is shown followed by the link between water availability and water quality. Information on water quality indicators and water quality monitoring is presented focusing in the Brazilian reality. Closing the

chapter, the water footprint concept is introduced concentrating on the water pollution dimension, the grey water footprint.

In chapter 5 the research methodology is presented and explanations on the calculations of both the GWF and WPL are given. The case study figures are outlined with qualitative information about the selected farm as well as spatial and temporal details on data use.

In chapter 6, the results of the calculations of the GWF of soybean cultivation and WPL in the local river basin are shown in a step-by-step approach of the methodology along with the associated discussions.

Finally, in chapter 7, the main conclusions and suggestions are presented. The goal of this chapter is to summarize the results providing information about limitations of the research and offering suggestions for further studies.

2

Soybean cultivation expansion

2.1

Commodity profile

Processed soybeans are the world's largest source of animal protein feed and the second largest source of vegetable oil (consumed as edible oil, and industrial products such as fatty acids, soaps and biodiesel; USDA- ECONOMIC RESEARCH SERVICE, 2012). Soybean is a high value and profitable crop. The economic viability of soy production is determined by the commercial utilization of both its sub-products, meal and oil, which, respectively, account for about two thirds and one third of the crop's economic value (THOENES, 2006).

Over the last 20-30 years, consistent improvements in average yield levels and reductions in production costs have steadily improved the competitive position of soybeans among arable crops. Among oilcrops, soybean covers a leading role at the global scale: today, soybeans account for about 35 % of total harvested area devoted to annual and perennial oilcrops and its share in global oilseed output is estimated at over 50 % (THOENES, 2006).

Soybean cultivation is highly concentrated geographically, with only four countries - USA, Brazil, Argentina and China - accounting for almost 90 % of world output (Figure 1). In 2013 Brazil was the second leading exporter of soybeans and its production has been increasing every year rapidly (Figure 2).

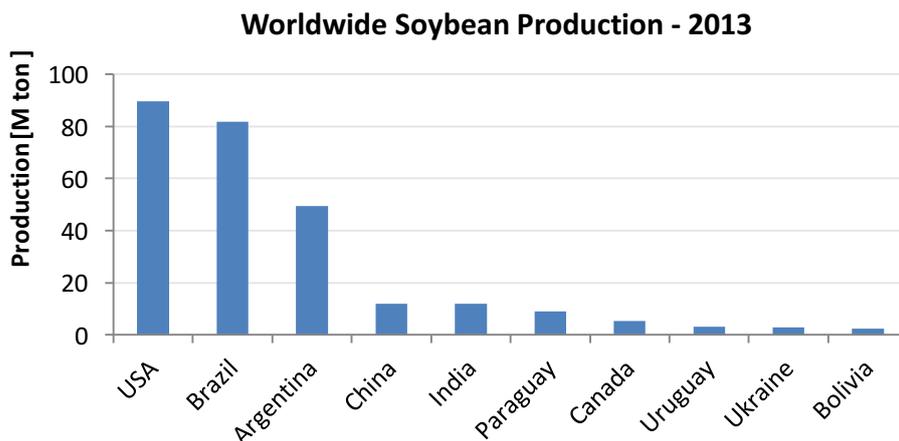


Figure 1 - Top ten soybean producing countries in 2013.

Source: FAOSTAT (2015). Elaboration of the author.

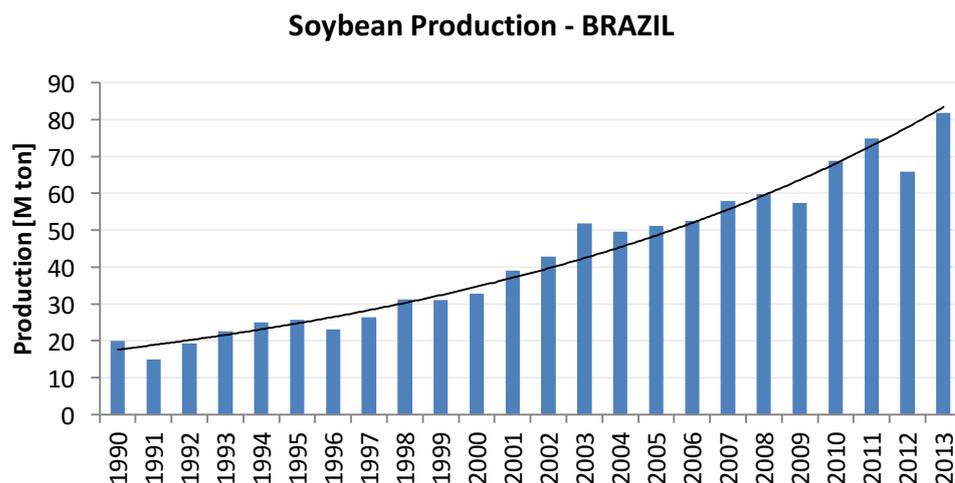


Figure 2 - Evolution of Brazilian soybean production in the last 23 years.

Source: FAOSTAT (2015). Elaboration of the author.

The rapid increase in soy production in Brazil over the last four decades was supported by government interventions to promote increased supply and increases in the global and domestic demand for soy derivatives. On the supply side, the factors affecting soybean expansion include major technological improvements in seeds in the 1970s, the introduction of credit subsidies and price supports in the 1980s, market deregulation and tariff reduction in the 1990s, and high global prices for soy and a competitive Real/US Dollar exchange rate in the late 1990s and 2000s

(GARRETT *et al.*, 2013). Soybeans cultivation is big business these days and require expensive machinery, skilled labour, and high levels of liquidity to finance yearly investments in soil correctives, defensives, and seeds (BROWN *et al.*, 2005)

Additionally, soybean is one of the crops where recent advances in biotechnology applications have been particularly important. Consequently, commercial production of genetically modified (GM) soybeans has risen sharply in recent years, with important repercussions for production, consumption and trade. In the world's three largest producing countries, the USA, Brazil and Argentina, about 70-90 % of soybean produced consists of GM varieties. On the consumption side, the advent of GM soybeans and other food crops has created considerable debate following consumer concerns about the safety of GM products (THOENES, 2006).

Soybean production and its supply chain are highly dependent on inputs such as land, fertilizer, fuel, machines, pesticides and electricity. The expansion of this crop in Brazil in recent decades has generated concerns about its environmental impacts (PRUDENCIO DA SILVA *et al.*, 2010).

2.2

Land use change in Brazil

In recent decades, agricultural expansion and the growth of domestic and international markets for food commodities have become the most important drivers of large-scale land cover change in Brazil (GARRETT *et al.*, 2013, *apud* DEFRIES *et al.*, 2010). In the Center West and Amazon regions, crop area expansion has resulted in the conversion of native savannas and forests and planted pastures to intensive agriculture.

The Brazilian Forest Code (FC) requires landowners to conserve native vegetation on their rural properties, setting aside a Legal Reserve (LR). The law also designated environmentally sensitive areas, the Areas of Permanent Preservation (APPs), aiming to conserve water resources and prevent soil erosion. APPs include both riparian preservation areas that protect riverside forest buffers, and hilltop preservation areas, high elevations, and steep slopes. The FC severely restricted deforestation on private properties but proved challenging to enforce, particularly in the Amazon (SOARES-FILHO *et al.*, 2014). Recent approval of

controversial revisions of the FC—the central piece of legislation regulating land use and management on private properties—may therefore have global consequences.

The increasing demand for soybeans in Brazil leads to the expansion of production in and around the Amazon rainforest. In an effort to “reconcile environmental preservation with the region's economic development,” growers and traders signed a moratorium in July 2006 to avoid production of soybeans on newly deforested Amazon rainforest, though the purchases of soy grown on land cleared before 2006 remain permissible (GIBBS *et al*, 2015). New research suggests that deforestation of the Amazon for soy production has declined under the moratorium. However, as the moratorium was only applicable to the Brazilian Amazon, a very different scenario has been playing out in the Brazilian Cerrado (NASA, 2015).

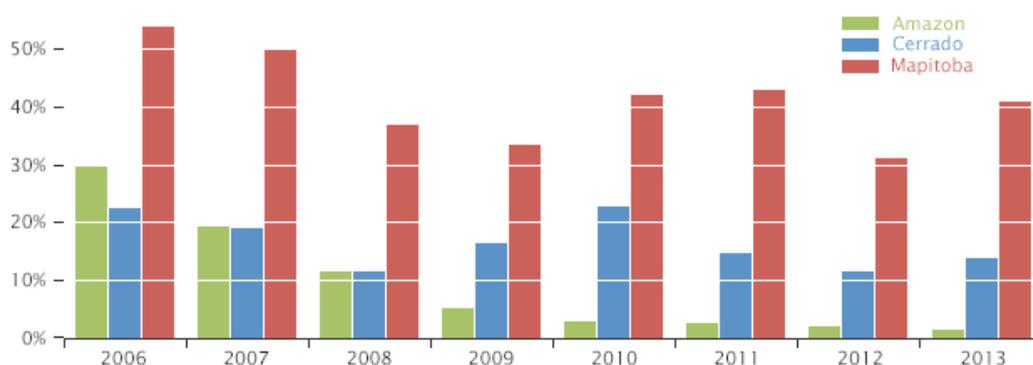


Figure 3 - Soybean Expansion into Native Vegetation.

Source: NASA (2015).

As can be seen on **Figure 3**, at the start of the moratorium in 2006, about 30 percent of soy expansion in the Amazon was achieved by cutting down Amazon forests. By 2013, that number dropped to about 1 percent as farmers transitioned to growing soy on previously cleared land. Without a corresponding moratorium, 11 to 23 percent of new farmland cleared each year for soy in the Cerrado was carved out of natively vegetated land. The expansion was even more widespread in MATOPIBA, which is the Eastern Cerrado region in the states of Maranhao, Piaui, Tocantins, and Bahia, where the deforestation for soybeans hovered around 40 percent (NASA, 2015).

2.3

Cerrado biome

The Brazilian Cerrado is recognized as one of the most threatened biomes in the world, as the region has experienced a striking change from natural Cerrado vegetation to intense cash crop production. About half of the Cerrado biome has been converted for agricultural production in recent decades, and these woodlands and savannas have less protection than Amazon forests under environmental laws (HUNKE *et al.*, 2015). Machado *et al.*, (2004) estimated that the natural biome outside of protected areas may disappear by 2030. On Figure 4 the effect of deforestation in the Cerrado is highlighted, showing that there is not much of the biome left in 2010.

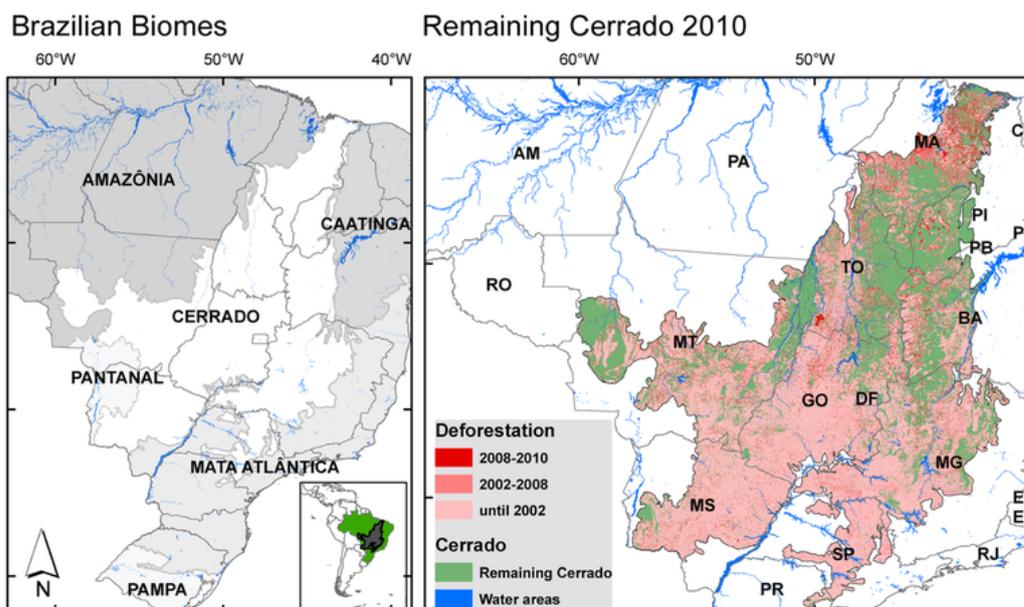


Figure 4 - The remaining Cerrado highlighting the deforestation hotspots from 2002-2010.

Data source: MMA; Hunke *et al.*, 2015

The Cerrado is one of the biologically richest of all tropical savannah regions in the world and has high levels of endemism. It is characterized by an undulating topography with wide interfluvial areas interrupted by tributaries of three major Brazilian drainage basins: Amazonian, San Francisco and Prata basins. The Cerrado vegetation is a mix of grasses, woody plants, fire-resistant twisted trees with thick, corky bark, sclerophyllous leaves, and vibrant flowers (JEPSON, 2005). It is an

area of huge importance for wildlife and is the second largest biome in Brazil, covering approximately 21 % of the country.

The region was once thought to have unsuitable characteristics for crop plantation but the scenario completely changed in the last decades. Chemical technologies have corrected the low fertility, high acid soils through the application of limestone, phosphate fertilizers and trace minerals. Nevertheless, correcting these soil deficiencies with current technologies is relatively expensive. Biological technologies have resulted in the development of high yielding soybean varieties with a high tolerance to high aluminum soils, droughty soils, and to low latitude tropical climates (MCVEY *et al.*, 2000).

The accelerated expansion of agricultural activities has led to a significant increase in crop yields and economic wealth in the region over a short time, but it has also contributed to serious environmental problems associated with soil degradation, water shortages, pesticide contamination and increasing costs to control pests and diseases (HUNKE *et al.*, 2015).

Impact studies on how current and future land use intensification affects land and water resources are pivotal to assess the Cerrado's potential for the continued provision of its ecosystem services. It is rather unclear if and how soil and water resources of the Cerrado are already negatively impacted and how the entire region is likely to develop under current and future land use intensification and climate change (HUNKE *et al.*, 2015).

3

Agrochemicals usage concerns

3.1

Development scenario

During the era of the "Green Revolution" [approximately early 1940s to late 1970s], new plant breeding technologies were developed under the auspices of the Rockefeller Foundation and the Ford Foundation. These efforts largely focused on the development of high-yielding varieties of seeds that would allow for more intensified cropping patterns. The new forms of hybrid seeds were [and are] dependent on chemical applications in the form of pesticides and fungicides as well as the need for concentrated fertilization and irrigation. The use of fertilizers, pesticides and irrigation techniques are not mutually exclusive. Heavy watering and fertilizer application can create conditions that are favourable to the proliferation of pests, which often leads to increases in the application of pesticides (JORGENSEN & KUYKENDALL, 2008). Partly resulting from the dissemination of new plant breeding technologies, global grain production increased threefold from 1950 to 1990, while worldwide fertilizer and pesticide use increased more than tenfold during the same period (EHLICH *et al.*, 1993).

In Brazil, pesticides are used since the decade of 1960-1970, as the solution for the control of pests that affected crops (MOISES *et al.*, 2011). The Brazilian pesticide market experienced a rapid expansion over the last decade (190 %), at a pace of growth more than double that of the global market (93 %), placing Brazil at the top of the world rank, since 2008. According to the Brazilian National Health Surveillance Agency (ANVISA), for the 2010/2011 harvest 936,000 tons of pesticides were used, involving financial transactions of US\$ 8.5 billion among ten companies that control 75 % of the market in the country. The permission for the use of GM seeds in crops, and their dissemination in farming areas are associated with increase in consumption (RIGOTTO *et al.*, 2014).

In Figure 5 and Figure 6, a recent outline on the increasing trends in pesticides and fertilizer consumption can be seen in more detail. The demand for all agrochemical have been increasing, in particular, the herbicides consumption has seen an exponential increase, with 252 % growth from 2002 until 2013.

