ASSESSING THE WATER FOOTPRINT OF COTTON PRODUCTION IN SOUTH AFRICA

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DECLARATION

I, Takalani Tshibalo, hereby declare that this dissertation submitted for the degree of *Magister Agriculture* in the Faculty of Natural and Agricultural Sciences, Department of Agricultural Economics at the University of the Free State, is my own independent work, and has not been previously submitted by me to any other university. In addition, I cede the copyright of this dissertation to the University of the Free State.

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January 2019

DEDICATION

I dedicate this dissertation to my beloved mother Elizabeth Nkhangweleni Tshibalo, to whom I will always be grateful for this life time opportunity and support.

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"Because of the Lord's great love we are not consumed, for his compassions never fail. They are new every morning; great is your faithfulness. I say to myself, The Lord is my portion; therefore I will wait for him." The Lord is good to those whose hope is in him, to the one who seeks him; it is good to wait quietly for the salvation of the Lord."

Lamentations 3:22-26 (Bible.com, 2019)

Above all, I send my sincere gratitude to my Lord and saviour Jesus Christ who granted me His sufficient grace, love, strength, and courage to embark on this dissertation and endure until the end. His mercy never ceases to amaze me. I would also like to thank my family and friends for their continuous support and encouragement. A special thanks to Thendo Tshibalo and Dakalo Tshibalo for their words of encouragement. To my mother, I would like to thank you for your love, prayers, encouragement, finances, and the sacrifices you made throughout my studies. To my spouse Mpfareleni Steven Maandamela, I appreciate your love, patience, support, and understanding throughout my studies.

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ABSTRACT

Water remains an essential natural resource for life, and it is a vital component for economic activities in South Africa. The main objective of this study was to assess the water footprint of cotton in South Africa. The water footprint of cotton on farm level was calculated; both green and blue water footprints were considered. However, due to a lack of data, the grey water footprint was not considered. Water productivity on farm level was also determined. The study was conducted as a case study in Marble hall, under the Loskop irrigation scheme.

This study employed the Global Water Footprint Standard (GWFS) approach in order to calculate the volumetric blue and green water footprint of cotton. The approach was employed in two different planting times/seasons, namely September and October. The results indicate that cotton planted in September under irrigation accounts to 1172.92m^3/ton with a yield level of 4.8/ha. A total of 58% of the 1172.92m^3/ton of water was the green water footprint and 42% was the blue water footprint. Cotton in the Loskop irrigation scheme is less dependent on irrigation water since the rainfall water contributes more compared to irrigation water. The results concluded that cotton planted in October under irrigation accounts for 1054m^3/ton of blue and green water footprint. Of the 1054m^3/ton of blue plus green water footprint, rainfall contributed 63% of the water required, which indicates that even in late planting time, the water that cotton require is mostly met by rainfall. The results further indicated improved water usage in both different planting seasons / time.

The study also assessed the water productivity of cotton, where the value added to water was quantified on farm production. The economic water productivity (EWP) of the September planting season was R7.23 and obtained per cubic metre of the water used for cotton production. The EWP of the October planting season was R8.69 as obtained per cubic metre of the water used for cotton production. The EWP of cotton planted in October was found to be higher than the cotton planted in September. October proved to be the most sustainable month for cotton production. Hence, it is recommended that cotton production in the Loskop irrigation scheme should take place in October rather than September.

Keywords: Cotton production, water footprint, water sustainability, economic water productivity

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LIST OF ACRONYMS AND ABBREVIATIONS

ARC	Agricultural Research Council
AR	Chemical Application Rate
CWU	Crop Water Use
DWA	Department of Water Affairs
DAFF	Department of Agriculture, Forestry and Fishery
EWP	Economic Water Productivity
ET	Evapotranspiration
FAO	Food and Agriculture Organization
GWFS	Global Water Footprint Standard
ISO	International Standard Organization
LCA	Life Cycle Assessment
PWP	Physical Water Productivity
SA	South Africa
SAPWAT	South African Procedure for estimating irrigation Water requirements
WF	Water Footprint
WRC	Water Research Commission

CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

Ellis (2008) stated: “If agriculture goes wrong, nothing else will have a chance to go right in the country.” In 2008, he added: “If conservation of natural resources goes wrong, nothing else will go right.” The role of natural resources cannot be underestimated, therefore, there is a need to measure the natural resources used in the agricultural sector in order to ensure the effective and efficient use of these resources.

Water is an essential natural resource for life (Blignaut and Heerden, 2009), and it is regarded as a vital component for economic activities. The scarcity of fresh water is increasing as the population grows and pollution increases. In addition, the devastation of river catchment increases due to deforestation, urbanisation, and the destruction of wetlands, industry, mining, and agriculture, which causes water pollution. Some of the factors contributing to water scarcity are among the broader changes caused by climate change and global warming (Department of Water Affairs, 2013).

South Africa was ranked as the 30th driest country in the world, (Olofintoye, 2015) and is continuously developing into a water scarce country (Blignaut and Heerden, 2009). In South Africa, 12% of the landmass is arable, with 3% being very fertile. The production of 30% of the country’s crops can be ascribed to only 1.5% of the landmass being irrigated (Department of Water Affairs, 2013). In Southern Africa, agriculture consumes around 61% of exploitable runoff (Department of Water and Sanitation, 2018). The high volume of water used in the agricultural sector places policymakers and water managers in a difficult position to inform water users on how to use water efficiently and sustainably. For example, at farm level, it is difficult for farmers to reduce their water use, while also maintaining the yield of the crops (Department of Water and Sanitation, 2018).

The Agricultural sector is regarded as an important sector to developing countries and with South Africa not being an exception. The role played by this sector remains imperative to the socio-economic importance of creating employment opportunities, earning foreign currency, social welfare, and ecotourism. Agriculture directly contributes to merely 2.5% of the Gross Domestic Product (GDP) of South Africa. Therefore, this sector may be regarded as an inefficient user of the scarce fresh water resources (Nieuwoudt et al., 2004). However, if one considers the agricultural sector's contribution to the economy through the forward and a backward linkage to other sectors, agriculture contributes more than what is recorded as GDP contribution (Greyling, 2012). Thus, this sector is significant to the economy, and the resources used in this specific sector must be used effectively and efficiently.

Globally, cotton is considered to be an important crop. Cotton is a raw material for clothing, textile, footwear, and the leather industry. It also plays an important role in the economic and social development of developing and industrialised countries (Fairtrade Foundation, 2015). Cotton was classified as the most important natural fibre, contributing to about 40% of the global textile industry (Chapagain et al., 2006). Cotton accounts for 74% of fibre and 42% of all processed fibre in South Africa; therefore, it is an important source of fibre. Furthermore, cotton production in South Africa is a source of employment in the agricultural sector (Fairtrade Foundation, 2015). Approximately 60 000 to 80 000 jobs are created in the textile and clothing industry. When considering the contribution of cotton production towards GDP in South Africa, it was found that it contributes to nearly 8% of the agricultural sector's contribution towards GDP (Business/Partners, 2014).

In addition, water is an important element during cotton production. Given that South Africa has a scarce water economy, it is vital to assess the amount of water used during cotton production. Unfortunately, cotton production was found to be one of the crops which consume large volumes of water (Aldaya et al., 2010). Of the total (blue and green) water consumed by agriculture in central Asia, cotton uses 33%. The amount of fresh water used by cotton during production and its economic contribution to the South African economy stresses the importance of knowing the volume of fresh water used, the degree of sustainability in the area where cotton is produced, and the economic value of the water used during cotton production.

According to Hoekstra et al. (2011), it is vital to evaluate the environmental sustainability of the water used in the production of cotton. The water sustainability of the basin or catchment depends on the balance between the needs of that specific environment and the scarce water availability. During the time cotton growers' start planting their crop, the Limpopo River basin presents severe blue water scarcity. Therefore, it is imperative that the cotton growers are aware of the water needed by the crop and how the water can be used sustainably, while taking the environmental implications into consideration.

Water footprint is developing as an important indicator of sustainability within both the agriculture and food industries (Ridoutt et al., 2011). Water footprint refers to the volume of fresh water used in order to produce a product and it is measured according to the value chain of the product, which includes the inputs and also the end result; thus when the product reaches the consumer (Hoekstra et al., 2011). Water footprint can be a useful tool to address the use of water during cotton production. Van der Laan et al. (2013) concluded that water footprint may be used in agricultural production as it monitors and notifies policymakers on how to manage water. In addition, it can also lead to improved understanding of the risk related to water shortages that could aid water management. The water use information may also possibly help to determine changes in order to moderate the water usage at farm level.

Furthermore, consideration should be given to the economic productivity of the water footprint. Economic productivity is the measure of the value of output in relation to the input used to produce a unit of output (Pfister et al., 2012). Hoekstra (2015) emphasised that there are three pillars under wise fresh water allocation. These include sustainable (environmental), efficient (economical), and equitable (social) water use. Previously, the emphasis of water footprint research was mainly on the environmental impact of water (Chapagain et al., 2006). However, it is important to also consider the economic water productivity during water footprint assessment (WFA). The water users need to understand the economic contribution from using the scarce resource. As a result, it can be determined whether the current allocation is efficient or not.

1.2 Problem Statement

Limited scientific information exist, which is able to assist South African's on the amount of fresh water used and needed during the production of cotton. Therefore, water users may use water inefficiently and ineffectively in the production of cotton (Eslamian and Eslamian, 2017).

Internationally, cotton is regarded as one of the crops which uses a lot of fresh water. Chapagain et al. (2006) evaluated the water footprint of cotton use by assessing the impact of the global use of cotton products on water resources in those countries that are known for producing cotton. Whilst Aldaya et al. (2010) assessed the water footprint of cotton and the production of other crops in Central Asia, Hoekstra and Mekonnen (2012) evaluated the water footprint of humanity. These authors highlighted the components of water footprint, which includes green water (consumption of effective rainfall), blue water (consumption of ground or surface water for irrigation), and grey water (indicators representing water pollution during the growth or processing stage). From the assessments conducted, blue water footprint was the highest volume of fresh water used. The large volume of blue water suggests increased pressure on the scarce fresh water resource. Results further indicated that cotton production requires a vast amount of fresh water.

It is evident that cotton production is significant to the South African economy and the abovementioned research effort in cotton production requires a lot of water. It is imperative to comprehend the economic water productivity of the fresh water used during cotton production as part of assessing the sustainability of fresh scarce water resources. In South Africa, however, the economic value of fresh water used during cotton production is not known. Internationally, Chouchane et al. (2015) assessed the water footprint of Tunisia from an economic perspective. Schyns and Hoekstra (2014) evaluated the added value of water footprint assessment for national water policy using Morocco as case study. In a study conducted by Rudenko et al. (2013) the value added by a water footprint, the micro and macroeconomic analysis of producing cotton, and the processing and export thereof in water-bound Uzbekistan, was explored. The results indicate that economic water efficiency is vital to the ecological environment policies. According to the author’s knowledge, no similar study has been undertaken in South Africa for cotton production.

Despite the broad global application of a water footprint assessment the use of this assessment in South Africa is limited, especially with regards to cotton. Thus, no scientific information on water footprint is available, which is able to inform sustainable water use in the production of cotton. Given the contribution of the cotton industry towards the South African economy, the water footprint assessment cannot be ignored, especially since it is essential for sustainable water use.

1.3 Aims and Objectives

The study aims to assess the water footprint and economic water productivity of cotton in South Africa that is produced under irrigation and used as raw materials for clothing, textile, footwear and leather industry, and feed for animals.

The three sub-objectives formulated to achieve the aim of the study, include:

- Sub-Objective 1: To compute the volumetric water footprint indicator of cotton.
- Sub-Objective 2: To evaluate the economic productivity of the water footprint of cotton.
- Sub-Objective 3: Formulate response strategies towards more sustainable water use for cotton production.

1.4 The Scope of the study

Considering the geographic and climate variation of where cotton is produced in South Africa, it is feasible to conduct this type of study in a specific area. Therefore, the study was based on a case study, namely the Loskop irrigation scheme for the production of cotton on farm level since most of the water is used on farm level during the process of growing cotton. Although the water footprint assessment was conducted, the research will mainly focus on calculating the water footprint and the economic valuation of water.

1.5 Chapter Layout

The background of and motivation for the study were set out at the beginning of this chapter. It included a detailed explanation of how the water is used and the economic impact that cotton has on the South African economy. The problem statement was formulated and enabled the researcher to outline the aim and objective of the study. Chapter 2 includes a discussion on the state of water as a scarce resource in South Africa, the cotton industry in South Africa, as well as the theoretical framework of the water footprint. Furthermore, a discussion on available studies around water used in order to produce cotton, and on the sustainability of water footprint, is included. Chapter 3 provides more detail on the chosen methodology for the study.

Chapter 4 entails an illustration of the results from the chosen method and a discussion around the results obtained. Lastly, Chapter 5 outlines the summary, conclusion, and recommendations based on the findings of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Chapter 2 encompasses a discussion on the state of water as a resource in South Africa and the cotton industry. The theoretical framework will be outlined, followed by a discussion on the water footprint concept, method for water footprint, and decision on the method to be used. Furthermore, related studies and economic valuation of the water footprint will also be explored. Lastly, the conclusion based on the related studies will be discussed.

2.2 The state of water as a resource

According to Water Wise (2017), there is no life without water, although the amount of water available for consumption from the total water on earth is limited in percentage. About 70% of the earth surface is covered with water, while approximately 97% of the available water is salt water, and the residual of 3% is fresh water (Water Wise, 2017). Only 1% of the 3% of fresh water is available for life on earth, while the rest is ice at the poles (Water Wise, 2017). Today, the mismatch between water availability and water demand on earth has aggravated the dire water scarcity problem, which can be regarded as a critical environmental concern (Van Beek et all., 2011).

The availability of fresh water is the utmost important aspect that hinders South Africa’s agricultural production. Furthermore, the situation might probably worsen due to both the increasing demand from other economic sectors and climate change. Water supply is further impacted by temperatures that rise due to evapotranspiration rates increasing and the decreasing run-off. Increased incidences of droughts and floods occurred as a result of changes in the frequency and intensity of rainfall (DAFF, 2015). According to the Department of Water Affairs (2013; 2015) and De Wit (2016), SA is ranked as the 30th driest country in the world (average annual precipitation is 450mm; nearly half of the world’s average of 860mm). Thus, SA is prone to constant or long-lasting droughts. The annual rainfall is lower than the annual evaporation in some parts of SA (De Wit, 2016). The demand for fresh water in SA is higher than the water supply or availability, as water is regarded as a critical resource in sustaining human needs and is vital during the production of goods and services.

According to De Wit (2016), groundwater resources are scarce. Hard rock foundations within some parts of the land further limit groundwater accessibility. As a result, approximately 20% of South Africa's groundwater is currently used. Figure 2.1 illustrates the water distribution to the different sectors in SA. It indicates that agriculture is the highest consumer of water compared to the other sectors. Irrigation agriculture is accountable for about 60% of the available fresh water, followed by municipal /domestic with 27%. Considering that SA is a water scarce country, the distribution of water must, however, be beneficial to the economy. Agriculture makes the lowest contribution towards GDP, and considering the water used by this sector, it is thus regarded as an inefficient user of fresh water (Nieuwoudt et al., 2004).

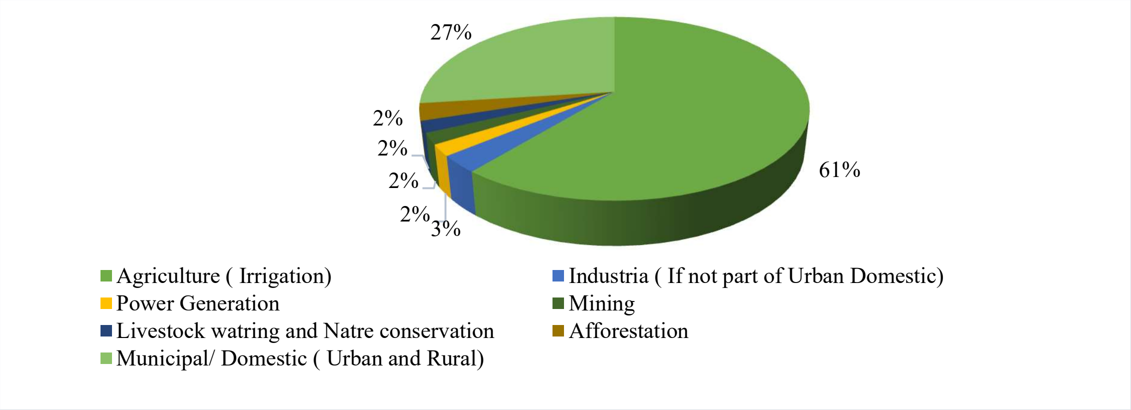

Figure 2.1: Water distribution per sector in South Africa

Source: Department of Water and Sanitation (2018)

DAFF (2015) highlighted that the current water usage is above the dependable yield, which will cause serious water shortage challenges. Since the current water usage already exceeds reliable yields, significant water restrictions might occur in the event of a country experiencing a drought year. Therefore, it is vital to be aware of how much water is needed for producing a certain product within a certain sector, while optimising the use of water during production. Improvement in water productivity will be of significance while trying to meet the demands of the country with the limited fresh water resources (Mekonnen, 2014). It is important that water is used to its optimal level according to South Africa's National Water Act, namely economic efficiency, environmental sustainability, and equity, which is currently neglected.

2.3 The cotton industry in South Africa

2.3.1 The cotton life cycle

Cotton is a summer crop and planting season normally starts from October. Cotton takes approximately 105 to 130 days to grow. Preparation of the fields include proper soil moisture or be irrigated to increase the soil moisture (Agricultural Research Council, 2017). Throughout the first germination and growth stage, the plant demands wet soils. When planted, the seed must be at a depth between 25-40mm. Germination of the seedling shows within seven days under optimal conditions of soil moisture (Agricultural Research Council, 2017). Three weeks after germination, thinning should take place in order to adjust the population to 35 000 plants/ha for dryland conditions or 80 000 plants/ha for irrigation conditions. The blossoming starts around day 70 after planting. The bottom stage starts around day 105, and the final stage after 130 days of planting. Thereafter, maturation of the crop should occur under favourable conditions with proper moisture, enough nutrients, and sufficient solar energy (Agricultural Research Council, 2017).

Figure 2.2 illustrates the cotton value chain from the farm to the end user or the buyer. There are two major products produced from cotton, namely cotton lint and cotton seed (DAFF, 2015). After harvesting, the fibre is separated from the seed. The cotton seed is either packaged in bales of 150-200kg or in mass bins. Thereafter, the farmer sells the cotton seed to the ginner, and they receive the price according to the grade of the cotton seed. Cotton seed grading is done according to the appearance of the cotton seed.

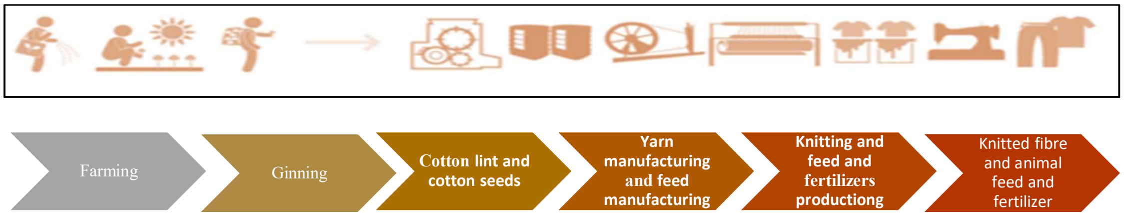

Figure 2.2: Cotton value chain

Source: (Rieple and Singh, 2010)

The cotton fibre is the most important product on the cotton structure, and it contributes to approximately 37% of the total mass of cotton (DAFF, 2015). Contrasting to seed grading, the colour of the fibre, insect, fungal, or foreign materials determine the price of the fibre. After cotton is traded to the spinners, the processors buy the cotton lint and cotton seed in an attempt to spin it into yarn and animal feed. The yarn is then sold to the weavers and knitters who produce a range of products (textiles, denim, canvas, etc.). Cotton can be used to produce oil, hulls, and linters and also as seeds in order to replant more cotton.

Cotton is used as raw material for clothing, textile, footwear, and in the leather industry. Furthermore, when the seed is crushed, oil can be extracted and the husks can be separated from the pulp. Artificial rubber is produced from the husks and the remaining pulp, which is high in nutritional value, are sold to livestock farmers as cotton cake (Agricultural Research Council, 2017). Water is needed in each and every stage of production along the value chain in which cotton can be used as an input.

2.3.2 The importance of the cotton industry to the South African economy

Cotton is considered as one of the important crops which contribute towards South Africa's economy. Production of cotton takes place in many countries, including South Africa. Cotton is regarded as a cash crop. Cotton production was introduced in Mpumalanga, Tzaneen, and Rustenburg around 1904 (Cotton SA, 2015). Thereafter, cotton was legitimately accredited as an agricultural crop according to Section 102 of the Co-operative Societies Act (Act 29 of 1929) (Cotton SA, 2015).

Cotton is also regarded as one of the utmost versatile cash crop grown by mankind. It is known for its good appearance and appealing comfort. Furthermore, thousands of jobs are generated by this industry in SA (DAFF, 2016). Cotton forms part of the backward and forward linkages, for instance, the earner of foreign exchange, buyer and seller of cotton, and processers; this indicates that cotton is influential for SA's economic growth. The gross value of cotton production is depicted in Figure 2.3.

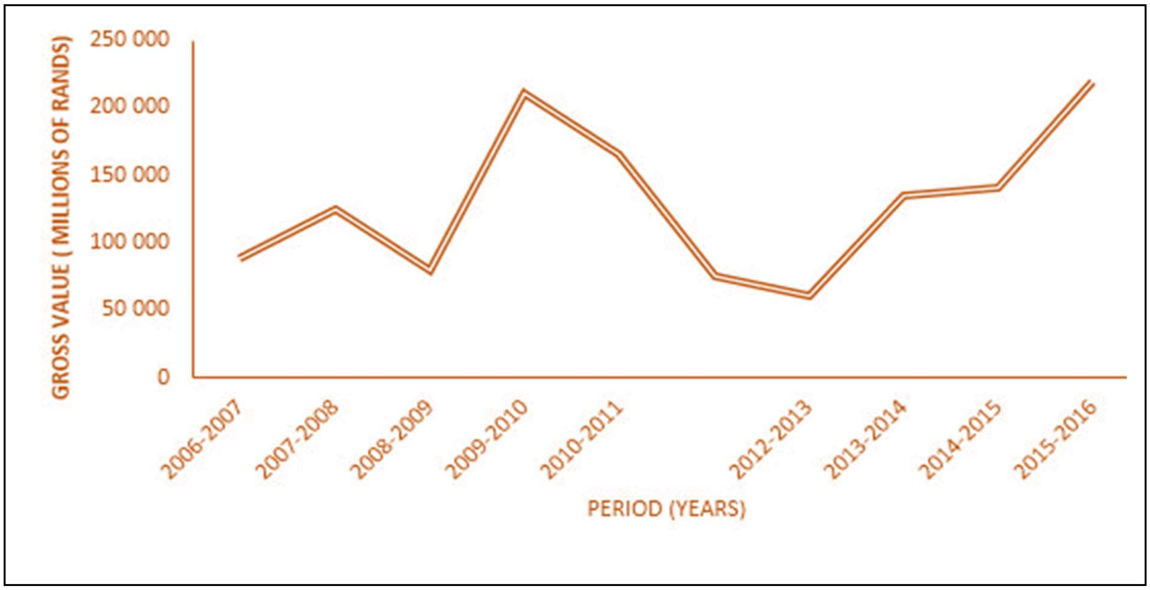

Figure 2.3: The gross value of cotton production from 2006/2007 to 2015/2016 marketing season.

Source: Adapted from DAFF (2016)

Figure 2:3 illustrates the variation in the gross value of cotton production from the 2006/2007 to the 2015/2016 marketing seasons. From the 2012-2013 to 2015-2016 marketing seasons, the gross value indicates an increase in an increasing rate, indicating a higher contribution of cotton towards SA's economy each and every season. The fluctuation of the gross value could be attributed to lower production and productivity and other influential factors during some production seasons. In general, the contribution of the cotton industry towards the gross value of cotton production indicates that cotton is an important crop for economic growth and one needs to evaluate the true value of resources used in order to produce this crop.