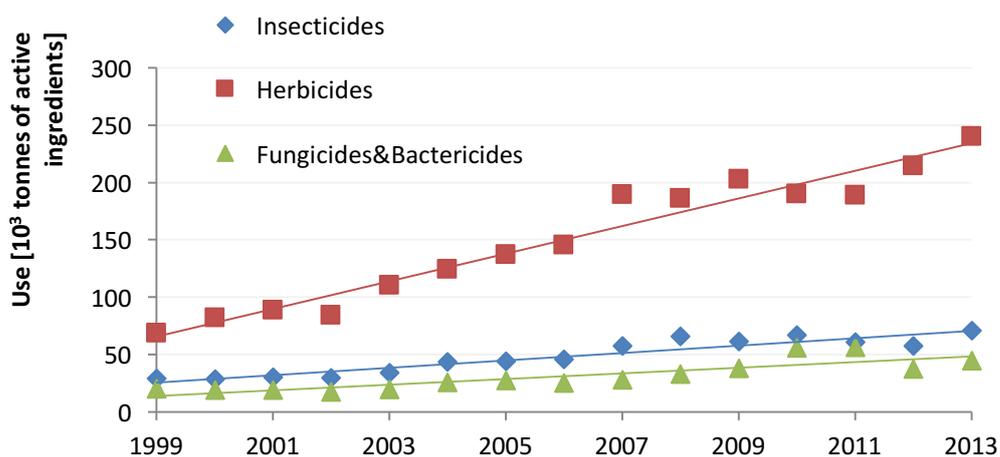


Figure 5 - Pesticides consumption in Brazil

Source: FAOSTAT, 2015. Elaboration of the author.

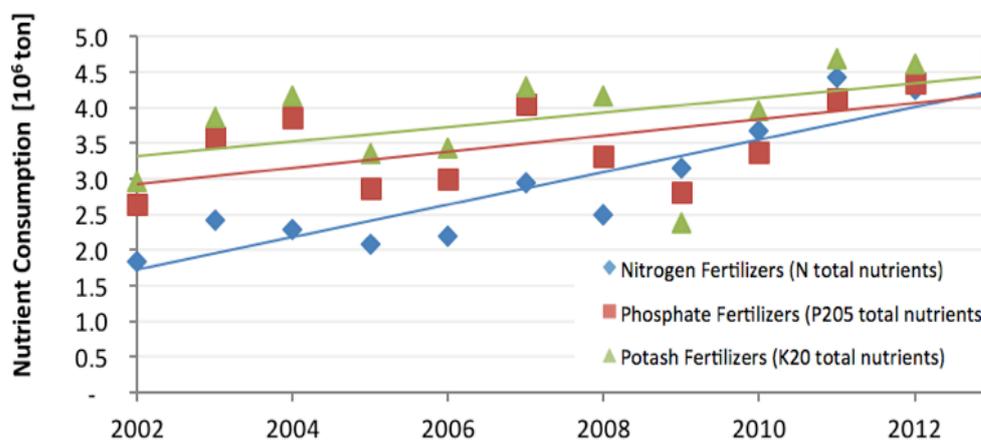


Figure 6 - Fertilizer consumption in Brazil

Source: FAOSTAT, 2015. Elaboration of the author.

In the Brazilian harvest of 2011, 71 million hectares of temporary crops (soybeans, corn, sugar, cotton) and permanent (coffee, citrus fruits, eucalyptus)

were planted, which corresponds to about 853 million litres of sprayed pesticides on these crops, mainly herbicides, fungicides and insecticides (IBGE-SIDRA, 2012; SINDAG, 2011). The soybeans cultivation by itself used up to 40 % of the total volume of pesticides sprayed in Brazilian lands (CARNEIRO *et al.*, 2012).

The average consumption of pesticides has increased also in relation to the planted area. This increase is related to several factors, such as the expansion of the planting of GM soy that extends the use of pesticides, the growing strength of the herbs pests, fungi and insects, requiring greater use of pesticides and increasing diseases in crops that allows for an intensification in the consumption of agrochemicals (CARNEIRO *et al.*, 2012). Additionally, some important stimulus to consumption comes from lower prices and the tax exemption of pesticides, causing farmers to use larger amount per hectare (PIGNATI & MACHADO, 2011).

About 434 active ingredients and 2,400 pesticide formulations are registered in Brazilian Ministries of Health, Agriculture, Livestock and Supply and Ministry of Environment and are allowed in the country according to the criteria of use and indication established in their Monographs. Nevertheless, out of the 50 chemicals most widely used in the Brazilian fields, 22 are banned in the European Union (CARNEIRO *et al.*, 2012). ANVISA is reviewing 14 of these pesticides since 2008. Out of the pesticides under review, some have already been banned, like acephate, a pesticide in the scope of this research. The banned on acephate, however, was partial and some cultivars like soybeans can still use it. In the case of soybeans, the main used agrochemical is the herbicide glyphosate, which is mostly used in the control of plant pests in GM crops, followed by methamidophos and endosulfan (insecticides), 2,4-D (herbicide), tebocunazol (fungicide) and atrazine (herbicide), however methamidophos and endosulfan have recently been withdrawn from the Brazilian market as a function of their potential toxic to human health (MOREIRA *et al.*, 2012).

3.2

Environmental and human health distresses

While agrochemicals have helped to increase crop yields and thus reduce hunger and malnutrition in many less-developed countries, the use of both pesticides and fertilizers in agriculture production is linked to a variety of human

health and environmental problems, including forms of cancer, the poisoning of fisheries and global warming (JORGENSEN & KUYKENDALL, 2008)

As pesticides are toxic chemicals designed to kill living organisms, they can have harmful effects on human health. Pesticide exposure is linked to various forms of cancer in children, including leukaemia, lymphoma and brain cancer (JORGENSEN & KUYKENDALL, 2008 *apud* ALTIERI, 1995; COYE, 1986; US EPA, 2007 and WORLD RESOURCES INSTITUTE, 2005).

The World Health Organization estimates that for every reported case of poisoning by pesticides, there are 50 others that do not appear in statistics. Rigotto *et al.* (2012) argues that in their empirical study, 54 % of small farmers surveyed did not seek medical care when they have acute symptoms of intoxication and 43.3 % had this account at some point in their lives. The picture gets worse with regard to chronic effects of occupational or environmental exposure to pesticides, less known and most challenging in establishing links and relationships when faced with cases of cancers, impaired reproduction, central and peripheral neurological cases, liver or haematological diseases, respiratory, kidney, among others (RIGOTTO *et al.*, 2012).

Agrochemicals are also known to indirectly affect the health of humans and the environment. Fertilizers and pesticides can enter ground and surface waters via surface run-off, soil cracks, and drains, seriously affecting the quality of drinking water and the cost of treatment. Nitrate contamination of aquifers, which results from fertilizer application, is widespread in many regions of the world, and nitrate consumption is associated with methemoglobinemia in children as well as gastric, bladder and esophageal cancers in adults (JORGENSEN & KUYKENDALL, 2008 *apud* ALTIERI 2000; OECD 2005)

When water bodies are overly enriched with nutrients (e.g., fertilizers) --a process known as eutrophication--rivers, lakes, estuaries and coastal oceans often experience losses in fish and shellfish as well as increases in toxic algae blooms (WHO & UNICEF, 2005). Furthermore, spray drift and run-off from pesticide use can result in the unintentional poisoning of organisms in areas adjacent to their area of application (ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT, 2005). The use of synthetic fertilizers is also known to contribute to nitrous oxide emissions, which is a greenhouse gas that contributes to global warming and climate change (WHO & UNICEF, 2005). By speeding the rate

at which ammonium and nitrates are broken down by microbes in the soil, fertilization intensifies the release of this highly-efficient heat trapping gas (VITOUSEK *et al.*, 1997). Moreover, the use of both pesticides and fertilizers in large-scale agricultural production indirectly contribute to carbon dioxide emissions through the use of energy-intensive tractors and other machinery for their transport and application (JORGENSEN & KUYKENDALL, 2008).

3.3

Fragility of agrochemicals regulations in Brazil

While the use of pesticides in Brazil appears to be governed by a total lack of control, there is a "Pesticides Law" (Lei dos Agrotóxicos) in the country which, if fulfilled by all links in the chain (manufacturers, traders, inspection agencies and farmers), it would considerably minimize the damage the chemicals cause (LONDRES, 2011).

The importance of legal instruments for the control of hazardous substances is indisputable. In the case of chemicals used to control pests and diseases in agriculture, the Pesticides Law, enacted in 1989 (Law No. 7.802 / 89) has special importance. Among the various issues that the law regulates, the registration of pesticides is imperative. In the registration process the results of previous studies on aspects of agronomic efficiency and potential impacts to public health and the environment are evaluated. Registration defines whether a substance or commercial product can be used and under what conditions, and it is from this process that virtually all other aspects of the control and use of pesticides are defined (GARCIA GARCIA *et al.*, 2005).

Under current law, the pesticides are registered by MAPA (Ministry of Agriculture, Livestock and Supply) that evaluates their agronomic efficacy, but following the guidelines and requirements of the Ministry of Environment (MMA) and ANVISA, who opine, respectively, on the effects on the environment and human health. Unlike with medicines for human use, which have their registration reviewed every five years, and other countries that make the periodic review of pesticides, in Brazil this is not foreseen in the Pesticides Law. The registration of pesticides, according to Brazilian law, should only be reassessed when an evidence arises on the occurrence of risks that argue against its use and where international

organizations which Brazil is an integral member had released an alert of threat to either human health, food or the environment (FRIEDRICH, 2013).

Under Article. 65 of Decree 4.074 / 2002, which regulates the Brazilian Pesticides Law, it is declared that the prescription should be specific to each crop or problem and it should contain information such as the diagnosis, application rates and total product quantities to be purchased, timing of application, withdrawal period among others. Theoretically, a trader can only send an agronomic prescription prior to visiting the farm or examine sample of infected material. However, there are endless reports that this requirement does not usually represent impediment to the unregulated trade of pesticides (LONDRES, 2011).

Brazil's performance in the international market of agricultural commodities drives the development of agribusiness. This situation supports economically and politically the increasingly use of these products. This fact overloads the regulatory framework in Brazil, partly characterized by institutional vulnerabilities of the monitoring and control agencies, hampered by the continental dimensions of the territory and the lack of human and financial resources (FRIEDRICH, 2013).

Even though environmental scientists have warned that the overuse of pesticides in modern agriculture damages wildlife, has adverse effects on human health, and may even create hyper-resistant pests that cannot be controlled using chemical ingredients, pesticide overuse results from a market failure that government regulators so far have been unable to correct (MARCOUX & URPELAINEN, 2011 *apud* ZILBERMAN *et al.*, 1991). The existing literature emphasizes that various special interests, and the agrochemical industry in particular, have strong incentives to capture the regulators and avoid efficacious policies that would reduce pesticide use to a sustainable level (MARCOUX & URPELAINEN, 2011 *apud* COWAN & GUNBY, 1996; CROPPER *et al.*, 1992; DAHLBERG, 1993; HOUGH, 1998; WILSON & TISDELL, 2001).

There are numerous examples of cases in which compensation for damage caused by pesticides would be appropriate, when crops and / or people's health are affected by the drift of pesticides from neighbouring properties; when crops and / or people's health are affected by aerial spraying where it is prohibited; when the health of workers is affected by lack of use of safety equipment; or even when the health of people is affected by the consumption of water with pesticide residues above the permitted limits. Unfortunately, the pesticide legislation in Brazil does

not determine which individuals, communities or companies affected by pesticides contamination are compensated for losses or other damages. To try to get compensation for damages (financial or health), what is left to do is trigger the Justice seeking reward (LONDRES, 2011).

To allow for reduced negative effects of pesticides on human life, Friedrich (2013) suggests that the introduction of periodic review of pesticide registration into the law must incorporate studies conducted by independent research groups and without conflicts of interest and whose results have been obtained using scientifically validated methods, not only by the prescribed international guidelines. Toxicological studies contributed at the time of registration should include more in-depth assessments of the effects on the immune and endocrine systems. In addition, current practices need to be in compliance with the legislation, demanding more effective inspections and application of penalties for those who do not conform to the statute.

3.4

Permitted levels in Brazil

The issue of establishing permitted levels of pesticide residues in water and human food supply is quite complex. On one hand we know that the establishment of "safe levels" of poison that we could eat every day is a fallacy. No laboratory study can confirm with certainty that a poison level is harmless to health. Studies made on rats suggest that certain residue levels appear to not produce side effects, until the advent of more modern techniques or new scientific evidence proven otherwise (LONDRES, 2011). For some experts, the determination of acceptable residue levels is actually the "legalization of contamination" to others, however, the establishment of these limits is an important tool to reduce the risk of poisoning by eating food and by drinking and being in contact with water.

ANVISA coordinates the actions in the area of toxicology at the National Sanitary Surveillance System, in order to regulate, manage, control and supervise the products and services that involve health risks, just like pesticides. The Food Pesticide Residues Analysis Program (PARA) is run by ANVISA and aims to continuously evaluate the pesticide residue levels in plant foods that reach the consumer's table.

Defensives leave residues wherever they are employed, sometimes unchanged in its original chemical form and often in the form of degraded products, until there is its ultimate degradation, whose duration is variable. In the environment, the most persistent chemicals can move from one culture to an animal, and from that animal to man. It is established in law the maximum amount of pesticide residues allowed for a given agricultural product, called tolerance value or maximum residue limit (FERMAM & ANTUNES, 2013 *apud* FERREIRA, 1987). The establishment and regulation of maximum residue limits in foods by government agencies from different countries and by international bodies, have become more frequent over the past decade (FERMAM & ANTUNES, 2013 *apud* JARDIM & ANDRADE, 2009).

The results of the PARA show that in 2011 only 22 % of the 1,628 samples analysed were free from contaminants. Attention is drawn to the presence of at least two pesticides that have never been registered in Brazil, azaconazole and tebufenpyrad, which suggest product smuggling and lack of control of public policies (RIGOTTO *et al.*, 2014). There is much scientific uncertainty in the definition of the limits, for instance the samples without residues only refer to the active ingredients surveyed, a total of 235 in 2010, which do not affirm the absence of the another 400 substances, including glyphosate, widely used pesticide and not researched by the PARA program (CARNEIRO *et al.*, 2012). Friedrich (2013) states that the safe use of pesticides is a misleading statement, considering scientific findings that demonstrate the appearance of effects incompatible with minimum conditions for welfare and the maintenance of life.

Ordinance 518 of the Ministry of Health, published in March 2004, provides in Art. 14 a list of chemicals that pose health risks. It states for these substances maximum residue limits that may be presented in drinking water. The law requires the monitoring of the presence of these contaminants in drinking water but it is known that no municipality or water company makes regular analyses of such substances and if they do, the results are not being released to public (LONDRES, 2011). The issue of pesticides in water for human consumption in Brazil is a little researched topic and with only a small number of official sources of information accessible for consultation (CARNEIRO *et al.*, 2012).

Data from the Ministry of Health was analysed by Neto (2010) and reported that from the total water supply systems registered in SISAGUA in 2008, 0.5 %

have claimed to have some information on the monitoring of water quality for pesticides. It should also be noted that the figures refer to the average of 16 Federation Units, since 11 states did not carry out such analyses and or not feed this system information with data in that year (CARNEIRO *et al.*, 2012 *apud* NETO, 2010 p. 21).

In the environment side, the maximum concentrations of the pesticides and fertilizers active ingredients that can be present in water bodies is regulated by Conama Resolution 357 (BRASIL, 2005). The Resolution provides the classification of water bodies according to its main uses and environmental guidelines for its framework and establishes the conditions and effluent discharge standards. Though, the resolution establishes maximum concentrations to only a fraction of the agrochemicals allowed the use. The National Water Agency, ANA maintains a Federal database on water resources, which mainly combines the results of water quality monitoring of state environmental agencies; these data are available through webportals (Hidroweb, SNIRH) and a desktop application (HUNKE *et al.*, 2015). However, to this date, data on active ingredients in the water bodies is presented in virtually none ANA monitoring stations.

4

Water pollution

4.1

Freshwater consumption

Freshwater is the most important resource for mankind, cross-cutting all social, economic and environmental activities. It is a condition for all life on our planet, an enabling or limiting factor for any social and technological development, a possible source of welfare or misery, cooperation or conflict (UNESCO). Water is at the core of sustainable development. Water resources, and the range of services they provide, underpin poverty reduction, economic growth and environmental sustainability. From food and energy security to human and environmental health, water contributes to improvements in social well-being and inclusive growth, affecting the livelihoods of billions (UNITED NATIONS WORLD WATER ASSESSMENT PROGRAMME - WWAP, 2015).

According to the Millennium Development Goals Report 2012, 783 million people, or 11 per cent of the global population, remain without access to an improved source of drinking water (UNITED NATIONS, 2012). Additionally, 2.4 billion people (one in three) still lack improved sanitation facilities (UNICEF & WHO, 2015).

Over the past several decades, ever-growing demands for – and misuse of – water resources have increased the risks of pollution and severe water stress in many parts of the world. The frequency and intensity of local water crises have been increasing, with serious implications for public health, environmental sustainability, food and energy security, and economic development. The fact is that there is enough water available to meet the world's growing needs, but not without dramatically changing the way water is used, managed and shared. The global water crisis is one of governance, much more than of resource availability,

and this is where the bulk of the action is required in order to achieve a water secure world (CONNOR *et al.*, 2015).

Demand for water is expected to increase in all sectors of production (WWAP, 2012). By 2030, the world is projected to face a 40 % global water deficit under the business-as-usual scenario (2030 WRG, 2009).

In Brazil the distribution of surface water resources is quite heterogeneous, while the basins along the Atlantic Ocean, which concentrate 45.5 % of the total population, boasts only 2.7 % of the water resources of the country available, in the North where only 5 % of the population live, these resources are abundant, about 81 %. The total consumptive demand estimated for Brazil in 2010 was 2,373 m³/s. The irrigation sector is responsible for most of withdrawal (54 % of the total), followed by the withdrawal flows to urban human supply purposes, industrial, animal and rural (ANA, 2014).

In Figure 7 the withdrawal flow by watershed in Brazil can be seen. The regions with highest withdrawal are marked. The case study region (west of Bahia state, highlighted in number 6) is a region of high demand for irrigation purposes.

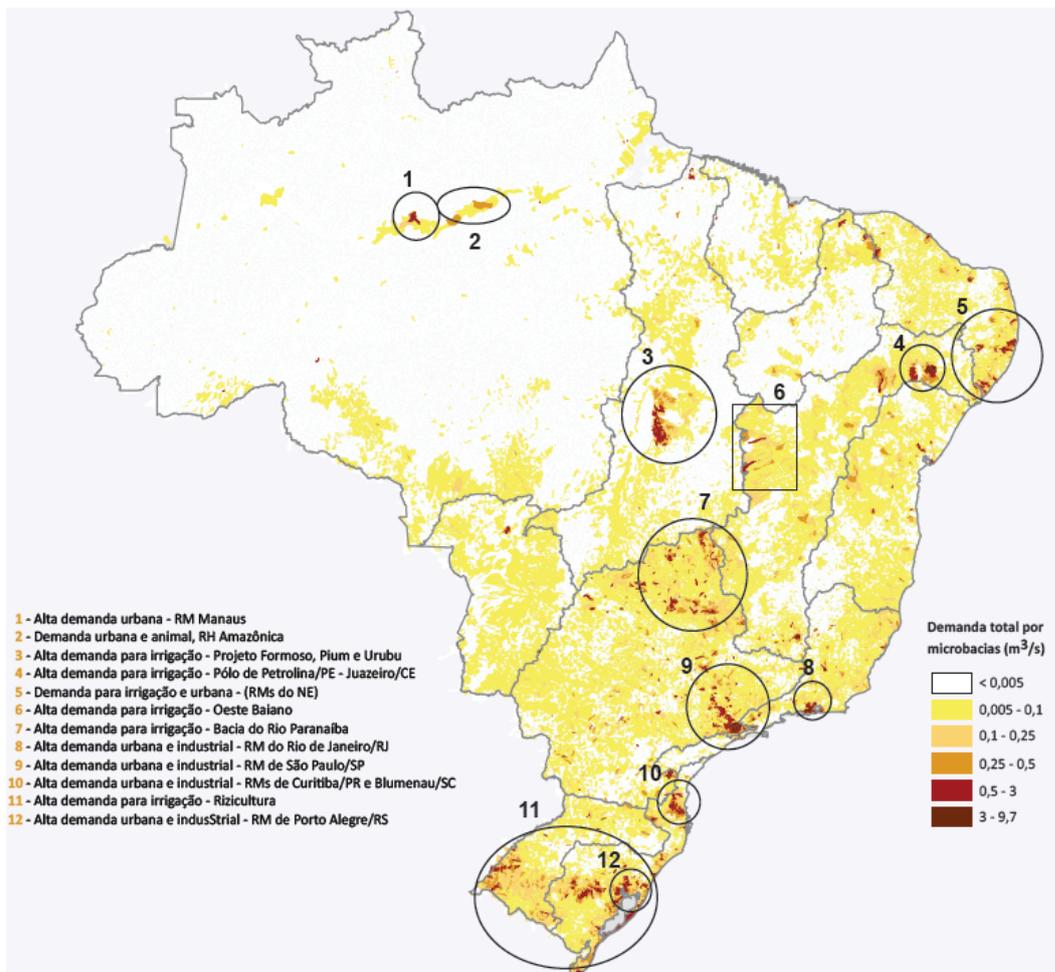


Figure 7 - Total withdrawal flow by watershed in Brazil

Source: ANA (2014)

The water balance, which here is the balance between the supply of water and the quantitative and qualitative demands is of fundamental importance for the diagnosis of the Brazilian basins. Based on current information of water supply, consumptive demands and quality of water, a diagnosis of major rivers and Brazilian basins can be made, defining critical areas. Examination of the criticality of maps reveals that much of the country has course stretches of water with low criticality (Figure 8). On the other hand, it shows that important watersheds present elevated criticality (granted demand exceeding 70 % of water availability). The water balance between water supply and demand in the region is considered to be in the “comfortable level”, meaning that the granted demand is above water availability in the 5-10 % range (ANA, 2015).

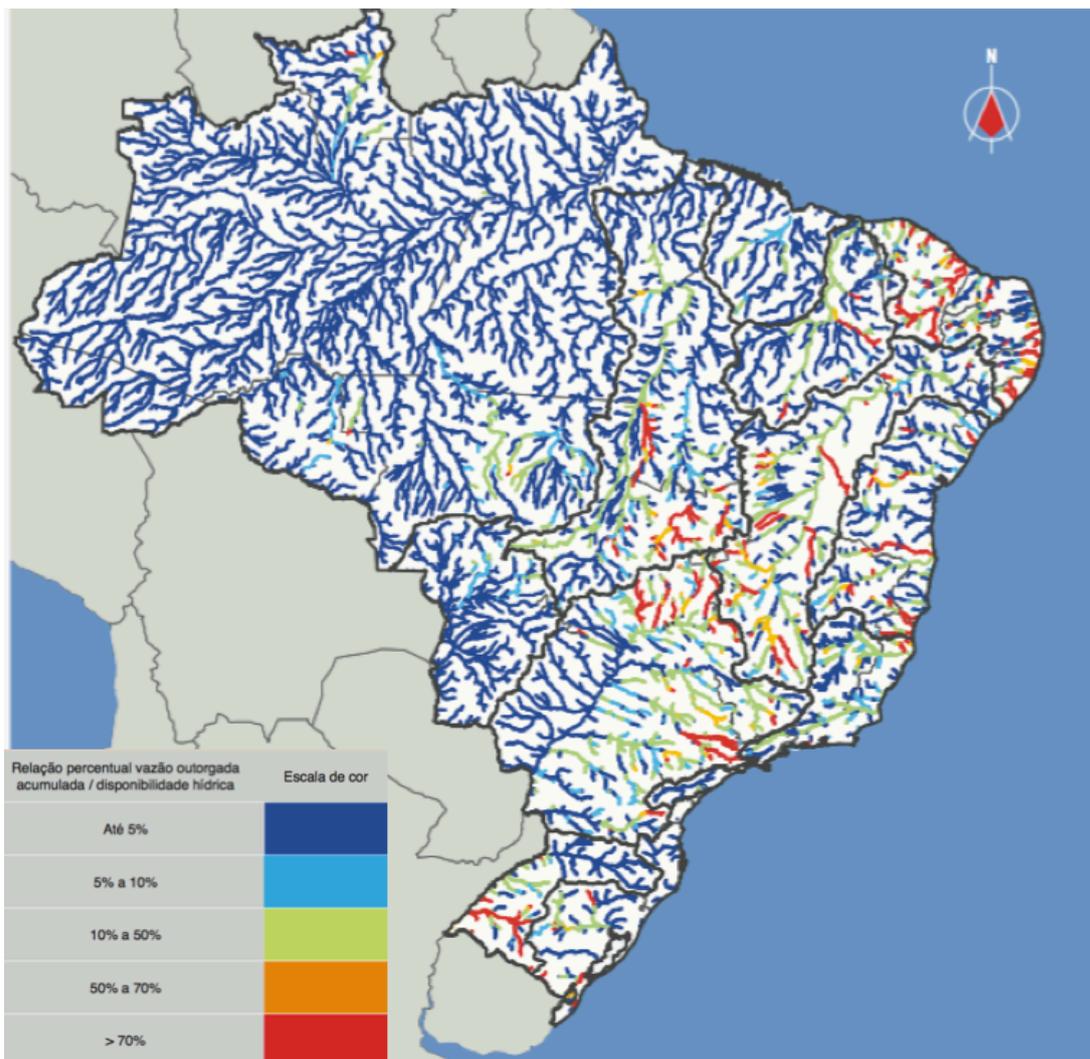


Figure 8 - Water balance in watercourse stretches in Brazil.

Source: ANA (2015)

4.2

Water quality connection to water quantity

Sufficient water supply of appropriate quality is a key ingredient in the health and well-being of humans and ecosystems, and for social and economic development. Water quality is becoming a global concern of increasing significance, as risks of degradation translate directly into social economic impacts. Water quality is just as important as water quantity for satisfying basic human and environmental needs. Moreover, the two are inextricably linked, with poor water quality impacting water quantity in a number of ways. For example, polluted water

that cannot be used for drinking, bathing, industry or agriculture may effectively reduce the amount of water available for use in a given area (WWAP, 2012).

The distribution and availability of freshwater resources, through precipitation and runoff, can be erratic, with different areas of the globe receiving different quantities of water over any given year. Water availability is also affected by pollution. Most problems related to water quality are caused by intensive agriculture, industrial production, mining and untreated urban runoff and wastewater. Expansion of industrial agriculture has led to increases in fertilizer and pesticides applications. These and other industrial water pollutants create environmental and health risks. Excessive loads of nitrogen and phosphate, the most common chemical contaminants in the world's freshwater resources (WWAP, 2009), contribute to the eutrophication of freshwater and coastal marine ecosystems, creating 'dead zones' and erosion of natural habitats (UNITED NATIONS). The water pollution problem worsens in areas affected by water scarcity, where there is great pressure on water use and pollutants are less diluted due to the reduced stream flows (LIU *et al.*, 2012).

4.3

Diffuse water pollution

'Diffuse pollution' is a useful catch-all term for all sources of pollution that enter waters other than from identifiable entry points. Hence, it encompasses contaminants that enter waters through surface water run-off or by percolation through soil, or wherever the point of entry cannot be precisely located. Diffuse pollution can arise from run-off from a wide range of land uses. This kind of contamination may be less damaging than point source emissions in terms of the concentration of harmful substances involved but, cumulatively, the problem of diffuse pollution is massive. In the past, impacts from unacceptable point source emissions may have masked the extent of the problem of diffuse pollution (HOWARTH, 2011).

Agricultural activities are generally regarded as giving rise to the most harmful kinds of diffuse polluting activities, particularly where these involve the application of pesticides, fertiliser or animal manure to agricultural land. The high profile of agriculture as a contributor to diffuse pollution is highlighted by the

economic costs to which this gives rise. Between 2004 and 2009 water companies in England spent some £189 million removing nitrate, £92 million removing pesticides and an unquantifiable amount removing bacterial contamination, largely attributable to agriculture, from raw water to enable it to meet water supply quality requirements. These figures do not attempt to quantify the ecological damage done to natural waters by the presence of these contaminants; hence, the overall environmental cost of agricultural diffuse pollution must be substantial by any reckoning (HOWARTH, 2011).

In Europe, the EU Water Framework Directive (2000/60/EC) has made the abatement of diffuse water pollution from agriculture (DWPA) a priority.

4.4

Water quality monitoring in Brazil

To improve information on water quality in the country, ANA created the National Assessment Program for Water Quality (PNQA) to be implemented in partnership with state management bodies of water resources and environment. The main component of PNQA is the National Network Quality Monitoring for Surface Water (RNQA) which was created and had the guidelines set by the Resolution No. 903 of July 22, 2013. The main objectives of the RNQA are: to allow the analysis of quality development trends of surface water in the country; assess whether the current quality meets established uses for framework of water bodies (CONAMA 357/2005); identify critical areas with regard to water pollution; to assess the effectiveness of management of the recovery actions of water quality and supporting of action plans, grants and supervision (ANA, 2015)

The RNQA has a goal that by December 2020 all states and the Federal District will contain a total of 4,452 monitoring point (ALVES, 2014). In total there are 1,340 outlets across the country, in which analysis are made of four basic parameters (pH, dissolved oxygen, conductivity and temperature). However, only those parameters do not allow proper assessing the development of the quality of Brazilian waters, requiring other parameters that need sample collection and laboratory analysis. Despite the commitment of each federal unit, who keep their monitoring networks, there are still large gaps in monitoring the quality of Brazilian

surface water. This is one of the challenges to be overcome with the implementation of the RNQA.

Law No. 9433, the National Water Resources Policy, establishes as one of its objectives to ensure current and future generations the necessary availability of water with quality standards appropriate to their uses (BRASIL, 1997). This law also establishes the framework, as one of its instruments. In the analysis of the water quality monitoring results, the data should be compared to the limits established by the framework for that category of water body at the site of sample collection. The framework of water bodies is to establish the level of quality to be achieved or maintained in one segment of water over time. More than a simple classification, the framework must be seen as a planning tool, it must be based not on the current condition of the water body, but the quality levels that it should have or be kept in the body of water to meet the requirements set by society. The framework seeks to ensure the water quality is compatible with the most demanding uses for which they are intended and to reduce the costs of combating water pollution by permanent preventive measures (PROGRAMA NACIONAL DE AVALIAÇÃO DA QUALIDADE DAS ÁGUAS, 2014).

The framework is a benchmark for other water resources management instruments (grants, charging) and environmental management tools (licensing, monitoring), and is therefore an important link between the National Water Resource Management and the National System Environment (ANA, 2015). However, in reality there are few water bodies in the country with a framework set, this makes monitoring water quality not an effective task. The evaluation of quality of surface water in a country of continental dimensions like Brazil is hampered by the absence of state monitoring networks in some units of the Federation and the heterogeneity of existing monitoring networks in the country with different number of analysed parameters, frequency of collection and standards of lab testing (PNQA, 2014).

4.5

Brazilian water quality indexes

The use of water quality indexes arises from the need to synthesize information on various parameters, aiming to inform the public and guide the

actions of planning and management of water quality. ANA provides an annual report of the situation of water resources in Brazil since 2009. The document aims to monitor the situation of water resources from the point of view of quantity and water quality, and to evaluate the evolution of the institutional framework for managing these resources. The section on water quality, provides data on each river basin district. The report on the situation of Brazilian water resources in 2014 showed water quality data for three parameters in the monitoring stations where they were available: IQA (water quality index), biochemical oxygen demand (BOD) and phosphorus (ANA, 2015).

Some of the main water quality indicators that are used in at least one Brazilian UF to determine the water quality for its different uses, are presented.

Water Quality Index (IQA) - The IQA is the water quality index most widely used in the country. The IQA is calculated from the dissolved oxygen, faecal coliform, pH, biochemical oxygen demand, temperature, total nitrogen, total phosphorus, turbidity and solids. The assessment of water quality obtained by the IQA has limitations, since this index does not address several important parameters for public supply, such as toxic substances (e.g. heavy metals, pesticides, organic compounds), parasitic protozoa and substances that interfere with the properties organoleptic water (PNQA, 2014). However, the evaluation of this indicator can be useful for managing water quality if used along with other indexes considered important for the targeted water use.

Trophic State Index (IET) - The Trophic State Index aims to classify water bodies in varying degrees of hypertrophy. It evaluates the quality of water related to nutrient enrichment and its effects related to excessive algae growth or increased infestation of aquatic weeds. The index results are calculated from the values of phosphorus (PNQA, 2014).

Bathing index (IB) - The bathing index evaluates the quality of water bodies for primary contact recreation, being used both in coastal beaches and inland. In places where it is carried out monthly monitoring the index is calculated from the densities of *E. coli*. (CETESB, 2014).

Raw Water Quality Index for Purposes of Public Supply (IAP) - The index is composed of three groups of parameters: IAQ, parameters that evaluate the presence of toxic substances (mutagenicity test, trihalomethane formation potential,

cadmium, lead, total chromium, mercury and nickel); and parameters that affect the organoleptic quality of the water (phenols, iron, manganese, aluminum, copper and zinc; CETESB, 2014).