In SA, cotton is mainly grown within the Northern Cape, North West, and Limpopo provinces. However, cotton is also produced in KwaZulu-Natal, Mpumalanga, and Eastern Cape Provinces, even though it is on relatively small production scales. DAFF (2016) recorded that approximately14 522 tons and 2 923 tons of cotton seeds were in stock at the cotton ginners. Figure 2.4 portrays the total lint production versus the area planted with cotton.

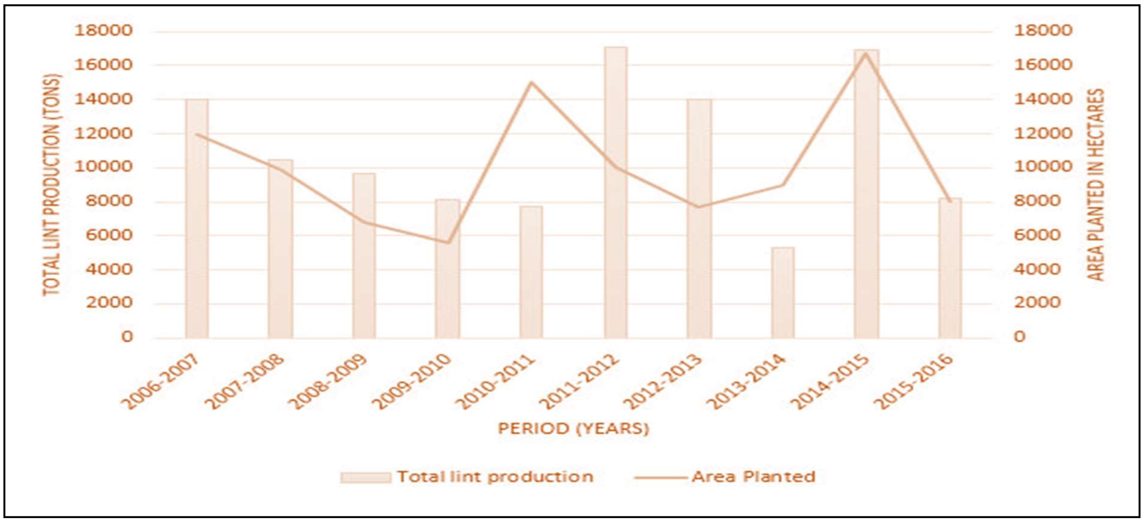

Figure 2.4: Total lint production vs. Area planted with cotton

Source: Adopted from DAFF (2016)

Figure 2.4 illustrates that during the 2006-2007 to 2009-2010 marketing seasons, the land used to plant cotton decreased. Similarly, the total lint produced during this period indicates a continuous decrease. The 2010-2011 marketing season depicts that the area used is not equivalent to the total lint produced. The period between 2010 and 2016 is characterised by substantial fluctuations in the area planted and the total lint production. The fluctuations can be a result of water fluctuations, among other factors. Therefore, it is important to ensure that the resources are used efficiently and effectively.

2.4 Theoretical framework

2.4.1 The water footprint concept

A number of methods are available to calculate the water footprint. (These include the consumptive water use, which is based on the volumetric WF method and is referred to as the Global Water Footprint Standard (GWFS) (Hoekstra et al., 2011), and the stress weighted water Life Cycle Assessment (LCA) as proposed by Pfister et al. (2009), and the hydrological water balance method loosely based on the methods developed by Hoekstra et al. (2011).

The concept of WF was firstly introduced by Hoekstra (2003). The WF measures direct and indirect fresh water used by consumers or producers, by comparing yield and the water usage.

The WF includes three types of water components/indicators, that is, the blue, green and grey water footprint indicators (Hoekstra et al., 2011). The WF is a geographically and temporally explicit indicator, displaying not only volumes of water use and pollution but also its locations. Characteristically, the vital intention of the WF assessment is to determine the sustainability of water resources by making the comparisons amongst WF and fresh water availability (Hoekstra and Mekonnen, 2010:2011). The following section focuses on explaining the different concepts and types of WF.

The consumptive water use based volumetric WF is based on the green, blue, and grey WF components (Hoekstra et al., 2011). Figure 2.5 illustrates the components of the WF indicator as per GWFS.

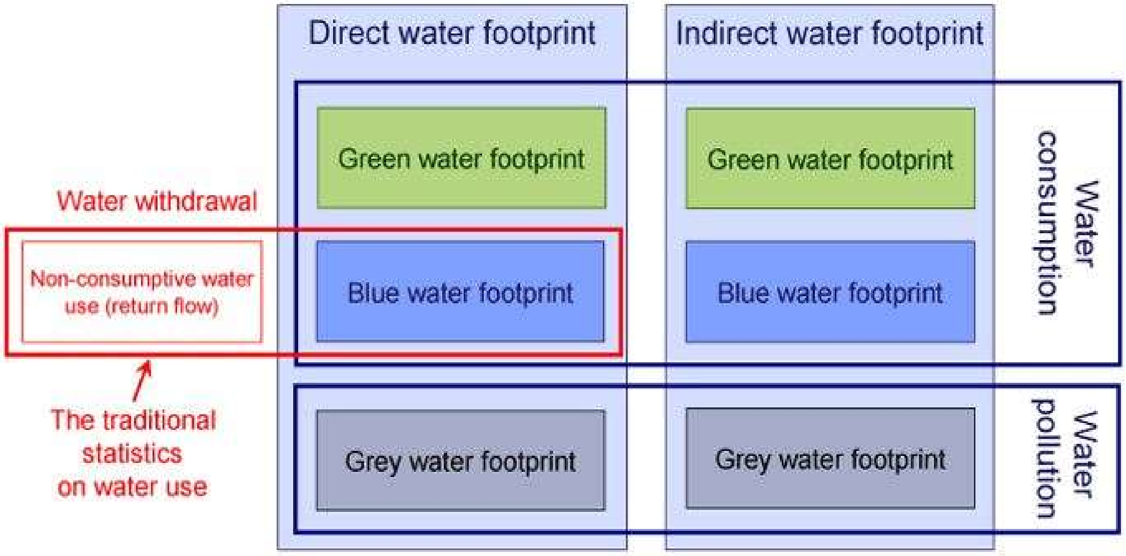

Figure 2.5: A schematic illustration of the components of a water footprint indicator
Source: Adapted from (Hoekstra et al., 2011)

The schematic illustration of the components of a WF indicator indicates surface and groundwater (blue), rainfall that does not become runoff, and the degradation of the water quality (Hoekstra et al., 2011). Direct and indirect WF usage is inclusive of blue, green, and grey WF. Direct WF refers to the fresh water consumed during the production of goods and services, and indirect WF refers to fresh water consumed while customers are using the product after production. Water withdrawal is part of the WF, as indicated in Figure 2.5.

- **Blue water footprint**

This indicates the consumptive use water; including fresh surface or groundwater. The term 'consumptive water use' refers to water that evaporates and water used in a product. It also refers to water that returns to a different catchment area or the sea and water that is withdrawn from a scarce period to a wet period (Hoekstra et al., 2011).

Therefore, consumptive water use does not mean water that simply dry out. Water will always form part of the evapotranspiration process (Hoekstra et al., 2011). It is a renewable resource, but its availability is not unlimited, this includes the amount of water that recharges groundwater reserves and flow through a river.

- **Green Water Footprint**

The green water footprint refers to the rainfall water (on land) that remains in the soil, does not run-off and is consumed by the crop. However, that does not necessarily mean that the crop has utilised all the green water. Only rainwater utilised during production is referred to as green water. The water which has evaporated during the period where production was not taking place is not considered as green water. In order to estimate the use of green water, the use of empirical formulas is employed and crop models are used to estimate evapotranspiration. Climate, crop characteristics, and soil are useful data while estimating green water used by the crop (Hoekstra et al., 2011).

- **Grey water footprint**

Grey WF refers to the volume of fresh water used to decrease the pollutants to an acceptable level. This water component indicates the severity of environmental damage by pollution. In addition, it is also a method used to decrease pollution to an acceptable level (Hoekstra et al., 2011).

- **Total water footprint**

The total WF is calculated by adding the blue WF, green WF and the grey WF components. Hoekstra et al. (2011) define different types of WF used to assess the impact of human behaviour on sustainable water use. These include the water footprints of a consumer (or a group of consumers); a geographically delineated area; a business; a product; and national.

2.4.1.1 Different types of water footprint

- **A consumer or group of consumers**

The WF of an individual consumer or group of consumers is specified as the total volume of fresh water used and polluted during the production of goods and services. This metric measures the use by the individual consumer or group and added together equates to the total WF. This calculation considers both fresh water consumed and the amount of water polluted during production. Also, the WF of a consumer is calculated by adding both the direct WF of the individual and his/her indirect WF (Hoekstra et al., 2011).

- **A geographically delineated area**

The WF within a certain geographic area encompasses the total amount of fresh water use, including the pollution, within the boundaries of that specific area. The area can be a catchment area, a river basin, a province, state or nation, or any other hydrological or administrative spatial unit. The WF for a specific spatial unit is expressed as the volume of water per time unit. It can also be expressed in terms of water volume per monetary unit if the WF per time unit is divided by the income in the area. The calculation of the water footprint for a geographically delineated area forms part of a much bigger assessment regarding the sustainability of the water resources in a specific area (Hoekstra et al., 2011).

- **A business**

The WF of a business can be defined as the total volume of fresh water used (either directly or indirectly) in order to operate and support the business. It consists of two main components, which include the operational and supply chain WF. The operational (or direct) WF of a business comprises of the volume of fresh water consumed or polluted due to the sole operations of the business (Hoekstra et al., 2011). The supply chain (or indirect) WF of a business encompasses the volume of fresh water consumed or polluted in the production of all the goods and services that represents the production inputs of the business. The aim of a business WF entails evaluating the impact of a specific business on water resources. The WF of a business is mainly imported from, for example, water-intensive inputs produced in another catchment. The WF of a business comprises the sum of the WFs of the final products produced by the business, which include both the operational WF and the supply chain WF of the business (Hoekstra et al., 2011).

- **A product**

A product's WF is specified as the total volume of fresh water used (either directly or indirectly) in producing it. It is estimated based on the water consumption and pollution involved in all steps of the production chain. The accounting procedure is similar to all types of products (e.g. products derived from the agricultural, industrial or service sector). A product's WF consists of three components, namely green, blue and grey water. It is a multidimensional indicator, which presents water consumption volumes by source and polluted volumes by pollution type with all components of a total WF specified geographically and temporally. A product's WF therefore consists of the sum of the WFs of the process steps taken in the production of the product (Hoekstra et al., 2011).

A product's WF is estimated by using two approaches, namely the chain-summation approach and the stepwise accumulative approach. The chain-summation approach is optimal where the production system produces one output product. The stepwise accumulative approach, however, accounts for production processes with more than one input and several outputs (Hoekstra et al., 2011).

- **National water footprint**

The national WF includes both an internal and external component. The internal component includes all the WF found within the national boundaries of the country where the products produced are consumed within the country whilst the external component refers to the WF in other countries for producing products imported by and consumed within the country (Hoekstra, 2014).

2.4.2 Other approaches

2.4.2.1. Life cycle assessment

The Life Cycle Assessment (LCA) methodology framework will be the tool for assessing and estimating the environmental influences of products. This assessment includes the effect of denying human users and ecosystems the water resources, as well as the potential impact that might arise from the discharged pollutants affecting water, through different impact pathways (Milà i Canals et al., 2008). According to ISO 14046 (2014) this tool is also used to assess the potential environmental effect caused by the production of products and services. The reason for the assessment is to determine the different types of potential environmental influences that contribute to the entire life cycle of a product (Hellweg and Milá ì Canals, 2014). According to Pfister et al. (2009), the LCA approach accounts for all consumptive water use that comprises of all fresh water withdrawals transmitted to different watersheds merged into the products or the water loss associated with evaporation

A complete LCA must include several stages within the process of evaluation, namely goal-setting and scope of the assessment, the WF inventory analysis, WF impact assessment, and also the interpretation of the results. All these stages have a direct application to product, development, strategic planning, public policy making, and marketing (Boulay et al., 2013). The study further revealed that measuring virtual water is a vital way in determining the consumptive water use in a production process.

These talks to the volume of water required in the production of goods or services, and it is inclusive of all influencers to the supply chain of production (Hoekstra, 2007). The LCA method uses the virtual water database developed by Chapagain and Hoekstra (2004) in order to determine the volume of water used in the production of relevant products. The water source and type of water used during the Life Cycle Inventory (LCI) phase is equally vital as the quantity of water used in the LCA report. Completing this, the Water Stress Index (WSI) is determined. The LCA provides the water quality influences, although this does not apply to the grey water method as proposed by Hoekstra et al. (2011). (Pfister et al., 2009).

The LCA method as introduced by Pfister et al. (2009), only considers the blue virtual water footprint because the green water footprint does not contribute to the environmental flows until it becomes blue water. According to Ridoutt and Pfister (2010), in the LCA context, it is more suitable to include water quality impacts under other impact categories (e.g. freshwater toxicity or eutrophication), or to apply multifaceted fate and effect models. After Ridoutt and Pfisters (2010) argued that WFA as per LCA does not account for green water use directly due to the use of this water being directly related to the occupation of land, however it is accounted for in the complete LCA. These methods have not articulated the water requirements to produce a product or a service in the value chain of a product but rather looked at the effect on water resources (Hastings and Pergram, 2012). Hoekstra et al. (2011) criticised the LCA, as it excludes the analysis of the grey water component. According to Riddoutt and Pfister (2010), LCA considers the water quality impacts and therefore, they recommend that it is more accurate to indicate water quality impacts under other impact groups such as freshwater toxicity or eutrophication in the LCA. According to Pfister et al. (2009) and Bayart et al. (2010), the LCA has its own inadequacies. Nonetheless, it has apparent attributes that provides a bridge to potential users of intermediate indicators whilst the protecting human health, the biotic environment, and other resources.

Ridoutt (2014) further stated that ISO 14046:2014 does not prescribe the exact methodology to apply in the computation of WF, but it is available to guide on what the consideration should be in computing a complete WF assessment. The LCA approach extensively considers the impacts connected with water consumption and assesses the water quality and quantity over a set period.

2.4.2.2. Hydrological water balance method

The Hydrological water balance method considers the blue, green, and grey water. The method recognises the explanation of blue, green, and grey water, as defined by Hoekstra et al. (2011). According to Deurer et al. (2011), wider factor components of water balance such as inflows, outflows, and changes in water storage are considered while calculating WF using the hydrological water balance method. In contrast to the consumptive water-based volumetric method, the hydrological water balance method allows both negative and positive WF. Therefore, the distinctiveness of the hydrological water balance method depends on its ability to include negative WF when accounting for ground water.

2.5 Discussion of the different approaches

According to the above discussion of different methods of WF assessment, the methods for calculating the WF differ. The discussion provides confirmation that the GWFS account for blue, green, and grey water, whereas Life Cycle Assessment accounts for only the blue water footprint. The LCA, however, focuses on the assessment of prospective environmental effect of the product, but excludes issue of sustainable, resourceful, and justifiable allotment of limited fresh water resources from the catchment to global level is not within the scope (Hoekstra, 2016). The LCA has, however, been criticised for neglecting the green water footprint.

Hoekstra (2016) concluded that GWFS and LCA are equally valuable to conduct, as it fulfils different purposes and it would be significant to integrate the two assessments of fresh water shortage. The LCA accounts for the resources depletion category, and assumes the limited accessibility of fresh water globally for productive use. Therefore, it is paramount to quantify (volumetric) WFs of the products; to measure the relative assertion of different products with scarcity of fresh water. With the hydrological water balance method, blue, green, and grey water footprints are determined annually on a local scale and the calculation system differs from that of the GWFS. The GWFS is often used as a fresh water sustainability indicator and it further formulates the strategic response in order to decrease the water used to produce a product.

In conclusion, the GWFS proposed by Hoekstra et al. (2011) proves to be the most suitable method for this study, as it accommodates the aims and objectives of the study. The GWFS will therefore, be adopted for the purpose of this study. Related studies on cotton WF assessment will be discussed in the next section.

2.6 Related Studies

Researchers conducted studies on WF assessment on different types of products, although this section will only focus on studies related to WF assessment of cotton. Studies exploring water footprint of cotton include those of Chapagain et al. (2006); Aldaya et al. (2010); Zeng et al. (2012); Ercin et al. (2013); Rudenko et al. (2013); Wei et al. (2016).

Chapagain et al. (2006) assessed the effect of global utilisation of cotton products on water resources in cotton producing countries. In the assessment there was a distinction made between the three components of water footprint (green, blue and grey water footprint) and the effect of these on the total WF. The CROPWAT model was utilised in order to estimate effective rainfall and irrigation requirements of different countries. The study found that the global utilisation of cotton products requires 256Gm^3 of water per year. Clearly, cotton requires a larger proportion of water, and 42% of the water was blue water indicating that the global utilisation of cotton products requires a lot of irrigation water. Within the South African context, the utilisation of cotton products required about 80mm^3 per year of blue water, 80mm^3 per year of green water and 47mm^3 per year was associated with grey water.

Aldaya et al. (2010) explored the WF of cotton and other crops produced in Central Asia using the Hoekstra et al. (2009) approach. In the Aral Sea Basin area, which forms part of the Southern region cotton is one of the main crops produced. The results indicated that an average of 6875m^3/ton for the blue water footprint was used in the production of cotton, which is a fairly large proportion for one crop. They concluded that cotton production in the Aral Sea Basin countries contributed to the scarcity of water in Aral Sea resulting from a significant volume of water and fertiliser used during production. The authors recommended that reduction or improved supervision of water as a resource may possibly be attained through importation of agricultural products from green water-abundant regions.

Zeng et al. (2012) assessed the WF at a river basin level. Heihe River basin in Northwest China was used as case study and cotton was one of the products which were irrigated using the water from this basin. The aim of this study was to determine the WF within that basin. The assessment was based on the Global Water Footprint Standards, as proposed by (Hoekstra et al., 2011). The research results recorded a large water footprint of about 1768 million m^3/year in the Heihe River basin. The virtual water content of cotton was reported as 3384m^3/ton; the largest consumer of water compared to other crops. The virtual water content of cotton was an exception, although the value estimated was double the national average value. These results also indicate that cotton utilises large volumes of water.

Ercin et al. (2013) analysed the allocation of fresh water resources in an attempt to quantify the water footprint of selected agricultural products. Data used for the study was obtained from

Mekonnen and Hoekstra (2010; 2011) and the monthly blue water scarcity study from Hoekstra and Mekonnen (2011) and Hoekstra et al. (2012). From all the crops planted in those regions, eight were identified as a matter of concern. Among those, three major crops were assessed, namely cotton, sugarcane, and rice. Approximately 47% of the water footprint was associated with those crops. The research results highlighted that the largest share (roughly 22% of the total virtual water import) relates to the import of cotton and its resulting products. Results also indicated a 52.7Gm^3/year green WF of imported products, with cotton products having the largest green WF. The blue WF of the imported products was 10.5Gm^3/year. Of the 10.5Gm^3/year of blue water, 56% was due to cotton products. Cotton was also the second largest consumer of water considering the water used to assimilate pollution in the industry. The researchers concluded that cotton and its derived products are leading factors contributing to the blue water scarcity.

Rudenko et al. (2013) explored the macroeconomic analysis of cotton production, processing and export in water-bound Uzbekistan. Cotton production in this area consumes around 41% of all irrigation water; approximately 6000 to 8000m^3/hectare. In order to produce a ton of cotton, about 6819m^3 was needed, which again emphasise the large proportion of water that cotton uses.

Lastly, Wei et al (2016) incorporated water consumption into crop WF. Among the crops produced in China South-North water diversion project, cotton presented a high blue WF due to high irrigation water dependency. Following the studies conducted by Hoekstra and Chapagain (2008), cotton was found to be one of the primary crops that use a lot of water. The results indicate that cotton uses high volumes of irrigated water and thus, it is vital to take note of the volumes of water used by crop grown in any country.

2.7 Efficiency of water use

Evaluating the efficiency of water use occurs by comparing the WF of a specific process or product to a WF benchmark for that specific process or product; based on the best available technology and practice (Mekonnen and Hoekstra, 2014; Chukalla et al., 2015). Assessing the equitability of water use follows by comparing the WFs related to the consumption levels and patterns of different communities (Seekell, 2011; Hoekstra, 2014). Furthermore, by analysing the extent to which companies/communities depend on unsustainable water use within their supply chain, the water dependency and security can be assessed (Ercin et al., 2013). Generally, the study of how water volumes are allocated to the challenging demands are included in the various types of analysis. A vital element includes determining the water volumes, which explains the apprehension in the water resources community to talk in terms of "weighted cubic metres" of water; a key element in the LCA community.

2.8 Discussion of related studies

Given the above review of related studies, the WF concept has been taken into consideration given the global water scarcity. However, only a few international studies have been conducted on cotton. To the author's knowledge, there are limited studies exploring the use of fresh water during cotton production in South Africa. The literature reviewed reveals the importance of conducting the water footprint assessment of cotton, as it has proved to be a contributing factor towards fresh water scarcity. The WF indicator is a basic indicator used in determining environmental sustainability. The following section focuses on the sustainability of the WF.

2.9 Water footprint sustainability

2.9.1 Environmental and Social water sustainability

The sustainability assessment concerns the assessment of the relationship between the availability of water on earth and the human water footprint (Hoekstra et al., 2011). Under the umbrella of wise fresh water allocation there are three pillars, namely environmental, social, and economic water use (Hoekstra, 2015). These three pillars ensure the sustainability of fresh water use and the benefits of fresh water use to the users thereof. Therefore, it is important to evaluate the environmental, social, and economic productivity or sustainability of cotton production. In order to ensure the sustainable, efficient, and equitable water use, all three pillars must be taken into cognisance. However, only the environmental sustainability received considerable attention, and not the economic productivity and social sustainability aspects.

The sustainability of cotton depends on the geographic context in which cotton production takes place. The product on the certain catchment or area water footprint can be regarded sustainable if it does not compromise the environmental needs and the standards set by the water management. If not, the water footprint is not sustainable, and it can be considered economically inefficient (Hoekstra et al., 2011); an environmental hotspot per se.

According to Hoekstra et al. (2011) the environmental sustainability of a certain catchment depends on the balance between the environmental needs and pollution with the water availability. Blue and green water scarcity and the water pollution levels need to be calculated in order to determine the environmental sustainability. It is important to know the green and blue water availability on the catchment. If the environmental needs exceed the availability of the water, it is regarded as unsustainable. The social water sustainability relates to the environmental sustainability where basic human needs are not met through the distribution of the available water, and thus creates a social hotspot (Hoekstra et al. 2011). The water footprint can be regarded as sustainable if water on a certain catchment is safe and clean to use for document tasks. The following authors considered environmental sustainability: Hoekstra et al. (2011), Zeng et al. (2012), Hoekstra (2015), Pellicer-Martinez et al. (2016) and many others. The following section provides literature on environmental sustainability.

Zeng et al. (2012) assessed the WF at a river basin level in China. They found that the blue WF exceeds the water availability in Heihe River, thus it is regarded as unsustainable. This indicates that human needs were met by violating the environmental flows. The author emphasised that crop optimisation is key to sustainability.

Pellicer-Martinez et al. (2016) explored the WF as an indicator of environmental sustainability in water use at the river basin level. The sustainability assessment was analysed in three different forms, namely the green, blue, and grey WF. The sustainability of the water of Segura River Basin depends on the following components: pollution, overexploitation of aquifers, competition for the use and other alternatives, among others. The blue water use was found to be sustainable due to the generalised overexploitation of water geological formation. Furthermore, the author revealed that surface water pollution was due to phosphate concentrations.

Determining the WF sustainability of cotton production is one of the objectives of this study. WF of the process depends on the process that it takes in producing cotton as a product. For the purpose of this study, the WF sustainability will be assessed on the Limpopo River basin, along the Olifantsriver under Loskop irrigation scheme, in Limpopo province. The water footprint sustainability of cotton production is evaluated in three different dimensions, which includes the environmental, social, and economic.