Index of Marine Life Protection (IVA) - The IVA first started being used by CETESB and has as objective the evaluation of water quality in order to protect the aquatic fauna and flora. The index is composed of two sub-indices: IET - Trophic State Index Carlson modified by Toledo and IPMCA (Minimum Parameters Index for the Preservation of Aquatic Life). The IVA assesses the concentration of substances that cause toxic effects on the aquatic environment, in addition to pH and dissolved oxygen. The parameter limits are those set by CONAMA Resolution No. 357 for the framework classes that are intended to preserve aquatic life (PNQA, 2014).

Each federal unit has its own state environmental agency, thereby the management actions vary across the country. The National water quality programme recognizes different water quality indexes, even though the majority of them are not used. For instance, the most comprehensive indexes presented in the country so far, the IVA and the IAP, are currently only used by CETESB, the water managing company in the state of São Paulo. One of the reasons these indexes are not used more broadly is due to lack of data on the necessary parameters throughout the country.

Another consideration about the use of these water quality indexes is that even though there is a wide range of measurements and pollutants considered for the analyses, they are not suitable for making comparisons of the pollution impacts across different geographical areas (PELLICER-MARTÍNEZ & MARTÍNEZ-PAZ, 2016 *apud* Jiao *et al.*, 2013).

4.6

Water footprint concept

The water footprint (WF) concept was created in 2002 by Arjen Hoekstra and its application as a freshwater appropriation indicator has been growing across the planet. According to Hoekstra (2013), the interest in the water footprint is rooted in the recognition that human impacts on freshwater systems can ultimately be linked to human consumption, and that issues like water shortages and pollution can be

better understood and addressed by considering production and supply chains as a whole.

The WF is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use. The WF can be regarded as a comprehensive indicator of freshwater resources appropriation, next to the traditional and restricted measure of water withdrawal. The WF of a product is the volume of freshwater used to produce the product, measured over the full supply chain. It is a multidimensional indicator, showing water consumption volumes by source and polluted volumes by type of pollution; all components of a total water footprint are specified geographically and temporally. The WF can be distinguished into three colours: the green, blue and grey WF. The green WF refers to the consumption of rainwater, the blue WF refers to consumption of surface and ground water and the grey water footprint (GWF) is an indicator of water pollution. The GWF is defined as the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentration and existing ambient water quality standards (HOEKSTRA *et al.*, 2011).

The WF helps us understand for what purposes our limited freshwater resources are being consumed or polluted. The impact it has depends on where the water is taken from and when. If it comes from a place where water is already scarce, the consequences can be significant and require action.

4.7

GWF and sustainability of water pollution

Measurement and monitoring of the pollution in continental waters is one of the main challenges in water resources management as pollution is the principal cause of degradation of aquatic ecosystems, leading to the subsequent reduction of ecosystem services. The grey water footprint (GWF), allows examination and contrast of the impacts of different pollutants located in different geographical areas, although it can also be used to compare the contamination impact with other types of impacts, such as the water extraction in aquifers (PELLICER-MARTÍNEZ & MARTÍNEZ-PAZ, 2016)

The GWF converts the impact of pollution on water resources into a homogeneous unit: fresh water volume. Thus, the environmental impacts produced

by different pollutant discharges in water bodies with distinct natural conditions and under different quality standards can be compared. In contrast, the maximum pollutant concentrations allowed and the current levels of contamination are different in each country and they cannot be compared.

Additionally, the sustainability of the pollution can be studied by calculating the WPL, which is the GWF applied to the local river basin runoff. The analysis consists of the determination of whether the water body is able to assimilate the pollution load received while maintaining the required quality standards. For this purpose, the GWF in a water body is related to the flow passing through it. If the flow is higher than the GWF, the water body can bear the pollution load that it receives (HOEKSTRA *et al.*, 2011).

The GWF has become a sustainability indicator in wastewater management. For this purpose, the GWF must be calculated in the territorial unit of the relevant water resources management authority, which is usually the river basin so as to assess the pollution management of a given territorial unit (PELLICER-MARTÍNEZ & MARTÍNEZ-PAZ, 2016 *apud* EC, 2000; FULTON *et al.*, 2014).

Mekonnen & Hoekstra (2015) state that an advantage of expressing water pollution in terms of the water volume required for assimilating the pollutants, rather than in terms of concentrations of contaminants, is that it brings water pollution into the same unit as consumptive use, in this way, the use of water as a drain and the use of water as a resource, two competing uses, become comparable.

5

Methodology

5.1

GWF accounting

Founded on a decade of research and application, the Global Water Footprint Assessment Standard lays out the internationally accepted methodology for conducting a Water Footprint Assessment. The standard includes detailed instruction and guidance on the following: (a) How to calculate the green, blue and grey water footprint to understand the geographic and temporal allocation of water resources for industry, agriculture and domestic water supply; (b) How to conduct a water footprint sustainability assessment which includes criteria for understanding the environmental sustainability, resource efficiency and social equity of water use, for both consumption and pollution; (c) How to use the results of the water footprint accounting and sustainability assessment to identify and prioritise the most strategic actions to be taken in local, regional, national and global scales, individually and collectively.

Fertilizer and pesticide use is widespread in the soybeans cultivation in Brazil. Zarate (2010) expresses that diffuse sources of pollution, like from agrochemicals applications in agriculture are notoriously difficult to quantify, as the substances applied on the field go through different degradation and transport processes through the soil until finally reaching the water bodies. To each extent each of the processes will affect the overall loss of a substance depends on the physicochemical properties of a substance, the soil characteristics, climatic conditions, terrain slope and land management practices. Loss of pollutants to water bodies can happen through leaching, runoff or return flow (DABROWSKI *et al.*, 2009).

The grey water footprint of a product is an indicator of freshwater pollution that can be associated with the production of a product over its supply chain. It is

defined as the volume of freshwater that is required to assimilate the load of pollutants based on natural background concentrations and existing ambient water quality standards. It is calculated as the volume of water that is required to dilute pollutants to such an extent that the quality of the water remains above agreed water quality standards (HOEKSTRA, 2011).

In this study the grey water footprint of the process of the cultivation of soybeans is evaluated. The pollutants inputs that are assessed are pesticides and fertilizers. The Water Footprint Assessment Manual recommends a three-tier approach for estimating diffuse pollution entering a water body. According to Franke *et al.*, (2013), from tier 1 to 3, the accuracy of estimating the load reaching a water body increases, but the feasibility of carrying out the analysis decreases because of increasing data demands.

Tier 1 simply uses a leaching-runoff fraction to translate data on the amount of a chemical substance applied to the soil to an estimate of the amount of the substance entering the groundwater or surface water system. The fraction is to be derived from existing literature and will depend on the chemical considered. This tier-1 estimate is sufficient for a first rough estimate, but obviously does not describe the different pathways of a chemical substance from the soil surface to surface or groundwater and the interaction and transformation of different chemical substances in the soil or along its flow path.

Tier 2 applies standardized and simplified model approaches and can be used based on relatively easily obtainable data (such as the chemical properties of the chemical substance considered and the topographic, climatic, hydrologic and soil characteristics of the environment in which the chemical substance is applied). These simple and standardized model approaches should be derived from more advanced and validated models.

Tier 3 uses sophisticated modelling techniques and/or intensive measurement approaches. Since this approach is very laborious, available resources should allow for it and the purpose of application should warrant it. Whereas detailed physically-based models of contaminant flows through soils are available, their complexity often renders them inappropriate even for use at tier-3 level. However, validated empirical models driven by information on farm practices and data on soil and weather characteristics are presently available for use in diffuse-load studies at this level (FRANKE *et al.*, 2013).

In the scope of this study, “The Grey Water Footprint accounting: Tier 1 supporting guidelines” was used to estimate the GWF. The decision is due to resource constraints and limited time and data.

According to the Water Footprint Assessment Manual, the GWF is calculated by dividing the pollutant load entering a water body (L , in mass/time) by the critical load (L_{crit} , in mass/time) times the runoff of the water body (R , in volume/time; see Equation 1).

$$\mathbf{GWF} = \frac{L}{L_{crit}} \times R \text{ [volume/time]} \quad \mathbf{Equation 1}$$

The critical load is the load of pollutants that will fully consume the assimilation capacity of the receiving water body. It can be calculated (see Equation 2) by multiplying the runoff of the water body (R , in volume/time) by the difference between the ambient water quality standard of the pollutant (the maximum acceptable concentration, c_{max} , in (mass/volume) and its natural background concentration in the receiving water body (c_{nat} , in mass/volume). The calculations are carried out using ambient water quality standards for the receiving freshwater body because the GWF aims to show the required ambient water volume to assimilate chemical substances.

$$\mathbf{L_{crit}} = \mathbf{R} \times (\mathbf{c_{max}} - \mathbf{c_{nat}}) \text{ [mass/time]} \quad \mathbf{Equation 2}$$

By inserting Equation 2 in 1, we obtain:

$$\mathbf{GWF} = \frac{L}{c_{max} - c_{nat}} \text{ [volume/time]} \quad \mathbf{Equation 3}$$

When assessing the GWF of an activity or process, the GWF for each contaminant of concern has to be calculated separately. The overall GWF is equal to the largest GWF found when comparing the contaminant-specific GWFs (FRANKE *et al.*, 2013).

In the case of diffuse sources of water pollution, estimating the chemical load is not as straightforward as in the case of point sources. When a chemical substance is applied on or put into the soil, as in the case of solid waste disposal or use of fertilizers or pesticides, it may happen that only a fraction seeps into the

groundwater or runs off over the surface to a surface water stream (FRANKE *et al.*, 2013).

On these terms, the load can be calculated by assuming that a certain fraction of the applied chemical reaches the ground or surface water (Equation 4). The dimensionless factor alpha (α) stands for the leaching-runoff fraction, defined as the fraction of applied chemical substances reaching freshwater bodies. The variable *Appl* represents the application of chemical substances on or into the soil (in mass/time).

$$L = \alpha \times Appl \quad [\text{mass/time}] \qquad \text{Equation 4}$$

Leaching and runoff are two different processes, which are influenced in different ways by the same or different factors. The value of α is the resultant of many factors and not an inherent property of the chemical substance, the soil or the way the chemical substance is applied to the field. When estimating the diffuse load of a chemical substance to surface or groundwater at tier 2 or 3, the value of α would be the output of a study of different chemical processes and pathways. At tier 1 level, the value of α is estimated based on (mostly qualitative) information about environmental factors and agricultural practice. Estimating the flows of chemical substances to groundwater and surface water separately is impossible at this level. Therefore, the approach is to estimate the overall leaching-runoff fraction, without making explicit which part refers to the leaching to groundwater and which part to the direct runoff to surface water. More advanced methods should be used if a differentiation is to be made (FRANKE *et al.*, 2013).

The estimation of leaching-runoff fractions is divided by chemical type as the list of influencing factors differs per chemical substance group: nutrients, metals, and pesticides. According to Tier 1 Guidelines, the state of a factor determines whether the leaching-runoff potential for a chemical substance will be relatively low or high.

The influence factors include physical-chemical properties of a contaminant, environmental factors such as soil texture and agricultural management practices, each of these parameters will influence the leaching-runoff of a chemical substance to a greater or lesser extent. Therefore, per listed influence factor (i) a certain weight (w) is given for each factor, denoting the importance of the factor. The weights

given to the separate influencing factors add up to a total of 100. Additionally, each influence factor (i) is associated and a certain score (s) between 0 a 1 is given according to the leaching-runoff potential. The scores ranges are as follow: very low (0), low (0.33), high (0.67) and very high (1).

The GWF tier-1 guidelines establishes which are the influencing factors per substance and the corresponding weights. A table containing the leaching-runoff fractions influencing factors, its weighs and the scores have been constructed per type of substance studied by the expert panel working on the tier-1. See Table 1 for an example of the factors influencing the leaching-runoff fraction of pesticides. The analysis of each influencing factor per chemical substance is done in detail in Chapter 6. Once each score has been determined for each substance, the leaching-runoff fraction α can be calculated using Equation 5. The values of the minimum and maximum leaching-runoff fractions are shown in Table 2.

Table 1 - Factors influencing the leaching-runoff potential of pesticides.

Category	Factor	Pesticides					
		Leaching-runoff potential	Very low	Low	High	Very high	
		Score (s)	0	0.33	0.67	1	
		Weight (w)					
Chemical properties	K_{oc} (L/kg) (see Appendix I, contaminant factors)	20	>1000	1000 - 200	200 - 50	<50	
	Persistence (half-life in days) (relevant for leaching) (see Appendix I, contaminant factors)	15	<10	10 - 30	30 - 100	>100	
	Persistence (half-life in days) (relevant for runoff) (see Appendix I, contaminant factors)	10	<10	10 - 30	30 - 100	>100	
Environmental factors	Soil	Texture (relevant for leaching) (see Appendix II Map 2)	15	Clay	Silt	Loam	Sand
		Texture (relevant for runoff) (see Appendix II Map 2)	10	Sand	Loam	Silt	Clay
		Organic matter content (kg/m^2) (see Appendix II Map 8)	10	>80	41 - 80	21 - 40	<20
	Climate	Rain intensity (relevant for runoff)	5	Light	Moderate	Strong	Heavy
		Precipitation (mm) (relevant for leaching) (see Appendix II Map 5)	5	0-600	600-1200	1200-1800	> 1800
Agricultural practice	Management practice (relevant for runoff)	10	Best	Good	Average	Worst	

Source: (FRANKE *et al.*, 2013).

$$\alpha = \alpha_{\min} + \left[\frac{\sum_i S_i \times W_i}{\sum_i W_i} \right] \times (\alpha_{\max} - \alpha_{\min}) \quad \text{Equation 5}$$

Table 2 - Minimum and maximum leaching-runoff fractions for the studied substances: phosphorus and pesticides.

Leaching-Runoff Fraction (α)	Phosphorus	Pesticides
α Minimum	0.0001	0.0001
α Maximum	0.05	0.1

Source: (FRANKE *et al.*, 2013).

The used guidelines suggest default global average leaching-runoff fractions that can be used if no local information is available. With some local information, one can make more site- specific estimates of leaching-runoff fractions. There are three categories of influencing factors, which should be considered to estimate the leaching-runoff fraction at tier 1 level: (a) physical-chemical properties of the chemical substance applied (like the soil-water partition coefficient K_d or the soil organic carbon-water partition coefficient K_{oc} , and the persistency of the substance); (b) environmental conditions (like soil properties and climatic conditions); and (c) management practices (like the application rate of the chemical substance, the harvest, the presence of artificial drainage). In each category, there are different specific factors that influence the leaching-runoff fraction. The list of influencing factors is slightly different per chemical substance group: nutrients, metals, and pesticides, whereby nutrients are further distinguished into nitrogen and phosphorus.

5.2

Water pollution level accounting

The water pollution level (WPL), which measures the degree of pollution within a catchment, is estimated as the ratio of the total of GWF in a catchment to the actual runoff from that catchment (R_{act} , $m^3/year$).

$$WPL = \frac{GWF}{R_{act}} \quad \text{Equation 6}$$

A WPL of 1 means that the pollution assimilation capacity has been fully consumed. A WPL larger than 1 indicates serious pollution in the water body. WPL values lower than 1 indicate that there is an average enough river water to dilute the pollutant to below the maximum acceptable level at the basin scale. However, it does not guarantee that there are no local or periodic pollution problems within the basin (LIU *et al.*, 2012).

5.3

Case study data

The analysed farm is located in the municipality of Correntina-BA, (13°43'S, 45°48'W, 560 m a.s.l.), in the Brazilian Cerrado (Figure 9).