The geographic sustainability of the WF of this study will be within the Olifantsriver. The environmental hotspot has a relationship with the blue, green, and grey water footprint in a catchment (Loskop irrigated scheme). The next section further elaborates on blue water availability and blue water scarcity.

Figure 2.6 illustrates the blue water availability, blue WF, and the environmental flow requirement of the Limpopo River basin. Blue water availability reaches a peak in February, thereafter it decreases as time goes on.

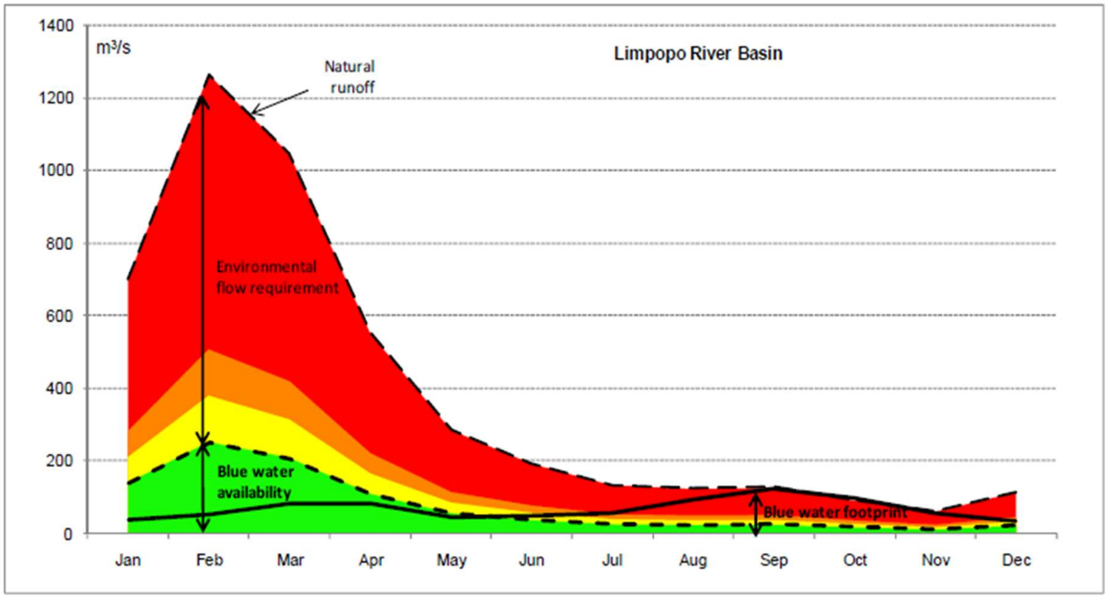

Figure 2.6: The blue WF over the year compared to blue water availability for Limpopo river basins for the period of 1996-2005.

Source: Hoekstra et al. (2011)

According to Hoekstra et al. (2011) a mismatch between water availability and water demand is present. From July to November, Limpopo River basin faces severe water scarcity, as indicated in Figure 2.6. From January to March it is the period where the environment also requires high volumes of water. The most severe scarcity period is experienced towards early spring due to a low runoff, as the demand for irrigation starts to increase. May to December is the period in which these basin faces low water scarcity. Large volumes of water is used for irrigation water in the agriculture sector, mostly for fodder crop, cotton and sugarcane, and added together accounts for approximately 52% of the water from this basin.

Table 2.1 depicts the planting and harvesting times for cotton in the Loskop irrigation scheme. The early cotton crop is planted from September and the harvest starts from May the following year. The late cotton crop is planted from October and harvested from June.

Table 2.1: Loskop irrigation scheme cotton planting and harvesting time

Crop	**Planting time**	**Harvesting time**
Early cotton	September	May
Late cotton	October	July

Source: Information from the farmer (2017)

When considering the time for planting cotton, as indicated in Table 2.1, blue water scarcity is severe during cotton planting season. Severe shortage of blue water scarcity occurs when the plants need water the most and the blue water scarcity is low when it is almost harvesting time. It is important that the farmer is aware of the blue water availability of the river basin, which they source water from, in order to align their production according to the water availability.

Figure 2.7 and Figure 2.8 illustrate the blue water scarcity for Limpopo River basin from January until December for the period of 1996-2005.

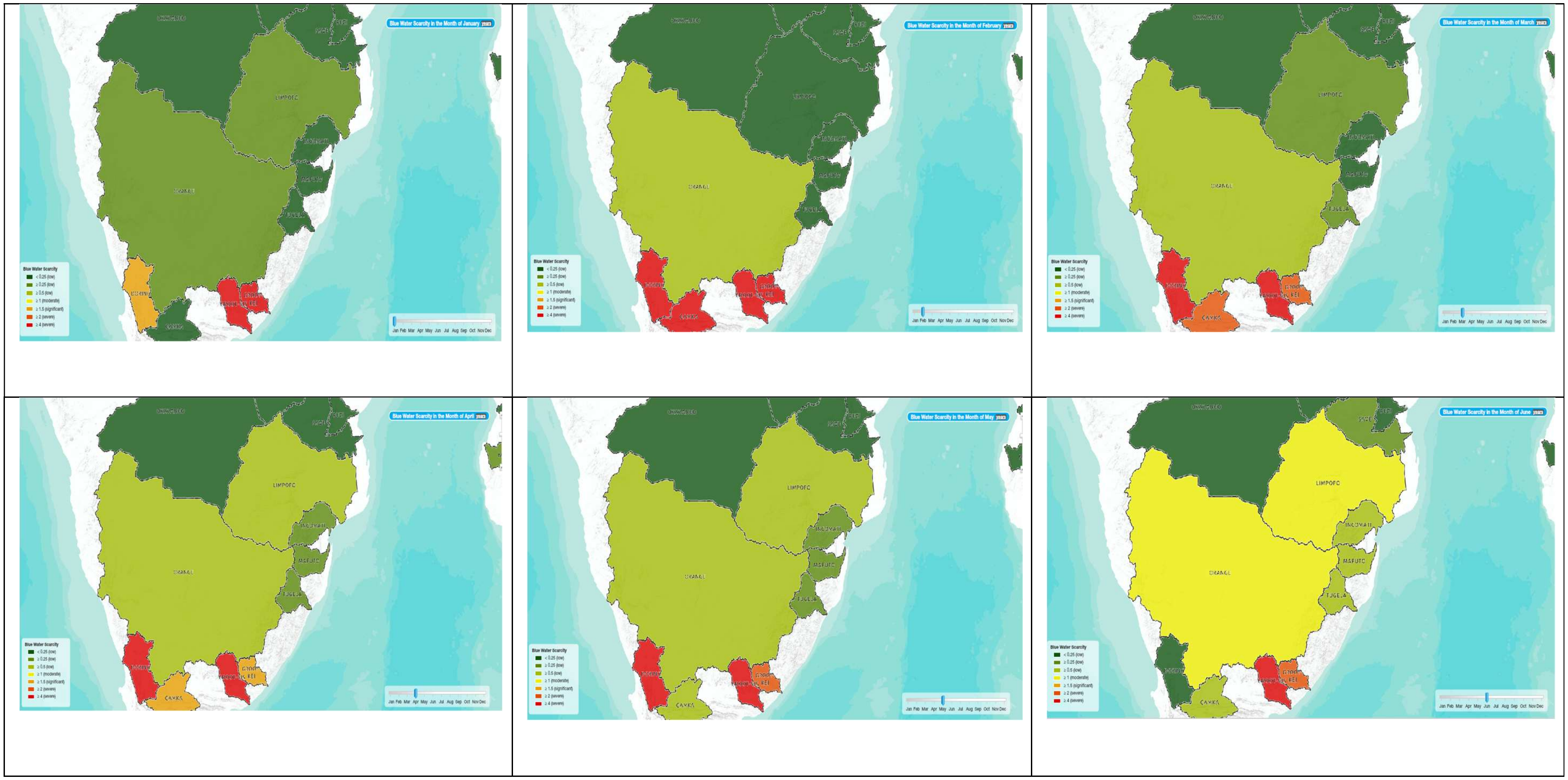

Figure 2.7: Blue water scarcity for Limpopo River basin from January until June for the period of 1996-2005

Source: Hoekstra et al. (2011)

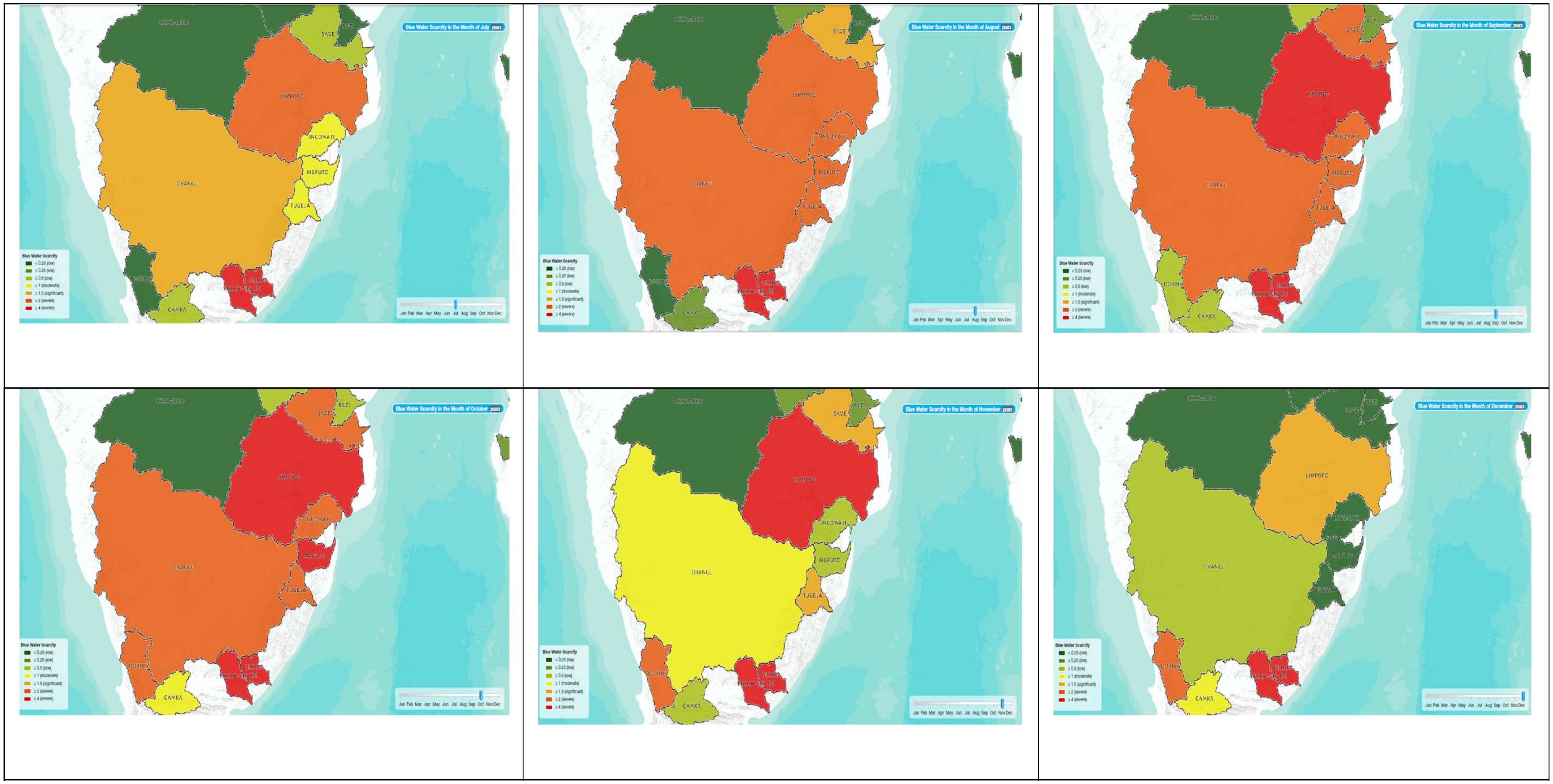

Figure 2.8: Blue water scarcity for Limpopo River basin from July until December for the period of 1996-2005

Source: Hoekstra et al. (2011)

Figure 2.7 and Figure 2.8 illustrate the blue water scarcity and the water availability of the Limpopo River basin. From January to the end of May illustrates a low blue water scarcity, and from June to August the blue water availability is moderate, with September to November indicating severe blue water availability. Blue water scarcity can be classified into four levels, namely: Low blue water scarcity (<100%) – generally when the blue WF is lower than 20% of the natural drainage, bigger than the blue water availability, and the environmental flow requirements are met; Moderate blue water scarcity (100-150%) – when the blue WF range between 20% and 30% of the natural drainage, and the environmental flow requirements are not met; Significant blue water scarcity (150-200%) – the blue WF is between 30% and 40% of the natural drainage and the environmental flow requirements are not met; Severe water scarcity (>200%), – when the blue WF is higher than 40% of the natural drainage and the environmental flow requirements are not met. Table 2.2 illustrates blue water scarcity levels in different colours and their meaning.

Table 2.2: Blue water scarcity levels

🟩	<0.25(Low)
🟩	≥0.25 (Low)
🟩	≥0.5(Low)
🟨	≥1(Moderate)
🟧	≥1.5(Significant)
🟧	≥2(Severe)
🟥	≥4(Severe)

Source: Hoekstra et al. (2011)

As mentioned, Table 2.2 illustrates blue water scarcity levels in different colours and their meaning. Green indicates that the blue water scarcity level is low, yellow refers to moderate levels of blue water scarcity, orange indicates that the blue water scarcity is significant and the red represents severe blue water scarcity levels.

2.9.2 Economic water productivity (economic water sustainability)

In order for the WF to be economically sustainable, water must be allocated in an economically efficient way. The results of using water must be economically beneficial to all (Hoekstra et al., 2011) and this can be assessed by computing the economic water productivity (EWP). Chouchane et al. (2015) designate EWP as the value of the marginal product of the agric-food products in relation to water. This can be calculated using two different steps. One can calculate EWP using the physical water productivity (PWP) or economic productivity of the product. The PWP is calculated by dividing the yield of the water footprint of the product. Economic productivity of the product can be calculated by multiplying the physical water productivity of the product by the monetary value of the product. Ensuring economic sustainability links with the National Water Act (No 36 of 1998) of SA (RSA, 1998), which aims to provide sufficient water in order to maintain economic growth and sustain the environment. Therefore, it is imperative to be aware of the EWP of cotton produced in SA, as it plays a vital role in the contribution of GDP by the agricultural sector.

Only a few researchers incorporated EWP while calculating the WF of products. Aldaya et al. (2010) calculated the economic blue water productivity of cotton and other crops in Central Asia. The blue water productivity of cotton was approximately 0.5 US$/m^3. Similar to the aforementioned studies, cotton had the highest WF along with the highest economic blue water productivity. Therefore, the country must invest in such crops, and aim to reduce the water use, which is a scarce resource.

Chouchane et al. (2013) found that 80% of the gross value can be contributed to the irrigated crops, while blue water accounted for 61%. It was also found that the blue water economic productivity (according to 2009 prices) ranged between 0.89 €/m^3 and 1.15 €/m^3 during that period. However, more income was generated from the utilisation of blue water in relation to the other types of water. According to the studies of Craffaord et al. (2004), the social, environment, and the economics of water use in irrigated agriculture and forestry was analysed. The economic benefits were measured by the enhancement to the value chain. Social impact was measured by its contribution to employment, social benefit cost, enterprises, and the perception of the household. The LCA was used in order to analyse the environmental impact. Economic analysis impact results illustrated that the direct value added per cubic metre of water ranged between 1.8ZAR/m^3 and 2.6ZAR/m^3 of water for the forest plantations, 1.3 ZAR/m^3 for sugarcane, and 3.2ZAR/m^3 to 8.7 ZAR/m^3 for subtropical fruit. After considering the indirect relation, value added per cubic metre of water ranged between 19.9 ZAR/m^3 and 32.1 ZAR/m^3 of water for the forest plantations, 9.9 ZAR/m^3 for sugarcane, and 3.2 ZAR/m^3 to 8.9 ZAR/m^3 for subtropical fruit. The study concluded that the more the product demands employment, the more benefits it provides, therefore it is important to evaluate all three factors.

Within the South African context, only a few authors considered the concept of economic productivity of the water used during production of agricultural crop. Since the agricultural sector is the largest user of fresh water, it is important to consider the economic productivity of the water used in order to produce a crop. To the author's knowledge, the economic productivity of the water utilised during cotton production has not been explored. The economic productivity of the water utilised to produce cotton will aid water users to allocate water to areas where it makes economic sense to produce. Therefore, it is imperative to include the economic productivity of the water used in producing cotton.

2.10 Conclusion

Water is a scarce and useful resource on earth. The availability of fresh water is low and therefore, water needs to be used efficiently and effectively, especially since SA is regarded as a water-stressed country. However, water remains a useful resource to the South African economy and irrigated agriculture plays a significant role towards the GDP. Thus, it is important to have knowledge of the water used by irrigated crops.

The literature explored confirms that the cotton industry is a major player in the South African economy. The industry contributes towards the economic growth through job creation, bettering the standard of living of the residence around the industry, and community development. Water is a scarce resource and is regarded as a major resource used in the cotton industry. It is, therefore, important to evaluate the use of this resource throughout the value chain of cotton.

Literature highlights the importance of evaluating the volume of water utilised to produce cotton. The WF concept is a useful tool to evaluate or assess the use of water during cotton production. The purpose of the WF assessment is to examine the sustainability of fresh water versus the scarcity of water as a resource. The evaluation can be done by using different methods, as discussed above. However, the method of Hoekstra et al. (2011) proved to be best suited for this study. This method accounts for blue, green, and grey water footprint. However, the data used in this approach is primarily average data of the region or province of which they do not show the unique consumption pattern of a specific product in a specific geographic setting (Paterson et al., 2015). LCA accounts for blue water and the environmental impact of the product, while the efficient and effective allocation of scarce water resources is not sustainable, or is not included.

The method of Hoekstra et al. (2011) is mostly concerned with the sustainability of the use of fresh water. WF assessment concept has been used to assess the water used by different crops. However, there are no scientific studies assessing the water footprint of cotton in South Africa. According to Hoekstra (2016), both WF and LCA are important, though it serves different purposes. LCA assesses the environmental impact of the product. The most important issue is sustainability, which is assessed by WF and provides a clear evaluation of blue, green, and grey water footprint. While using GWFS approach, it is possible to incorporate the economic evaluation of water used during the production of cotton. Therefore, the volumetric water used during cotton production and the water footprint sustainability is crucial and it needs to be addressed.

CHAPTER 3

METHODOLOGY AND DATA

3.1 Introduction

Chapter 3 encompasses a discussion of the methodology and data utilised in order to fulfil the aims and objectives defined in Chapter 1. The goals and scope of this study can therefore, be achieved by following the methodology of the water footprint (WF), as discussed in Chapter 2. Global Water Footprint Standard (GWFS) introduced by Hoekstra et al. (2011), was identified as the best approach aligned with the goals and scope of this study. The GWFS will be explained in detail, followed by a discussion on the location of the study and concluded by an illustration of the data used in order to fulfil the aims and objectives of this study.

3.2 Methodology

The GWFS (Hoekstra et al., 2011) method best suits the goals and scope of this study since it accounts for the blue, green, and grey WF, and it is more concerned with the sustainability of fresh water. The methodology to be discussed in this Chapter is grounded in the guidelines, as discussed by Hoekstra et al. (2011) in the Water Footprint Assessment Manual.

According to Hoekstra et al. (2011), the WF Assessment consists of four phases. Phase 1 involves setting the goals and scope of the assessment; Phase 2 concerns the calculation of the volumetric WF indicator; Phase 3 entails the evaluation of environmental, social, and economic perspective assessment in order to ensure the sustainability of water; Phase 4 reciprocate the development of strategies, which can be followed to enhance the sustainability of the scarce resource, namely water, in this study.

3.2.1 Phase 1: Setting the goals and scope

3.2.1.1 Goals of water footprint assessment

The research entailed assessing the WF of cotton. It found that product WF assessment best suits the aims and objectives of this study. Cotton was assessed at farm level to execute the analysis of the study.

3.2.1.2 Scope of the water footprint accounting

The following was included or excluded when setting up the WF account:

- Blue and green water WF was accounted for during the assessment. Generally, blue water is considered to be limited and higher in opportunity cost compared to green water. Thus, blue water accounting has been given greater attention historically. However, the supply of green water is also limited, thus emphasising the importance to account for green water, as well. Therefore, blue and green WF will be calculated for the purpose of this study.

- The total WF of the cotton as a product at farm level will be calculated. Furthermore, the truncation of the supply chain to a certain product is of significance to the analysis, but will be excluded for the purpose of this study as the assessment will only focus on the product on farm level.

- Water footprints will also be assessed in different levels of spatiotemporal detail for the purpose of this study. Level B of spatiotemporal explication in WF accounting will be analysed as the analysis was done on a farm in a selected region.

- Period of data: the availability of water fluctuates and the demand of water differs at times. It is, therefore, important to pinpoint the period of which the WF was accounted for. For the purpose of this study, only 2017 was considered with the use of SAPWAT 4 programme to further run the data.

- The direct WF of cotton was calculated in order to obtain the total volume of fresh water directly and indirectly used in producing cotton. However, historically the focus was only on the direct WF and not the indirect WF.

- When calculating the total WF in the production of cotton, labour was excluded in order to eliminate boundless accounting and repetition problems. The grey WF was also excluded due to limited information on water used to assimilate pollution.

3.2.2 Phase 2: Water Footprint Accounting as per GWFS method

The first objective of the study is to calculate the volumetric WF of cotton production on farm level. The product WF denotes the level of stress the product place on fresh water as a scarce resource in South Africa. The WF of growing cotton is calculated by calculating the sum of the blue and green water component.

$$\mathrm{WF}_{\mathrm{B\ and\ G}} = \mathrm{WF}_{\mathrm{cotton,blue}} + \mathrm{WF}_{\mathrm{cotton,green}} \qquad [\mathrm{Volume}\ /\mathrm{mass}] \tag{1}$$

Where;

$\mathrm{WF}_{\mathrm{B\ and\ G}}$= Blue and green water footprint

$\mathrm{WF}_{\mathrm{cotton,blue}}$= Blue water footprint

$\mathrm{WF}_{\mathrm{cotton,green}}$ = Green water footprint

The blue WF used to produce cotton is expressed as ($\mathrm{WF}_{\mathrm{cotton,blue,}}\mathrm{m}^3/\mathrm{ton}$), which is the irrigation water evapotranspired over the cotton production period and is calculated by dividing the blue component in cotton water use ($\mathrm{CWU}_{\mathrm{blue,}}\mathrm{m}^3/\mathrm{ha}$) by cotton yield (Y, ton/ha). The green WF used to produce cotton is calculated in the same manner as the blue WF, and it is expressed as ($\mathrm{WF}_{\mathrm{cotton,green,}}\mathrm{m}^3/\mathrm{ton}$), which is the volume of rain water that evapotranspired over the cotton production period and it is calculated by dividing the green component in cotton water use ($\mathrm{CWU_{green,}m^3/ha}$) by cotton yield (Y, ton/ha). The blue and green WF is determined by the following equations;

$$\mathrm{WF_{cotton,blue}} = \frac{\mathrm{CWU_{blue}}}{\mathrm{Y}} \quad [\text{volume /mass}] \tag{2}$$

$$\mathrm{WF_{cotton,green}} = \frac{\mathrm{CWU_{green}}}{\mathrm{Y}} \quad [\text{volume /mass}] \tag{3}$$

Where;

$\mathrm{CWU_{green}}$ is green cotton water use

$\mathrm{CWU_{blue}}$ is blue cotton water use

Y is cotton yield

The blue and green crop water use ($\mathrm{CWUm^3/ha}$) can be determined by following the equation below:

$$\mathrm{CWU_{blue}} = 10 \times \sum_{\mathrm{d=1}}^{\mathrm{lgp}} \mathrm{ET_{blue}} \qquad [\text{volume /Area}] \tag{4}$$

$$\mathrm{CWU_{green}} = 10 \times \sum_{\mathrm{d=1}}^{\mathrm{lgp}} \mathrm{ET_{green}} \qquad [\text{volume /Area}] \tag{5}$$

Where,

$\mathrm{ET_{blue}}$ is the blue water evapotranspiration

$\mathrm{ET_{green}}$ is the green water evapotranspiration

lgp is the length of growing period in days

10 as indicated in equation 4 and 5, is the factor to convert water depths in millimetres into water volume per land surface in $\mathrm{m^3/ha}$.