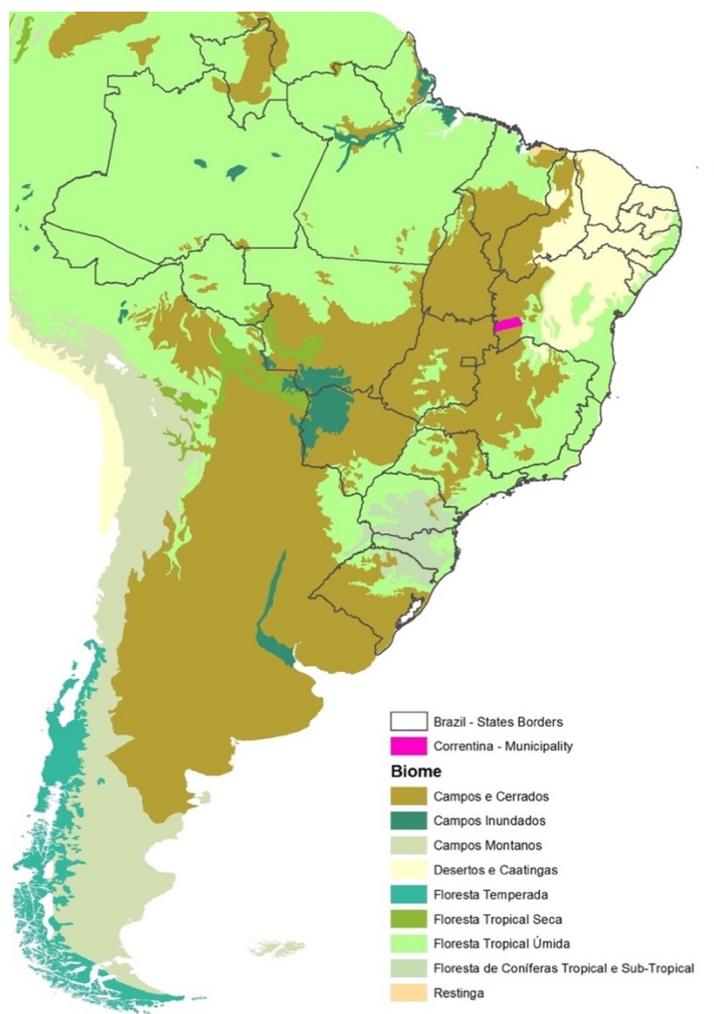


Figure 9 - Location of the municipality of Correntina in the Brazilian Biome Map

Source: ESRI; IBGE (2015). Elaboration of the author.

The studied farm has a total productive area of 6,931 hectares (2013-2014) and the main cultivation crops are soybeans occupying an average of 41 % of the total farm area. Cotton and maize crops are also present with substantial strength as well as cattle breeding. The present research is focused on soybeans cultivation. Soybean crops at the site are mainly from GM seeds.

The farm is located in two river basins, the ones that form under River Arrojado and River Correntina. Both the rivers are tributaries of the River Corrente, left tributary of the São Francisco River (Figure 10).

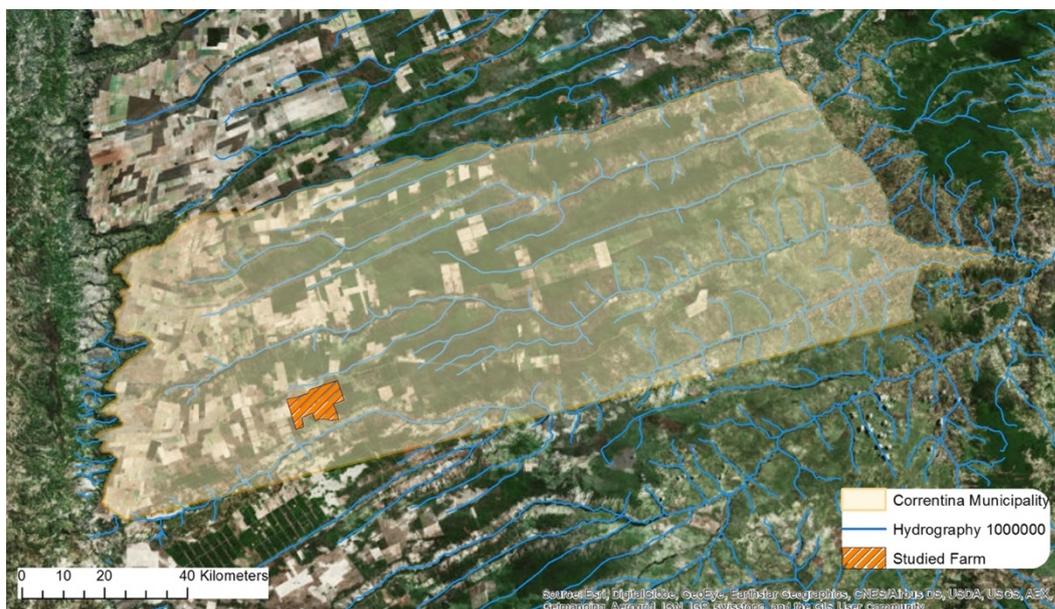


Figure 10 - Location of studied farm in Correntina municipality.

Source: ANA (2016); ESRI; IBGE (2013). Elaboration of the author.

This case study analyses mainly data released by the farm's management department. The information includes: farm maps, fertilizer and pesticide application files, soil analysis results and soybean yield files. Data from 5 cropping years were analysed: 2008/2009, 2009/2010, 2010/2011, 2011/2012 and 2013/2014. Data from year 2012/2013 was reported missing due to a technical failure in the farm's management department. Crop years start in September due to the rain pattern in the region.

6

Results and discussions

6.1

Priority substances

Soybeans fertilization in the studied farm is based on phosphorus and potassium. Fertilizers containing limestone and agricultural plaster are also added in some years depending on soil analysis. As the soybean plant supply most of its own nitrogen needs by fixation of atmospheric N₂ into ammonium, complementary nitrogen application is not usual in these crops in the Brazilian Cerrado. According to the tier-1 Guidelines for calculating the GWF (FRANKE *et al.*, 2013) the nutrients of concern are considered to be phosphorus and nitrogen. Thus only the fertilizers containing phosphorus will be evaluated for the case study.

As for the pesticides, in order to get to the priority substances, the commercial pesticides were first grouped into the active ingredients. The total application of active ingredients was summed for the 5 crop years in the analysed period and the pesticides that were responsible to up to 75 % of the total application were encountered (Table 3). The table also shows the total application of active ingredient for the studied period, the percentage of the total application that each substance was responsible, the accumulated application until 75 % of total application and whether any source of information on maximum concentration for the exposition of the substance was available in literature.

Table 3 - Main active ingredients pesticides applied in the case study farm in order of highest application

Substance	Active Ingredient Application (L or kg)	Percentage of total application	Percentage of accumulated application	Is there a Maximum Concentration Source Available?
Glyphosate	46,894	44 %	44 %	Yes
2,4 D	14,104	13 %	57 %	Yes
Acephate	5,917	6 %	63 %	Yes
Thiophanate-methyl	5,830	5 %	68 %	No
Methomyl	3,500	4 %	72 %	Yes
Carbendazim	2,712	2 %	74 %	No
Methoxyfenozide	1,227	1 %	75 %	Yes

Grey water footprint calculations are carried out using ambient water quality standards (maximum allowable concentrations) for the receiving freshwater body. Although ambient water quality standards exist in the CONAMA legislation they do not exist for all chemical substances and all places. Hoekstra *et al.*, (2011) states that if no local information can be obtained, the maximum allowable concentrations as based on the assessment of long term/chronic environmental effects should be used.

Local and worldwide sources were researched and no values of maximum allowable concentrations were found for the substances Carbendazim and Thiophanate-methyl. In this case the GWF cannot be calculated, therefore it was decided to leave these substances out of the study and to focus on the remaining active ingredients. The studied chemicals were still responsible to the majority of the pesticides applications, accounting 67 % of the total. In the GWF calculation, a total of 6 substances from fertilizers and pesticides were considered (see Table 4).

Table 4 - List of priority substances in the case study

Substance name	Type	Commercial products containing the substance
Phosphorus	Fertilizer	SuperSimples , MAP, NPK
Glyphosate	Herbicide	Roundap WG, Roundap Ultra, Roundup Transorb, Glifosato Atanor
2,4 D	Herbicide	Aminol
Acephate	Insecticide	Cefanol
Methomyl	Insecticide	Bazuka, Lanate
Methoxyfenozide	Insecticide	Intrepid

6.2

Influencing factors in the leaching-runoff fractions

The most influencing factors to the leaching-runoff fraction include matters related to soil, climate, agriculture practices and chemical properties. The factors vary between the different types of substance. For each influencing factor (i) a score (s) is given, with values from 0 (very low) to 1 (very high), as explained in the methodology section and a weight (w) is associated. The different ranges of score and its weights depending on the substance have been established by the expert panel that created the tier-1 guidelines to calculate the leaching-runoff fraction.

Understanding the influencing factors that determine the leaching and runoff of a chemical substance will help to obtain a better estimate of the leaching-runoff fraction. In the next section, each influencing factor will be examined in detail per type of chemical substance, and the score (s) will be given according to the analysis made. The alpha is a rough estimate that can be made of the leaching-runoff fraction based on (mostly qualitative) information about the local status of different environmental factors and agricultural practice.

6.2.1

Soil

The soils of the Cerrado are highly acidic, saturated with aluminium, deficient in phosphorous and have low water-holding capacity. Early on, many felt that the land in the Cerrado could not be cultivated. Contrary to popular belief, the soils in

the Cerrado proved to be deep and well drained with excellent physical characteristics suitable for mechanized crop production. About 234 million acres or 46 percent of the Cerrado's are suitable for large-scale crop production (MCVEY *et al.*, 2000).

Laboratory soil analysis were available locally for years 2008 and 2012. The tests were done across each of the farm's soybean fields. The average phosphorus content was calculated across the different samples (see Table 5).

Table 5 - Average phosphorus content

Year	Phosphorus (g/m ³)
2008	17.07
2012	21.85

Source: CAMPO - Centro de Análises Agrícolas (2008); Agrolab - Laboratorio Agropecuario (2012)

In all cases the phosphorus content was under the 200g/m³ range. According to the tier-1 approach, the outcome characterizes the phosphorus content in the local soil as “very low”. Furthermore, the soil texture was reviewed. and in all samples the percentage of sand was above 70 % (See Table 6).

Table 6 - Soil Texture Analysis

Soil Texture Type	Sample 1	Sample 2	Sample 3
Clay (%)	24.3	22.8	22.6
Silt (%)	3.8	3.4	3.4
Sand (%)	71.9	73.8	74

Source: Agrolab - Laboratorio Agropecuario (2012)

For the purpose of determining the leaching-runoff potential, the soil is classified as mainly sandy. In relation to the erosion potential, a global assessment on erosion vulnerability was prepared by the USDA in 2013, and the area is located in a moderate erosion risk (See Attachment A).

Cerrado soils are among the oldest on Earth. The soils are mainly derived from the Brazilian shield (MARQUES *et al.*, 2004) and they are deeply weathered (up to 50 metres or more) and well drained. To evaluate the drainage category, the

Global Map on Drainage Class published by the FAO in 2013 was analysed. The soil in the region was classified as being Excessively to Extremely Drained (See Attachment B).

The organic matter content in the soil is also an important factor, as it influences the biodegradability of the active ingredient of a pesticide. According to Global Organic Carbon Map (See Attachment C) the area is located in a region of very low organic matter. Since the studied farm makes use of “no tillage” management system, the organic content tends to be higher than in conventional cropping system (NETO *et al.*, 2010) therefore the organic matter content was reviewed and considered as slightly higher than suggested in global values.

6.2.2

Climate

The climate in the region according to the Köppen climate classification is Tropical Wet and Dry. The atmosphere is characterized by distinct wet and dry seasons, with most of the precipitation occurring in the summer (Figure 11).

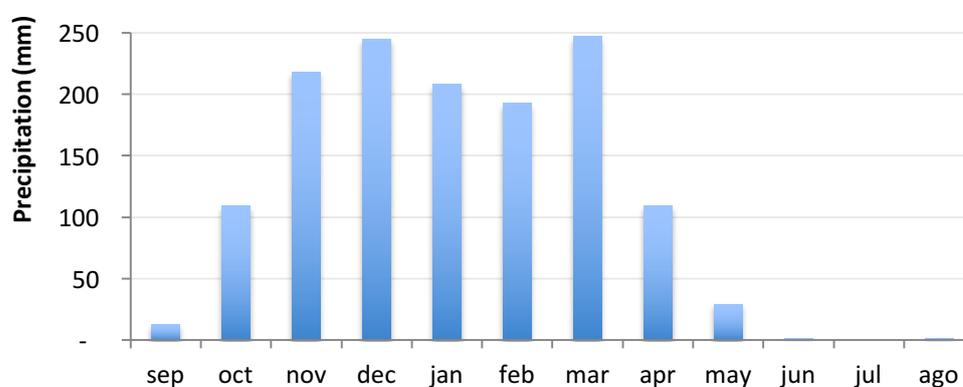


Figure 11 - Average monthly precipitation (mm) - 20 years data

Source: INMET(2015). Elaboration of the author.

Throughout the tropical wet and dry region, the cause of the seasonal cycle is the shift in the tropical circulation throughout the year. During the high-sun season, the intertropical convergence zone moves pole ward and brings convergent and ascending air to these locations, which stimulates convective rainfall. During the low-sun season, the convergence zone moves off to the winter hemisphere and is

replaced by the periphery or core of the subtropical anticyclone, with its subsiding, stable air resulting in a period of dry, clear weather (ENCYCLOPÆDIA BRITANNICA, 2015).

Convective precipitation is present on summer days, being generally intense, and of short duration. The daily average precipitation on rainy days was analysed for the target years 2008-2014 to better understand the intensity of the rains in the period. Historical data from INMET was used. The meteorological station used is located in Posse-GO, approximately 65 km from the studied area, being the closest weather station found. On the wet season it rains an average of 16 days/month and on these days the average rainfall is about 11.4 mm/day (Figure 12 and Figure 13).

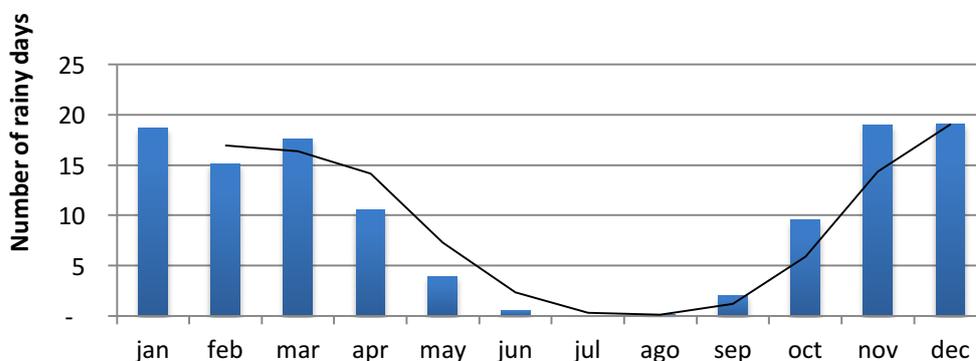


Figure 12- Average number of rainy days per month

Source: INMET (2015). Elaboration of the author.

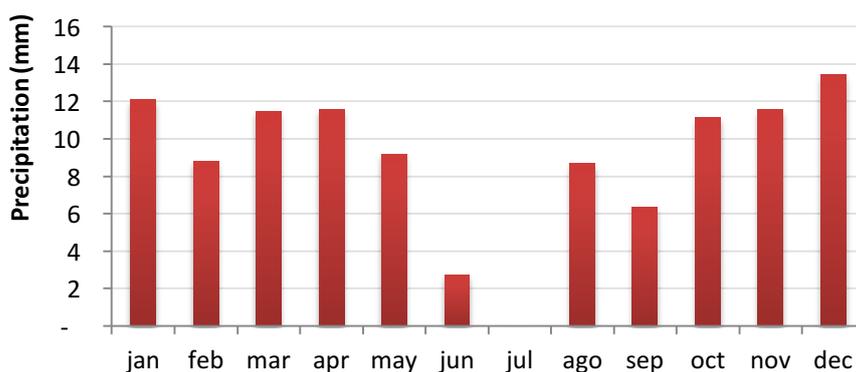


Figure 13 -Average daily precipitation on rainy days (mm)

Source: INMET (2015). Elaboration of the author.

The ideal type of data for defining the rain intensity would be the hourly rainfall, but this was not available locally. Crossing data from daily rainfall in summer, maximum rainfall, specific climate characteristics of the Cerrado region, and from verbal reports of local farmer's, the rain intensity level was defined as “strong”.

In order to calculate the average annual rainfall, data from INMET for 20 years (1995-2014) was analysed and an average annual rainfall of about 1378mm was found. According to tier-1, the precipitation is classified as “high”, as it is in the 1200-1800mm annual range (Figure 14).

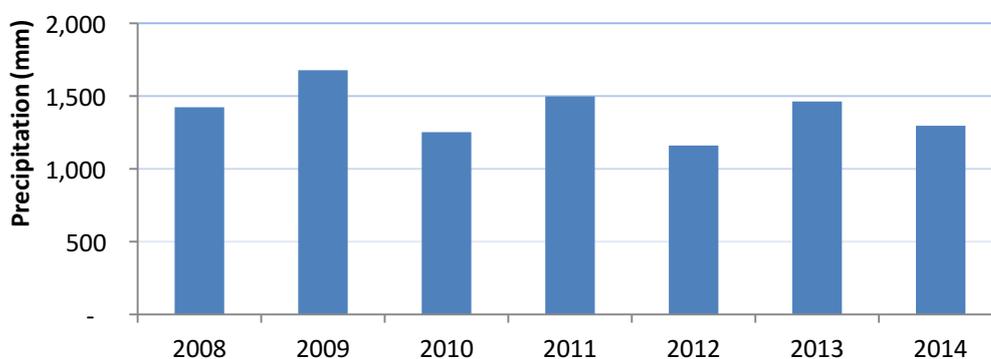


Figure 14 - Average annual precipitation (mm)

Source: INMET (2015). Elaboration of the author.

6.2.3

Chemical properties

According to tier-1, the leaching and runoff from pesticide is strongly related to their specific chemical properties. Values of soil half-life and sorption coefficient are strongly related to the potential to run-off. These values were researched for each of the pesticides (Table 7).

Table 7 - Pesticide Active Ingredients Properties

Pesticide active ingredient name	Soil half-life (days)	Sorption coefficient (L/kg)	Source		
Glyphosate	47	24000	U.S	NATIONAL	PESTICIDE INFORMATION CENTER
2,4 D	10	20	U.S	NATIONAL	PESTICIDE INFORMATION CENTER
Acephate	3	2	U.S	NATIONAL	PESTICIDE INFORMATION CENTER
Methomyl	30	72	U.S	NATIONAL	PESTICIDE INFORMATION CENTER,
Methoxyfenozide	7-10	1100	TOXICOLOGY	DATA	NETWORK, 2015

6.2.4

Agricultural practices

The agricultural practices can play an important role in determining the potential agrochemical's leaching and runoff fractions. The farm's manager was interviewed and the most important factors were examined.

- a. Controlled applications of agrochemicals - The substances are applied on top of the fields, which increase the nutrients efficiency but incur in substances losses. Applications of pesticides are rarely made by air, only when there is an unusual rain event or when the time planning is tight. All applications are done according to the pre plot made by the agronomist.
- b. Diffuse pollution mitigation measures - There are Riparian Forest Buffers closed to the margins of rivers streams, in accordance with the Brazilian Forest Code, which reduce the fraction of the contaminant entering a water body. The distance between the crops and the closest river is substantial, with the closest field 1.5km away. Additionally, the farm respects the area of legal reserve, keeping more than 20 % of the entire land with the original vegetation.
- c. Handling of chemicals (storage, transport, disposal) - Reverse logistics of agriculture chemicals packaging is compulsory in Brazilian legislation and

the practice is widespread. Empty containers of pesticides are returned to Aciagri, the company responsible for recycling. This action is coordinated by INPEV (Processing Institute of empty containers). The pesticides are stored at the farm's main headquarters, in a closed shed and isolated from others substances. The employees responsible for managing the products use protective equipment.

- d. Application timing - Pesticide application is done at the rain season. At this time, the products work better and it is when the plants present more disease.
- e. Drainage - The farm is drained naturally
- f. Soil organic matter management - No tillage and land rotation practices are used, increasing soil organic matter and reducing nutrient loss and erosion. Land use rotations include cattle grazing and different crops cultivation: soybean, cotton and corn.

Weighing the overall answers about the management practices, the farm had a score of good practices relating to the fraction of the substance that has the potential of runoff or leach.

Also in relation to management practices, the tier-1 approach requires a score for phosphorus crop yield and application rate. Application rates vary both spatially and temporally and so does the soybean's yield. A study from SOUSA & LOBATO, 2003 on phosphate fertilization varied phosphorus applications rates on soybeans species in the Cerrado soils. Ranges of phosphorus application and soybeans yield were adapted from the study. The range of values was set according to the maximum and minimum values found. The score was established dividing the values in 4 intervals. The score for each year was calculated according to the intervals (see Table 8 and Table 9).

Table 8 - Phosphorus Application Rates Score

Phosphorus Application Score	Phosphorus Application (kg/ha)
Very low	0-40
Low	40-80
High	80-120
Very High	>120

Adapted from SOUSA & LOBATO, 2003

Table 9 - Soybeans yield score

Yield Score	Yield (ton/ha)
Very low	0 - 1.25
Low	1.25 - 2.5
High	2.5 - 3.75
Very High	> 3.75

Adapted from SOUSA & LOBATO, 2003

The studied region had phosphorus application rates ranging from very low and low and soybean yields ranging from low to high due to temporal variation (see Table 10).

Table 10 - Phosphorus Scores for application rates and yield values.

Year	Phosphorus Application (ton/ha)	Yield (ton/ha)	Phosphorus Application Score	Yield Score
08.09	24.94	1.88	Very Low	Low
09.10	25.57	2.79	Very Low	High
10.11	22.84	3.14	Very Low	High
11.12	42.19	1.62	Low	Low
13.14	40.23	1.78	Low	Low

6.3

Estimation of the leaching-runoff fractions

In Table 11 the leaching-runoff potential factors, its scores and weight values can be seen for the nutrient phosphorus.

Table 11 - Factors influencing the leaching-runoff potential of phosphorus and its scores for the case study.

Category		Factor		NUTRIENTS - PHOSPHORUS				
				Leaching-runoff potential	Very low	Low	High	Very High
				Score (s)	0	0.33	0.67	1
				Weight (w)				
Environmental factors	Soil	Texture	15	Sand	Loam	Silt	Clay	
		Erosion	20	Low	Moderate	High	Very High	
		P-content	15	< 200	200-400	400-700	>700	
	Climate	Rain intensity	10	Light	Moderate	Strong	Heavy	
Agriculture practice	Application rate		15	Very low	Low	High	Very High	
	Crop Yield		10	Very High	High	Low	Very Low	
	Management practice		15	Best	Good	Average	Worst	

Adapted from FRANKE *et al.*, 2013

As both the application rate and the the crop yield had different score values through the studied period for phosphorus, the phosphorus leaching-runoff fractions for phosphorus will vary between the studied period.

In Table 12 the leaching-runoff potential factors, its scores and weights can be seen for the pesticide glyphosate. The tables for all studied pesticides have the same format as Table 12 (see Appendix A, B, C and D for detail on the scores for each substance), the only variations between them are the scores related to to the chemical properties: the sorption coefficient and half-life (see Table 7).

Table 12 - Factors influencing the leaching-runoff potential for pesticides and its scores for the case study.

		PESTICIDES - GLYPHOSATE					
Category	Factor	Leaching- runoff potential	Very low	Low	High	Very High	
			Score (s)	0	0.33	0.67	1
		Weight(w)					
Chemical	K _{oc} (L/kg)	20	>1000	1000-200	200-50	<50	
Properties	Persistence- leaching	15	<10	10-30	30-100	>100	
	Persistence- runoff	10	<10	10-30	30-100	>100	
Environmental factors	Soil	Texture-leaching	15	Clay	Silt	Loam	Sand
		Texture-runoff	10	Sand	Loam	Silt	Clay
	Climate	Organic matter	10	>80	41-80	21-40	<20
		Rain intensity	5	Light	Moderate	Strong	Heavy
Agriculture practice	Management practice	Precipitation	5	0-600	600-1200	1200-1800	> 1800
			10	Best	Good	Average	Worst

Adapted from FRANKE *et al.*, 2013

The values of $\sum (s * w)$ can be drawn from the previous tables by multiplying the score (s) for each factor (i) by its weight (w) and adding all of them. The leaching-runoff fraction (α) of each substance can be calculated using Equation 5 within the range of α_{\min} and α_{\max} (Table 1). The leaching-runoff fraction (α) for each substance is shown on Table 13.

Table 13 - Leaching-Runoff fraction for the studied substances

Substance	Leaching- Runoff fraction (α)	$\sum s * w$	α_{\min}	α_{\max}
Phosphorus	0.01	24.90	0.0001	0.05
Glyphosate	0.05	48.45	0.0001	0.1
2,4 D	0.04	38.3	0.0001	0.1
Acephate	0.05	51.7	0.0001	0.1
Methomyl	0.05	53.35	0.0001	0.1
Methoxyfenozide	0.03	31.7	0.0001	0.1

As both the application rate and the the crop yield had different score values through the studied period for phosphorus, the phosphorus leaching-runoff fractions for phosphorus has a variation between the studied period, with values ranging from 0.011 to 0.013 and an average of 0.0125. On Table 13, the average alpha for phosphorus is shown, however the alpha values used for calculating the GWF were the actual values for each year of phosphorus as shown in Table 14.

Table 14 - Leaching-Runoff fraction variation for Phosphorus per studied period

Crop Year	Leaching-Runoff fraction (α)
08.09	0.0109
09.10	0.0126
10.11	0.0126
11.12	0.0133
13.14	0.0133

6.4

Load of chemicals entering the water bodies

The load of chemicals entering a water body is calculated using Equation 4, which is the multiplication of the leaching-runoff fraction (alpha) by the total substance application in tons of the active ingredient.

The total application needs to be in terms of the active ingredient. The percentage of the active substance per commercial agrochemical can be seen on Table 15 and the total application of each substance per year is seen on Table 16.

Table 15 - Percentage of active substance per commercial agrochemical

Commercial product	Chemical	% of Active substance	Source
Glifosato Atanor	Glyphosate	0.36	ADAPAR
Roundap Transorb	Glyphosate	0.48	ADAPAR
Roundap Ultra	Glyphosate	0.65	ADAPAR
Roundap WG	Glyphosate	0.72	ADAPAR
Aminol	2,4 D	0.67	ADAPAR
Bazuka	Methomyl	0.22	ADAPAR
Lanate	Methomyl	0.22	ADAPAR
Cefanol	Acephate	0.75	ADAPAR
Intrepid	Methoxyfenozide	0.24	ADAPAR
SuperSimples	Phosphorus	0.08	UNIVERSIDADE FEDERAL DE UBERLÂNDIA
MAP	Phosphorus	0.23	UNIVERSIDADE FEDERAL DE UBERLÂNDIA
NPK - 02.20.10	Phosphorus	0.09	UNIVERSIDADE FEDERAL DE UBERLÂNDIA

Table 16 - Active ingredient application per cropping year

Year	Application of substance (ton)					
	Phosphorus	Glyphosate	2,4 D	Acephate	Methomyl	Methoxyfenozide
08.09	55.5	6.0	2.1	-	0.4	0.4
09.10	70.1	7.2	2.3	1.0	0.4	0.4
10.11	52.0	9.6	1.8	-	0.3	0.3
11.12	112.8	9.7	2.4	1.1	1.2	1.2
13.14	153.7	14.5	5.4	3.8	1.2	1.2

On Table 17 the pollutant's load entering the water bodies per studied chemical per harvesting year can be seen.

Table 17 - Load of chemicals entering the water bodies

Year	Load of chemicals (ton)					
	Phosphorus	Glyphosate	2,4 D	Acephate	Methomyl	Methoxyfenoziide
2008/2009	0.602	0.289	0.082	-	0.022	0.001
2009/2010	0.879	0.348	0.090	0.053	0.021	-
2010/2011	0.652	0.463	0.070	-	0.017	0.002
2011/2012	1.503	0.469	0.092	0.056	0.061	0.002
2013/2014	2.048	0.704	0.208	0.197	0.065	0.034

6.5

Maximum allowable substances concentrations in water bodies

According to Hoekstra *et al.*, (2011), the grey water footprint calculations are carried out using ambient water quality standards for the receiving freshwater body because the GWF aims to show the required ambient water volume to assimilate chemical substances. For a particular chemical substance, the ambient water quality standard may vary from one to another water body and also the natural concentration may vary from place to place. In this way, local information is always preferred over global values.

Ambient water quality standards often exist in national legislation but they do not exist for all chemical substances. In Brazil, the CONAMA resolution number 357/05 provides the classification of water bodies and sets water quality standards for different uses.

The CONAMA values for maximum allowable concentrations were used for all the substances it was available. In total, the CONAMA guidelines offer 90 parameters for ambient water quality but only cover 3 substances that are the priority of the study. For the purpose of this study, only the substances with published information on maximum concentration values were studied.

Local guidelines for ambient water standards were found for phosphorus, glyphosate and 2,4-D and global values were encounter for methoxyfenoziide. As for the values of maximum concentrations for acephate and methomyl, no official guidelines were encountered for ambient water. According to the tier-1, if no

information can be obtained, the proposal is to use the maximum allowable concentration as based on the assessment of long term/chronic environmental effects. In the case, the values used for the later substances were sourced respectively from: USPA Integrated Risk Information System and USPA Health Advisory Level (see Table 18).

Table 18 - Maximum Allowable Concentrations (C_{max}) values per substance and its sources.

Chemical Name	Maximum Allowable Concentration (C_{max})	Source of Values
Phosphorus	100 µg/L	CONAMA - Ambient Water
Glyphosate	65 µg/L	CONAMA - Ambient Water
2,4 D	4 µg/L	CONAMA - Ambient Water
Acephate	4 µg/L	USPA - Carcinogenic Drinking Water Risk Level
Methomyl	200 µg/L	USPA - Health Advisory Level
Methoxyfenozide	4 µg/L	EPA - NZ

6.6

Natural substances concentrations in water bodies

Natural background level is the concentration that is present owing to natural and geological processes only, i.e. the background level with no anthropogenic contribution ('preindustrial' levels) (EUROPEAN COMMISSION, 2011).

No local data was encountered on natural phosphorus concentrations. In this case, the guidelines in the tier-1 suggest using values that were derived from the natural concentrations referenced by CHAPMAN, 1996. The phosphorus background concentration used was 0.003 mg/l. Natural concentrations (C_{nat}) for anthropogenic organic substances and pesticides are considered as zero.

6.7

GWF of typical soybeans cultivation in the Cerrado

The grey water footprint of soybeans cultivation was calculated per priority substance per cropping year by applying Equation 3 to the previously calculated values: the load of chemicals, maximum and natural concentrations of the substances in the water bodies (see Table 19).

Table 19 - GWF per year and per substance for a typical soybean farm

GWF per substance (m ³ / year farm)						
Crop Year	Phosphorus	Glyphosate	2,4 D	Acephate	Methomyl	Methoxy-fenozide
2008/2009	6,226,009	4,444,195	20,510,467	-	112,048	164,687
2009/2010	9,089,821	5,360,063	22,426,576	13,127,897	103,897	-
2010/2011	6,742,416	7,130,463	17,429,399	-	85,298	583,342
2011/2012	15,533,947	7,218,505	22,993,312	14,049,663	307,471	519,698
2013/2014	21,166,244	10,838,177	51,901,376	49,367,878	325,805	8,473,330

As expected, the GWF for each substance resulted in different values per year as the application of pesticides and fertilizers vary greatly from one harvest to the other and so are the leaching-runoff fractions and the maximum and natural concentrations different between the substances. In Figure 15 the GWF per contaminant-specific is shown per year and the variation in the values can be better seen.

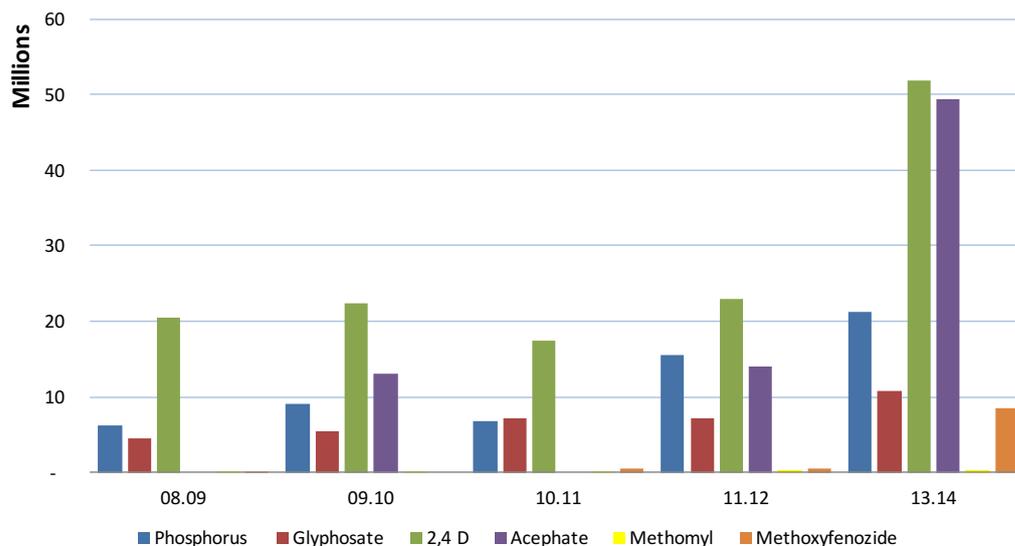


Figure 15 - Soybean cultivation GWF (Millions m³) per harvesting year for each substance.