Following Mekonnen and Hoekstra (2010), the WF of cotton per unit of production is determined as the WF per hectare/yield. The Economic Water Productivity (EWP) represents the economic value of the farm output per unit of water consumed and is determined as the average producer price for that period/ $WF_{blue+green}$. The economic productivity of water used to produce cotton gives the indication of how much income is generated from the water used in cotton production. The economic value of the farm output per hectare is represented by the economic value of the farm. Economic value of the crop is determined by multiplying the crop yield with the producer price.

The blue water productivity was calculated as follows (Hoekstra, 2014):

$$WP_{blue}=\frac{Yt_{blue}}{ET_{blue}} \qquad (6)$$

Where;

WP_{blue} is the blue water productivity

Yt_{blue} is the cotton crop yielded under irrigation

ET_{blue} is the evapotranspiration of blue water

The green water productivity was calculated as follows (Hoekstra, 2014):

$$WP_{green}=\frac{Yt_{green}}{ET_{green}} \qquad (7)$$

Where;

WP_{green} is the green water Productivity

Yt_{green} is the cotton crop yielded under rainfall

ET_{green} is the evapotranspiration of green water (rainfall water)

According to Chouchane et al. (2015) $\mathrm{Yt}_{\mathrm{green}}$ is determined as follows;

$$\mathrm{Yt}_{\mathrm{green}} = \left(1 - \frac{\mathrm{Y_a}}{\mathrm{Y_m}}\right) = \mathrm{RF_y}\left(1 - \frac{\mathrm{ET_a}}{\mathrm{CWR}}\right) \tag{8}$$

Where;

$\mathrm{RF_y}$ is the cotton yield response factor

$\mathrm{Y_a}$ is the actual cotton crop yield in kg per hectare

$\mathrm{Y_m}$ is the maximum yield attainable at optimum water level

$\mathrm{ET_a}$ is the actual crop evapotranspiration measured in millimetres per period

CWR is the crop water requirement in millimetres per period.

The total water productivity is then calculated according to the following equation;

$$\text{Total WP} = \mathrm{WP_{blue}} + \mathrm{WP_{green}} \tag{9}$$

The economic water productivity of cotton crop is therefore expressed as;

$$\mathrm{EWP} = \mathrm{WP} * \mathrm{PP} \tag{10}$$

Where;

EWP is the economic water productivity

WP is the water productivity

PP is the price of the product

3.2.3 Phase 4: Water Footprint Response

During the last stage of the WF assessment, strategies are formulated in response to the assessment conducted in Phase 1, Phase 2, and Phase 3. Strategies to solve the water challenge depending on the water used to produce cotton are formulated. The water users are informed on how to use water as a scarce resource effectively and efficiently considering the environment, social, and economic impact of fresh water use. These strategy formulations are discussed in detail in Chapter 5.

3.3 Data

This study's scope encompasses a case study of the WF of cotton in South Africa. The study made use of primary data from a farmer located in Loskop dam in Marble hall in Limpopo. SAPWAT 4 was used to confirm the data supplied by the farmer. The farm level data will give the true picture of the water used by a specific farmer in the specific area. Different geographic settings have different climate change and soil composition that influence the demand of water differently. Some parts of the region receive more rain than others, therefore the water requirement of a specific area will not be the same as the next region (Alam, 2011).

South African Procedure for estimating irrigation Water requirements (SAPWAT) is a programme that is used to make assumptions of the irrigation water requirements of crops and it is based on the CROPWAT model (Allen et al., 1998; Van Heerden et al., 2008; FAO, 2009). SAPWAT uses its core procedures, which contains the international guidelines that are accepted, to estimate the irrigation requirements. The programme utilises the climate data from the closest weather station in order to locate where the crop is produced, the programme is also linked to the weather stations, and it receives updates as new weather patterns are set up (Van Heerden et al., 2008). Other information that needs to be inserted in SAPWAT, includes: rainfall, type of crop planted, solar radiation, air temperature, humidity, and planting time (Allen et al., 1998). The weather data was extracted from Petersburg weather station.

The model employs a reference gross evapotranspiration, and the crop requirement is calculated based on any stage in the growth cycle of a crop (Allen et al., 1998). The model gives default values to all crops under irrigation in South Africa, with cotton being one of the crops. Monthly crop requirements are obtained by multiplying the monthly gross evapotranspiration by the monthly average crop factor. After running the model, the following results will be obtained: crop evapotranspiration (CR (ET)), rainfall (R), rain loss (RL), effective rainfall (ER), irrigation water (I), irrigation loss (IL), and effective irrigation (EI). The results are then used to calculate the WF of cotton.

3.4 Location

The research was conducted in Mable Hall, a town situated in the Limpopo Province and close to Mpumalanga Province. Farmers in Marble Hall under the Loskop irrigation scheme source water from the Olifants River. The Olifants River flows into the eastern direction from SA into Mozambique, as illustrated in Figure 3.1. Marble Hall receives an average rainfall of approximately 496mm per annum, with the most rainfall occurring mainly during summer.

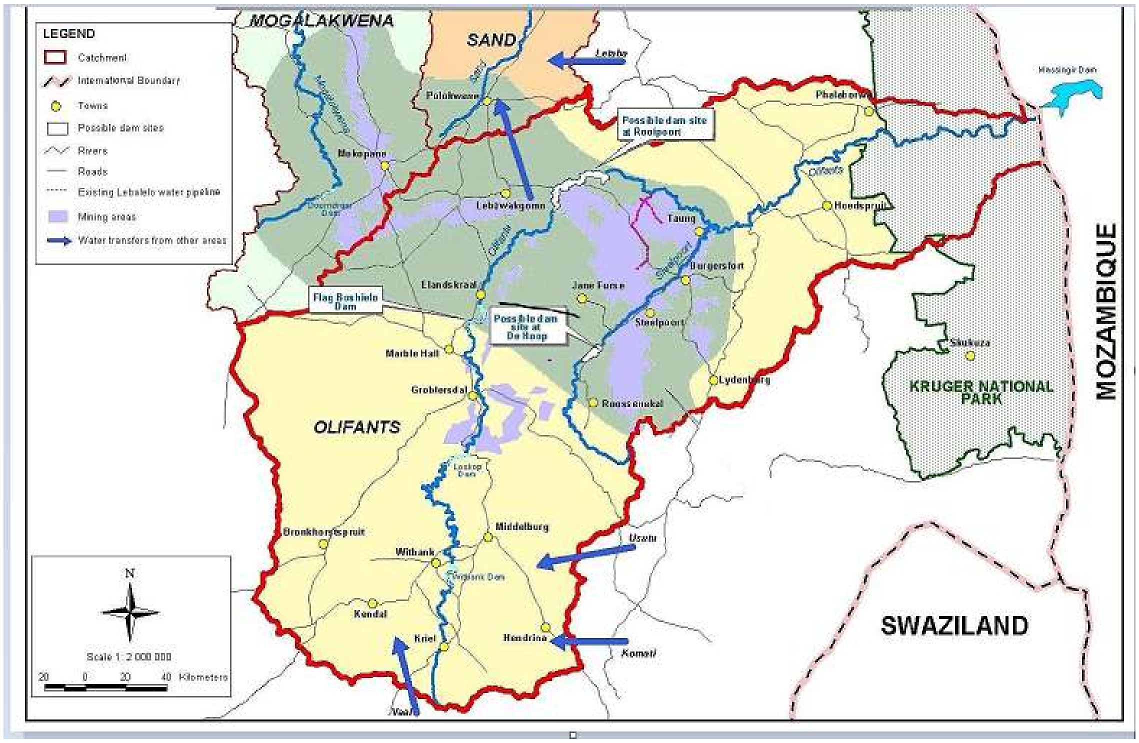

Figure 3.1: Layout of water flow from the Olifants River basin in Limpopo and Mpumalanga
Source: Department of Water and Sanitation (2018)

Loskop dam serves as a source of water to the Loskop irrigation scheme by means of canals. The irrigation scheme is made up of 624 farms (International Water Management Institute, 2000). The water supplied to farmers is measured in various sluice gates along the canals. Through the sluice gates, water can be delivered at $17m^3$/hour to $200m^3$/hour depending on the size of the gate (International Water Management Institute, 2000).

CHAPTER 4

RESULTS

4.1 Introduction

In this chapter, the results of the analysis found in this study are presented. The first section of the results presents the calculation of the volumetric water footprint (WF) of cotton. The second section highlights the Economic Water Productivity of producing cotton, where the value added to water during cotton production is assessed. Lastly, the conclusion drawn from the results follows.

4.2 Volumetric water footprint of cotton

The calculation of WF was based on two different planting dates. The early and the late cotton crops are planted in September and October respectively. Table 4.1 illustrates cotton production estimates from the Loskop irrigation scheme. For the early crop, the planting season of this cotton starts from September. The cotton yield per hectare was 4.8ton/ha, with crop evapotranspiration (CR (ET)) of 566mm, rainfall (R) of 383mm, and rain loss (RL) of 54mm. Effective rainfall (ER) was 329mm, irrigation water (I) of 300mm, irrigation loss (IL) of 66mm, and effective irrigation (EI) of 234mm.

Table 4.1: Summary of water use data at the measuring points in the Loskop irrigation scheme for planting date in September.

CROP	Cash crop	YIELD (ton/ha)	CR (ET) (mm)	R (mm)	RL (mm)	ER (mm)	I (mm)	IL (mm)	EI (mm)	EI+ER (mm)
Cotton	Medium Grower	4.8	566	383	54	329	300	66	234	563

Source: SAPWAT

Table 4.2 indicates the total evapotranspiration of cotton in Loskop of 566mm. ET was converted from mm to m^3 indicated by $\mathrm{CWU}_{\mathrm{green}}$ and $\mathrm{CWU}_{\mathrm{blue}}$.

Table 4.2: Cotton water use in Loskop irrigation scheme planting as of September

CROP	ET_{crop}(mm)	ET_{blue} (mm)	ET_{green} (mm)	CWU_{blue}(m^3/ha)	CWU_{green} (m^3/ha)
Cotton	566	234	329	2340	3290

Source: Own Calculation (2018)

Table 4.3 shows the calculation of WF_{blue}(m^3/ton) and WF_{green}(m^3/ton). $CWU_{blue}m^3$/ha in Table 4.2 was divided by the yield to obtain the WF_{blue}(m^3/ton); WF_{blue} was found to be 488m^3. Similar to WF_{blue}, the WF_{green} was obtained by dividing CWU_{green} by yield. The WF_{green} of cotton was 685m^3/ton. The WF_{b+g} was then calculated by adding WF_{blue}, and WF_{green}, therefore, WF_{b+g} was 1172.92m^3/ton.

Table 4.3: Blue and green water footprint of cotton planting as of September.

CROP	Yield(ton/ha)	WF_{blue}(m^3/ton)	WF_{green}(m^3/ton)	WF_{b+g}(m^3/ton)
Cotton	4.8	487.5	685.42	1172.92
Percentage (%)		40.22%	59.78%	100%

Source: Own calculation (2018)

For the early cotton crop planted in September, the WF_{blue} was approximately 40.22% and WF_{green} approximately 59.78% of the WF_{b+g}(m^3/ton). The results indicate that the high water volume, as required by cotton during production, is met through rainfall. It is important that the farmer attempts to use less irrigation since the country is experiencing water challenges. If the production of cotton can depend more on rainfall and still achieve the same yield as when under irrigation, then the water units can be allocated for other uses.

Table 4.4 depicts the summary of water use data during the middle planting season, which occurs in October. The yield of the middle planting season was assumed to be the same as the early cotton crop. The crop requirement of cotton planted in October was 547mm, with the rainfall (R) of 384mm, and rainfall loss (RL) of 66mm. The effective rainfall (ER) is the difference between the (R) and (RL), which was 318mm. Similar to the early cotton crop, one needs to compare the ER of 318mm and the EI, which was 188mm in Table 4.4. In this case, the ER is greater than EI, which indicates that a large portion of water required was met through rainfall.