The GWF of an activity or process is determined by the overall GWF, and this, in turn is equal to the largest GWF found when comparing the contaminant-specific GWFs (FRANKE *et al.*, 2013). As seen on figure 16, the GWF values for 2,4-D were the highest between the studied substances for all years. Consequently, 2, 4-D is the determining substance related to the GWF of soybeans cultivation for all years in a typical large scale farm in the Cerrado.

In Table 20, the GWF of soybean cultivation is shown in three different forms: per farm, per hectare and per tonne. The values of GWF in m³/farm, have an extra link with the area of cultivation of the crop, this is a good indicator for understanding the possible impact of one particular farm to the water bodies but it allows for little comparisons. The GWF in m³/ton and m³/ha can be very useful for comparing the pollution impact in the water bodies of different agricultural practices across different locations. The GWF in m³/ton has an additional productivity component attached to it and it can be linked directly with soybeans as a final product.

Table 20 - Grey water footprint of the case study soybean farm for the studied period.

Year	Soybean Cultivation Area (ha)	Yield (ton/ha)	2,4-D Appl (kg/ha)	GWF (m ³ /farm)	GWF (m ³ /ha)	GWF (m ³ /ton)
2008/2009	2,225	1.88	0.96	20,510,467	9,218	4,897
2009/2010	2,740	2.79	0.85	22,426,576	8,185	2,933
2010/2011	2,275	3.14	0.80	17,429,399	7,661	2,441
2011/2012	2,673	1.62	0.90	22,993,312	8,601	5,318
2013/2014	3,820	1.78	1.42	51,901,376	13,587	7,651

The calculated GWFs show a large variation among different periods. The GWF was the highest in 2013/2014, and the value that year was 43.6 % higher than the values in 2010/2011, the year with the smallest values of the tracking period. The variation of the GWF (per hectare) is due to a higher application rate of the chemical in the period. We can see that when considering the same substance, the GWF (m³/ha) is the highest when the Appl (kg/ha) is highest too, for instance the harvesting year of 2013/2014 reached the peak GWF of the period with the value of 13,587 m³/ha and with an average application rate of 1.42 kg/ha of 2,4-D throughout the soybean fields. It was reported by the farm's operational sector that in the cropping year of 2013/2014 the rise in the 2,4-D application was due to an increase in transgenic crops which had to be dissected with 2-4 D after the harvest.

The average GWF of soybean cultivation in the case study farm is 9,849 m³ per hectare and 4,496 m³ per ton of soybean. The average GWF per hectare is given by the average GWF (m³/farm) divided by the average soybean cultivation area (ha) and the GWF per ton of soybeans is given by the average GWF (m³/farm) divided by the average yield (ton/ha).

As the WF is a recent concept, the calculations are still in an initial stage and the references are not abundant yet. Nevertheless, a few studies on calculating the GWF for soybeans were found. Mekonnen & Hoekstra (2011) calculated the GWF for soybean crops but only considering the effect of nitrogen, coming to a total GWF per ton of crop of 15 m³/ton for the Bahia region and a total GWF per ton of crop of 35 m³/ton for Brazil as a whole. Kotsuka & Bleninger (2015) also calculated the GWF for soybean crops considering the effect of nitrogen for Maringá, Brazil coming to a GWF of 416.7 m³/ton. It is important to notice that

soybeans are a leguminous crop, capable of fixing atmospheric nitrogen, therefore these crops receive zero or very small amounts of nitrogen as a fertilizer (SMALING *et al.*, 2008). In this way, GWF of soybeans related to nitrogen is relevant to a short extent.

To this date, there are few studies on GWF that considered the use of pesticides. A study on the GWF considering pesticides was found for cotton crops in India for conventional and organic cropping systems. The fashion company C&A engaged with the Water Footprint Network to conduct a Water Footprint Assessment of its supply chain using the water footprint standards. Conventional farms resulted in larger GWFs compared to organic farming mainly due to the use of pesticides (FRANKE & MATHEWS, 2011). The average GWF for conventional cotton crops was 266,042 m³/ton and 53,257 m³/ton for organic systems.

Boldrin & Boldin (2012) has estimated that in 2009 it took more than 31 billion cubic meters of water to grow more than 5.8 million hectares of soybeans in the state of Mato Grosso. This particular study considered the green, blue and grey WF but it has not stated their individual values as well as it has not provided detailed information on the considerations made in the estimation.

Although the potential and the foundations of the GWF formulation are well developed, the existing methodologies for calculating the GWF are still in an initial stage, which allows for little comparisons so far.

6.8

Water pollution level in local river basin

The case study farm is located in between the sub-basins of River Arrojado and River Corrente. The analysed river basin is a joint of the later with another 4 sub-basins that unite just outside Santa Maria da Vitória (Figure 16). Data on the sub-basins comes from ANA on Ottobacias nivel 4. The basin choice is due to available data on runoff and the soybean cultivated area. In addition to this, it was decided to keep an area with similar environmental and cultivation properties as the ones studied at the local farm.

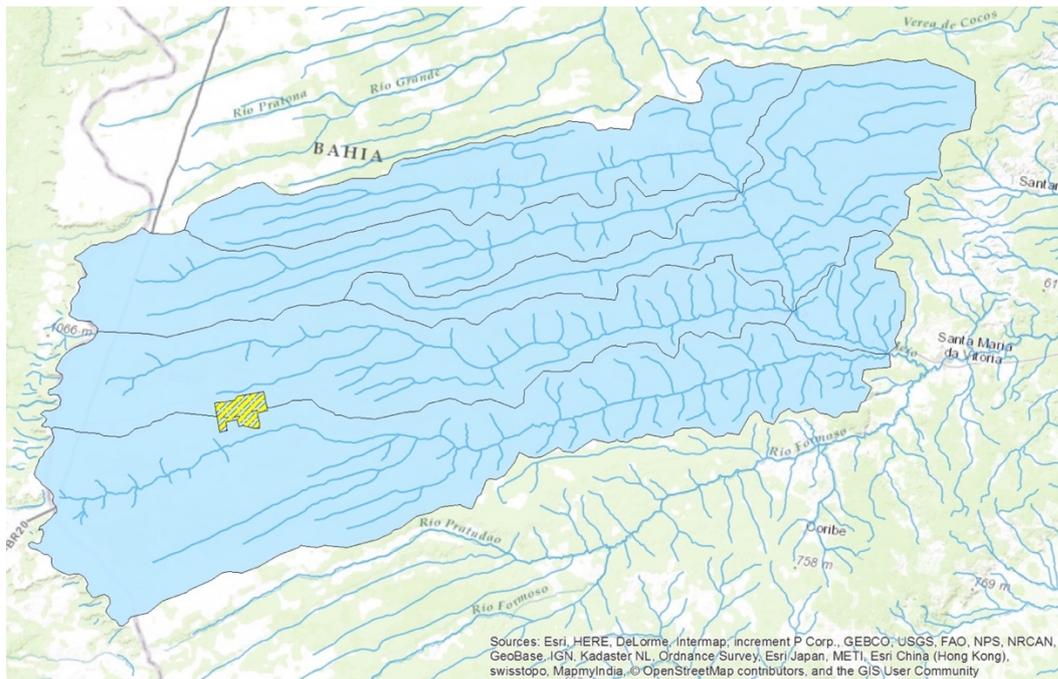


Figure 16 - Case study farm location in the analysed river basin

Source: ESRI; ANA; IBGE. Elaboration of the author.

Both the GWF and the runoff vary within the year, so that the water pollution level will fluctuate within the year as well (HOEKSTRA *et al.*, 2011). In the scope of this study, the calculations will be on an annual basis. Data on the runoff was obtained at two ANA hydrologic stations: Santa Maria da Vitória and Colonia do Formoso. The runoff values (m^3/s) used are the yearly average.

There was no information on the runoff available at the confluence of the studied sub-basin, therefore it was calculated from subtracting the contribution of the Formoso sub-basin from the total runoff at station Santa Maria da Vitória. In Table 21, the average runoff for the sub-basin can be seen on a yearly basis.

Table 21 - Runoff at confluence of the analysed sub-basin

Year	Average Runoff (m^3/s)	Runoff (m^3/year)
2008	99.08	3,124,457,993
2009	114.04	3,596,354,518
2010	104.80	3,304,940,996
2011	116.26	3,666,493,039
2013	106.32	3,352,921,295

For the scope of this study, it was assumed that all soybean cultivation areas in the region had the same GWF per hectare per year as the case study farm. These assumptions can be reasonable as the area has similar soil and climate characteristics. The management practices throughout the region can have greater variation and other studies are encouraged for more accurate results.

Information on the total soybean cultivation areas per municipality is available in IBGE's database on an annual basis (Table 22).

Table 22 - Soybean cultivated area per municipality per year

Year	Soybean Cultivated Area (ha) per Municipality- from IBGE				
	Baianópolis	São Desidério	Santa Maria da Vitória	Correntina	Jaborandi
2008	7,000	255,000	-	100,000	35,000
2009	6,500	230,000	-	99,500	43,163
2010	7,000	241,500	-	101,000	50,000
2011	7,000	211,380	-	110,000	50,000
2013	16,663	262,120	-	131,314	59,092

Source: IBGE (2016). Elaboration of the author.

To calculate the total soybean cultivated area for the region, the studied basin was dissected in the municipalities it belongs. The municipalities of Baianópolis, Correntina, Jaborandi, Santa Maria da Vitória and São Desidério are partially or fully present in the studied basin (see Table 23 and Figure 17).

Table 23 - Fraction of the municipalities' area within the analysed river basin

	Baianópolis	São Desidério	Santa Maria da Vitória	Correntina	Jaborandi
Fraction of municipality area within the basin	47 %	16 %	80 %	100 %	41 %

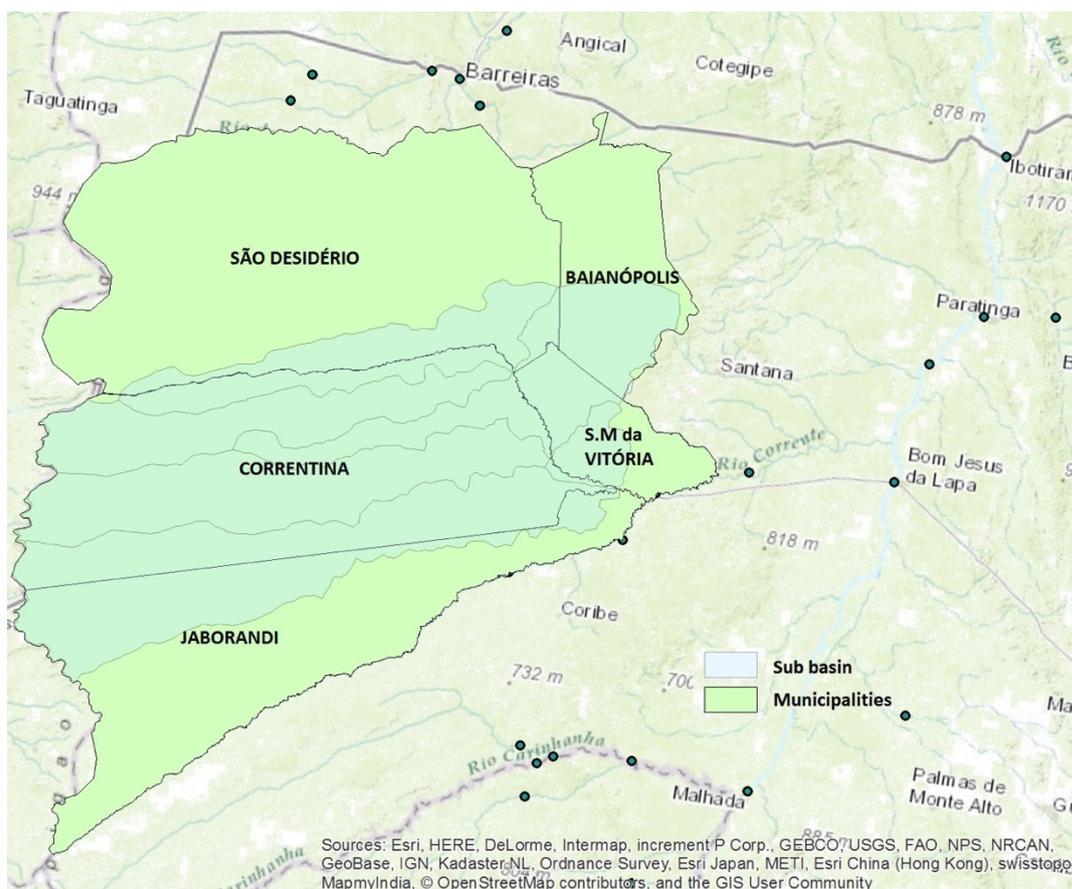


Figure 17 - Municipalities that have areas inside the analysed sub basin

Source: ESRI; ANA; IBGE. Elaboration of the author.

Assuming that the soybean cultivation area is spread homogeneously within the municipalities, the total soybeans cultivated area and the GWF values were calculated for the basin (Table 24).

Table 24 - Soybean cultivation area within the basin and related GWF

Year	Soybean cultivation area (ha)	GWF (m ³ / river basin)	GWF (m ³ /ha)
2008	159,136	1,466,949,914	9,218
2009	157,656	1,290,394,884	8,185
2010	164,055	1,256,866,888	7,661
2011	168,145	1,446,136,173	8,601
2013	205,982	2,798,625,144	13,587

Gathering the information on the GWF and the runoff per year for the sub-basin with Equation 6, the WPL was calculated (Table 25).

Table 25 - Annual WPL relating to soybean production in the region

Year	Runoff (m ³ /year)	GWF (m ³)	WPL (%)
2008	3,124,457,993	1,466,949,914	47
2009	3,596,354,518	1,290,394,884	36
2010	3,304,940,996	1,256,866,888	38
2011	3,666,493,039	1,446,136,173	39
2013	3,352,921,295	2,798,625,144	83

The WPL in the basin is related to the GWF of the region, which is associated with the soybean cultivated area, the application rate of the pesticide 2,4-D and the runoff in the river basin. If the WPL is greater than 100 % it implies that waste assimilation capacity of the basin is insufficient to take up the actual pollution, resulting in a violation of water quality standards.

Throughout the studied years the WPL varied from 36 % to 83 % with an average of 48.6 % in the period.

In the crop year of 2013/2014, the WPL reached peak levels of 83 % and it was close to reach the assimilation capacity. In the same period the soybean cultivation area has increased 29 % comparing to the first analysed values (from 2008) and the GWF (m³/ha) was 47 % higher. In this particular year the high levels of water pollution were related to an increase in the soybean cultivation and an increase in the application rate of the pesticide 2,4-D. The higher application of the pesticide is due to an increase in transgenic crops which had to be dissected with 2-4 D after the harvest.

It is important to consider that this particular study only accounts for the water pollution of one crop, the soybean. Soybean are the main cultivation in the region but not the only form of water pollution, they represent 61 % of the total temporary crops production in the region. In relation to pollution from agriculture, these other crops will also contribute to the WPL and they need to be assessed to form a better picture of the actual degree in which the water quality is committed by agrochemicals usage. For an even more comprehensive analysis, domestic and industrial sources should be accounted as well. Additionally, even though the

studied basin has a WPL < 1, this does not guarantee that at the sub-basin level or within particular periods of the year the assimilation capacity is not compromised. Considering the local trend of agricultural expansion in the Cerrado, this results indicate that the further intensification of large scale agriculture within the region will likely increase the pollution of dissolved agrochemicals in water bodies.

6.9

Local water quality

As reviewed in the legislation section of this study, one of the instruments of the National Water Resources Policy is the framework. The framing of water bodies is to establish the level of quality to be achieved or maintained in a body segment of water over time. In the analysis of the water quality monitoring results, the data should be compared to the limits established by the framework at the site of sample collection. To this date, no information on the classification of the local water bodies was available. In this way, the maximum concentrations allowed for the local water bodies are not defined yet.

The studied river basin presented a few ANA hydrological stations but none of them offer official data on the presence of toxic substances in the water bodies. Data on agrochemicals levels in water bodies was only found in a few scientific studies, for example, Hunke *et al.*, (2015) found that pesticides were consistently detected throughout the entire aquatic system in the Cerrado. In several case studies, extremely high-peak concentrations exceeded Brazilian and European Union (EU) water quality limits, which were potentially accompanied by serious health implications.

Final considerations

In this study the GWF of a typical soybeans cultivation farm located in West of Bahia state, in the Brazilian Cerrado was calculated for 5 different harvest years starting in the harvest of 2008/2009 up to 2013/2014, with the exception of data on the harvest of 2012/2013, which was not available. The focus of the study was on the potential water pollution impacts caused by the application of pesticides and fertilizers in the soybeans fields in the particular biodiverse biome of Cerrado.

The substances of analysis were the ones that represented up to 75 % of total agrochemicals applications in tonnes of active ingredient in the case study farm. A total of eight substances were encountered, out of which Carbendazim and Thiophanate-methyl were dismissed as no values of maximum allowable concentrations of exposure were available. The priority ingredients in order of higher application were found to be: phosphorus, glyphosate, 2,4 D, acephate, methomyl and methoxyfenozide. For the pesticides used, a more detailed research could be done, to better understand the leaching and runoff and its harmful potential to humans and the environment. It would be useful to see if they could easily be substituted by less toxic pesticides and with greater biodegradability or if their application rates could be better managed without compromising productivity.

For calculating the GWF, a leaching-runoff fraction was estimated using the tier-1 approach, which is sufficient for a first rough estimate, but does not describe the different pathways of a chemical substance from the soil surface to surface or groundwater and the interaction and transformation of different chemical substances in the soil or along its flow path. For a more accurate estimate a model should be applied.

The most significant pollutant for all years was found to be 2,4-D and therefore it is the substance determining the overall GWF. The calculated GWFs show a large variation among different periods with values ranging from 7,661-13,587 m³ per hectare of soybean cultivation and from 2,441 to 7,651 m³ per tonne

of soybean for the case study in the studied period. The year of 2013/2014 had discrepant high values, reaching a GWF of 13,587 m³ per hectare and 7,651 m³ per tonne. The result difference is mainly due to a higher application of the pesticide, from 0.80kg per hectare in 2010/2011 to 1.42kg per hectare in 2013/2014. The higher application of the pesticide is mostly due to an increase in transgenic crops which had to be dissected with pesticide after the harvest. The soybean average production of this site is 2.19 ton per hectare, considering the 5 years of analysis, which is lower than the national average, which was 2.9 ton per hectare (IBGE, 2016) in the same period.

Also, data on maximum concentrations allowed for ambient water was lacking for some active substances used and for other substances different sources of information has to be used. In an ideal scenario the maximum concentrations of all active substances used should be the ones determined by local authorities.

The water pollution level is calculated locally, at river basin level. The river basin analysed is a joint of 6 sub-basins, classified by ANA as “ottobacias - nível 4”, they meet just outside of the city of Santa Maria da Vitória, and are the ones that contribute to the runoff on the chosen hydrologic station. The average WPL for the 5 harvesting years of analysis was 48.6 %, with values ranging from 36 % to 83 %. The values for the last analysed year (2013/2014) were the highest, reaching 83 % and it is close to the maximum assimilation capacity only accounting the pollution of this crop. Even though the studied river basin has a WPL < 1, this does not guarantee that at specific areas within the basin or within particular periods of the year the assimilation is not reached. As the cultivation of soybeans represent 61 % of the total temporary crops production in the region, other crops are likely causing some pollution as well. For a better understanding of the actual degree in which the water quality is committed by agrochemicals usage other crops should be accounted as well. The results indicate that following the local trend of further intensification of large scale agriculture will increase the pollution of local water bodies with dissolved agrochemicals to the point that the local water quality standards will soon be violated.

In the estimation of the WPL, it was assumed that the GWF was the same throughout the whole region. In reality the management practices vary and the GWF can be considerable different between farms. In future studies, the analysis of the GWF of at least two more soybean cultivation farms within the river basin will

allow for a better understanding of the standards of the agrochemicals usage practices in the region and consequently a more precise picture of the soybean cultivation water pollution potential. It is also advised, if the available data allows, to add a monthly analysis of the WPL in further analyses, as important insights on the variation of the pollutants assimilation capacity along the year might be observed. Other suggestion for further research is to calculate the WPL considering the GWF of all agricultural activities impacting the river basin, as it will produce a more comprehensive result of the potential water pollution in the river basin related to the application of fertilizers and pesticides.

As for the monitoring of the water quality related to agrochemicals usage in the studied area, the local hydrological stations controlled by ANA are not currently observing levels of any toxic substance. Brazilian environmental laws are generally strict but what is seen in reality is that the management tools created for the compliance to the legislation to be checked are very recent and not running in most areas throughout the country. In the case study, firstly the framework should be available for the local river basin so that the level of water quality intended for the region is known, then the levels could be compared. The monitoring of toxic substances in ambient water throughout the country is basically non-existent and any type of controlling of the levels work in a remediation approach rather than in prevention. In this sense, if major complaints turn out, local authorities might start to observe the objections. Future research would benefit by performing lab testing in different river locations within the river basin to evaluate the presence of toxic parameters.

Although the potential and the foundations of the GWF formulation are well developed, the existing methodologies for calculating the GWF are still in an initial stage, which complicates matters when dealing with complex cases. Additionally, large volume of data is required for the GWF calculation, which is not available in all basins. In the future, more studies on GWF will allow for comparison between local pollution impacts of processes and products and will allow a better understanding of the influences and the potential environmental improvements of each type of practice.

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Appendix A - 2,4-D leaching-runoff estimation table

Category		Factor		PESTICIDES - 2,4-D				
				Leaching- runoff potential	Very low	Low	High	Very High
				Score (s)	0	0.33	0.67	1
				Weight(w)				
Chemical	K _{oc} (L/kg)	20	>1000	1000-200	200-50	<50		
Properties	Persistence- leaching	15	<10	10-30	30-100	>100		
	Persistence- runoff	10	<10	10-30	30-100	>100		
Environmental factors	Soil	Texture- leaching	15	Clay	Silt	Loam	Sand	
		Texture-runoff	10	Sand	Loam	Silt	Clay	
		Organic matter	10	>80	41-80	21-40	<20	
	Climate	Rain intensity	5	Light	Moderate	Strong	Heavy	
		Precipitation	5	0-600	600-1200	1200- 1800	> 1800	
Agriculture practice	Management practice	10	Best	Good	Average	Worst		

Appendix B - Acephate leaching-runoff estimation table

Category	Factor	PESTICIDES - Acephate					
		Leaching- runoff potential	Very low	Low	High	Very High	
		Score (s)	0	0.33	0.67	1	
		Weight(w)					
Chemical	K _{oc} (L/kg)	20	>1000	1000-200	200-50	<50	
Properties	Persistence- leaching	15	<10	10-30	30-100	>100	
	Persistence- runoff	10	<10	10-30	30-100	>100	
Environmental factors	Soil	Texture- leaching	15	Clay	Silt	Loam	Sand
		Texture-runoff	10	Sand	Loam	Silt	Clay
	Organic matter	10	>80	41-80	21-40	<20	
	Climate	Rain intensity	5	Light	Moderate	Strong	Heavy
		Precipitation	5	0-600	600-1200	1200- 1800	> 1800
Agriculture practice	Management practice	10	Best	Good	Average	Worst	

Appendix C - Methomyl leaching-runoff estimation table

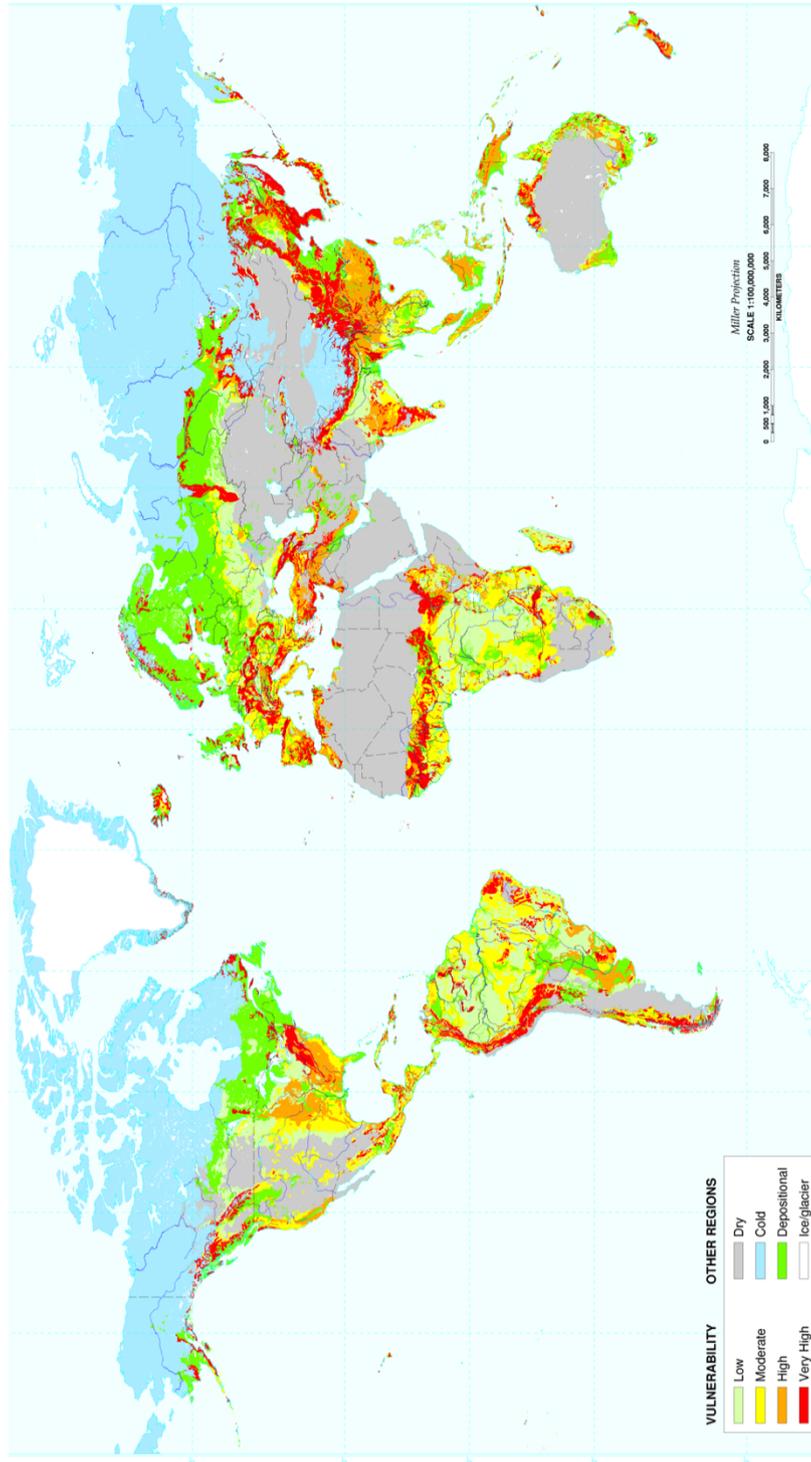
Category		PESTICIDES - Methomyl						
		Factor	Leaching- runoff potential	Very low	Low	High	Very High	
				Score (s)	0	0.33	0.67	1
				Weight(w)				
Chemical	K _{oc} (L/kg)	20	>1000	1000-200	200-50	<50		
Properties	Persistence- leaching	15	<10	10-30	30-100	>100		
	Persistence- runoff	10	<10	10-30	30-100	>100		
Environmental factors	Soil	Texture- leaching	15	Clay	Silt	Loam	Sand	
		Texture-runoff	10	Sand	Loam	Silt	Clay	
		Organic matter	10	>80	41-80	21-40	<20	
	Climate	Rain intensity	5	Light	Moderate	Strong	Heavy	
		Precipitation	5	0-600	600-1200	1200- 1800	> 1800	
Agriculture practice	Management practice	10	Best	Good	Average	Worst		

Appendix D - Methoxyfenozide leaching-runoff estimation table

Category		PESTICIDES - Methoxyfenozide					
		Factor	Leaching- runoff potential	Very low	Low	High	Very High
			Score (s)	0	0.33	0.67	1
			Weight(w)				
Chemical Properties	K _{oc} (L/kg)	20	>1000	1000-200	200-50	<50	
	Persistence- leaching	15	<10	10-30	30-100	>100	
	Persistence- runoff	10	<10	10-30	30-100	>100	
Environmental factors	Soil	Texture-leaching	15	Clay	Silt	Loam	Sand
		Texture-runoff	10	Sand	Loam	Silt	Clay
	Organic matter	10	>80	41-80	21-40	<20	
	Climate	Rain intensity	5	Light	Moderate	Strong	Heavy
		Precipitation	5	0-600	600-1200	1200-1800	> 1800
Agriculture practice	Management practice	10	Best	Good	Average	Worst	

Attachment A - Erosion Vulnerability Map

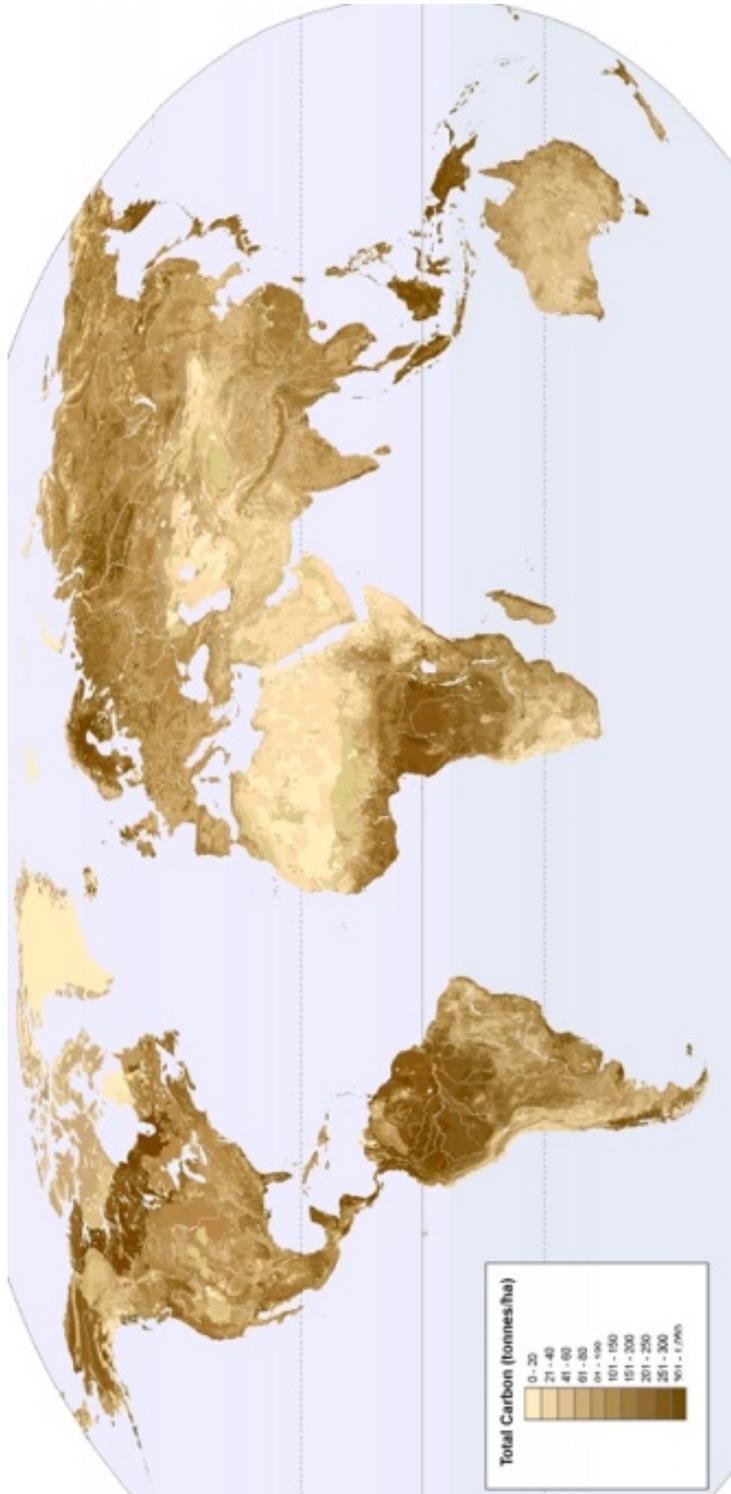
PUC-Rio - Certificação Digital N° 1413544/CA



Source: USDA (2013)

Attachment C - Global Map of Soil Organic Carbon

PUC-Rio - Certificação Digital Nº 1413544/CA



Source: SCHARLEMANN *et al.* (2011)