Table 4.4: Summary of water use data at the measuring points in Loskop irrigation scheme planting time in October

CROP	Cash Crop	YIELD (ton/ha)	CR (ET) (mm)	R (mm)	RL (mm)	ER (mm)	I (mm)	IL (mm)	EI (mm)	EI+ER (mm)
Cotton October	Medium Grower	4.8	547	384	66	318	250	62	188	506

Source: SAPWAT (2018)

Table 4.5 depicts how $\mathrm{CWU_{blue}}\,\mathrm{m^3/ha}$ and $\mathrm{CWU_{green}}\ \mathrm{m^3/ha}$ were calculated. The formula to calculate the $\mathrm{CWU_{blue}}\,\mathrm{m^3/ha}$ and $\mathrm{CWU_{green}}\ \mathrm{m^3/ha}$ cotton planted in October is similar to the one used for cotton planted in September in Table 4.2. The $\mathrm{CWU_{blue}}$ for the season was 1880$\mathrm{m^3/ha}$ and 3180$\mathrm{m^3/ha}$ for $\mathrm{CWU_{green}}$. Table 4.5 further illustrates the $\mathrm{ET_{crop}}$ of 488mm, $\mathrm{ET_{blue}}$ of 188mm, and $\mathrm{ET_{green}}$ of 318mm. Therefore, it is important to establish the crop water requirement of different planting times, and also attempt to irrigate according to crop water requirements as it differs during different seasons.

Table 4.5: Cotton water use in Loskop irrigation scheme planting time as of October

CROP	$\mathrm{ET_{crop}}$ mm	$\mathrm{ET_{blue}}$ mm	$\mathrm{ET_{green}}$ mm	$\mathrm{CWU_{blue}}\,\mathrm{m^3/ha}$	$\mathrm{CWU_{green}}\ \mathrm{m^3/ha}$
Cotton	488	188	318	1880	3180

Source: Own calculation (2018)

Comparing the $\mathrm{ET_{cotton}}$ of planting season of September in Table 4.2 and October in Table 4.5, the planting season in October does not require a lot of irrigation water compared to September since cotton planted in October uses more rainfall water as the probabilities for above normal rainfall are normally expected during that time (Viljoen, 2012). Cotton in October uses more water, but can still yield the same yield compared to the early planting date while using less water. Therefore, cotton growers are advised to consider the late planting season in October in order to save water. Table 4.6 illustrates the blue and green water footprint of cotton planting time in October.

Table 4.6: Blue and green water footprint of cotton planting time in October

CROP	Yield(ton/ha)	$\mathrm{WF_{blue}}(\mathrm{m^3/ton})$	$\mathrm{WF_{green}}(\mathrm{m^3/ton})$	$\mathrm{WF_{b+g}}(\mathrm{m^3/ton})$
Cotton	4.8	391.67	662.50	1054.17
Percentage (%)		37%	63%	100%

Source: Own calculation

Table 4.6 shows the calculation of blue WF and green WF of cotton during the October planting season. The $\mathrm{WF_{blue}}$ of 391.67$\mathrm{m^3}$/ton was calculated by dividing $\mathrm{CWU_{blue}}$ of 1880$\mathrm{m^3}$/ton from Table 4.5 by yield of 4.8ton/ha. Similarly, the $\mathrm{WF_{green}}$ of 662.50$\mathrm{m^3}$/ton was obtained by dividing $\mathrm{CWU_{green}}$ of 3180$\mathrm{m^3}$/ton by a yield of 4.8ton/ha. Of the $\mathrm{WF_{b+g}}$ of 1054$\mathrm{m^3}$/ton, 63% of the water required was contributed by rainfall, indicating that even in late planting times, the water that cotton requires is mostly met by water from the rainfall. Considering the water scarcity and climate change issues, cotton in this area might need more irrigation water; currently rainfall contributes more to the cotton water requirement.

The results of this study indicate that different planting times can impact the cotton water requirement and the WF as a whole. On average, the results of this study show that cotton planted at the Loskop irrigation scheme uses less water compared to the finding of Aldaya et al. (2010) who explored the WF of cotton and other crops produced in Central Asia. Aldaya et al. (2010) found that an average of 6875$\mathrm{m^3}$/ton for the $\mathrm{WF_{blue}}$ was used to produce cotton, which is a large proportion for one crop. The yield of the Loskop irrigation scheme was 4.8ton/ha compared to the yield of cotton in Central Asia of 2.26ton/ha. Cotton yield seems to have a major impact on the WF of cotton; this can be one of the reasons why cotton WF in Central Asia is relatively high compared to the Loskop irrigation. Similar to the study of Zeng et al. (2012), cotton was reported to be one of the crop that used a significant amount of irrigation water, namely 3384$\mathrm{m^3}$/ton.

According to Rudenko et al. (2013), cotton uses approximately 6000 to 8000m^3/ton of water which includes leaching and conveyance losses, yielding an average of 2.6ton of cotton. According to Zeng et al. (2012), the grey WF was not included due to a lack of comprehensive data on pollutant discharge. The same applies to other authors; they did not include grey water footprint of cotton from the farm level as they could not find proper data. For the purpose of this study, grey WF was not calculated due to lack of comprehensive data. Therefore, cotton growers are advised to keep data that can enable scholars and researchers to calculate the grey WF and share the results with the cotton growers.

In the next section, the results of the physical water productivity and economic water productivity will be discussed. In calculating the physical water footprint productivity and economic water productivity, the costs of irrigating the cotton can be determined, as well as the profitability when these costs are accounted for.

4.3 Physical water footprint productivity and Economic water productivity

Chouchane et al (2015) refers to the economic water productivity as the economic value obtained per used water unit. Table 4.7 illustrates the physical water productivity and economic water productivity of cotton during cotton production. Physical water productivity (PWP) is usually expressed in m^3/kg. Table 4.7 illustrates that the water productivity of cotton planted in September is 0.85m^3/kg and those planted in October has the water productivity of 0.95m^3/kg. Therefore, it takes 0.85 m^3 of water to produce 1kg of cotton which was planted in September and 0.95m^3 of water to produce 1kg of cotton planted in October. The early harvesters of cotton received ZAR8500/ton and late harvesters ZAR9150/ton from the farm gate during the harvesting period commencing in May until end of July. The cotton grower in the Loskop irrigation scheme provided the aforementioned information. In order to calculate the price of cotton per kilogram, ZAR8500/ton was divided by 1000, resulting in ZAR8.5/kg (0.65USD/kg) and ZAR9.15/kg (0.69USD/kg). Economic water productivity was calculated by multiplying PWP by the price of cotton. EWP of cotton in Loskop in September was 7.23 ZAR/ m^3(0.55USD/m^3), therefore, the value added to cotton production is 7.23 ZAR/ m^3(0.55USD/m^3). EWP of cotton in Loskop in October was 8.69 ZAR /m^3(0.66USD/m^3), indicating the value added to cotton production is 8.69 ZAR /m^3(0.66USD/m^3).

Table 4.7: Physical water productivity and Economic water productivity

CROP	PWP (m^3/kg)	Price (USD/kg)	Price (R/kg)	EWP (USD/m^3)	EWP (R/m^3)
Cotton in September	0.85	0.65	8.5	0.55	7.23
Cotton in October	0.95	0.69	9.15	0.66	8.69

Source: Authors calculations (2018)

Cotton growers who plant in October, for the late cotton, make more value on their cotton compared to the early cotton growers in September. Thus, cotton growers must rather consider planting their cotton in October, as it has more value for water than the one in September. The next section presents an overall discussion of the results of the study.

4.4 Discussion

Chapagain et al. (2006) assessed the impact of the worldwide consumption of cotton products on the water resources in the countries known for producing cotton. It was found that some countries were more preferred than others due to the irrigation requirement of cotton. Brazil and United States of America were more attractive due to the blue water footprint being lower than the green water footprint, which means low irrigation requirements. Similarly, this study found that cotton production required less irrigation water compared to rainfall water. Grey water footprint was not accounted for due to a lack of comprehensive data on pollutant discharge.

Contrary to the results of this study, Aldaya et al. (2010) assessed the water footprint of cotton and other crops produced in Central Asia and concluded that about $6875m^3$/ton for the blue water footprint was used to produce cotton. Comparing the results of Aldaya et al. (2010) and these findings, cotton planted in the Loskop irrigation scheme uses less water. Comparing the results of Zeng et al. (2012) of Heine River Basin, cotton uses more water compared to the findings of this study. Furthermore, the findings from Ercin et al. (2013) concur with the results of this study. Ercin et al. (2013) reported that approximately $1706m^3$ of water is used to produce one hectare of cotton and this study found the total water footprint in early planting season, namely September, to be $1054.17m^3$ per ton, compared to late planting season (October), which was $1172.9m^3$/ton

This study also found that in September almost R7.23 was obtained per cubic metre of the water used for cotton production, whilst it was R8.69 in October. Cotton growers planting in October, for the late cotton crop, generate more value per m^3 water used compared to the early cotton crop growers in September. Therefore, it is important that cotton growers consider planting their cotton in October as it has more value than those planted in September.

Cotton growers should also consider planting the late crop in October as it yield the same as those planted early, but it uses less water compared to the early cotton crop. The yield of production also affects the water footprint results. The plant breeders must perhaps breed a high yielding and more drought resistant varieties in order for the cotton growers to adapt to efficient production. Consequently, if the farmer can use more cost-effective irrigation methods, it can help reduce the usage of blue water.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary and conclusion

The main aim of this study was to determine the implications of cotton production on fresh water availability. The research was conducted for the Loskop irrigation scheme located between Limpopo and Mpumalanga along the Olifants river basin. The findings do not necessarily claim to represent the whole cotton production in South Africa, as production differs depending on the production method and climate conditions in different geographic settings. The conclusions of this chapter emerge from the analysis of the results of this study.

Water is an essential natural resource for life (Blignaut and Heerden, 2009), and regarded as an essential component for economic activities. The scarcity of fresh water is increasing as the population, pollution, and the devastation of river catchment increases due to deforestation, urbanisation, and destruction of wetlands, industry, mining, and agriculture, resulting in water pollution. Some of the factors affecting water scarcity are the broader changes caused by climate change and global warming (Department of Water Affairs, 2013). According to Olofintoye (2015), South Africa was ranked as the 30th driest country in the world, and water scarcity is still persistent (Blignaut and Heerden, 2009). In Southern Africa, agriculture consumes around 61% of exploitable runoff (Department of Water and Sanitation, 2018). The high volumes of water used in the agriculture sector place policymakers and water managers in a difficult position to inform water users how to use water efficiently and sustainably. For example, at farm level, it is difficult for the farmers to reduce water use while maintaining the yield of the crops (Department of Water and Sanitation, 2018).

Agriculture contributes approximately 2.5% to the total Gross Domestic Product (GDP) of SA. Thus, this sector can be regarded as an inefficient user of the scarce freshwater resources (Nieuwoudt et al., 2004). Furthermore, it is important to assess how much water this sector uses. Considering the agricultural sector's contribution to the economy through the forward and backward linkages to other sectors, agriculture essentially contributes more than what is recorded as GDP (Greyling, 2012). However, the sector is of paramount importance to the economy, and the resources used in this sector need to be utilised effectively and efficiently.

Given that SA is a water scarce economy, it is vital to assess the amount of water used during cotton production. Cotton is one crop, which consumes large volumes of water (Aldaya et al. 2010). For example, of the total (blue and green) water consumed by agriculture in central Asia, 33% is used by cotton. The amount of fresh water consumed by cotton during production and its economic contribution to the South African economy stresses the importance of knowing the volume of fresh water used, the degree of sustainability in the area where cotton is produced, and the economic value of the water used during cotton production.

Van der Laan et al. (2013) assert that the water footprint may be used in agricultural production as it monitors and notifies policymakers on how to manage water. WFA was used as an indicator to assess the fresh water used in the production of cotton at farm level in SA. To the author's knowledge, there has been no assessment of the water footprint of cotton on farm level in South Africa. The unavailability of scientific information to guide SA on how much fresh water is used and needed during cotton production, creates uncertainties while using and/or making irrigation water allocation decisions by the farmers of cotton, water managers, and policymakers. As a result, water users, use water inefficiently and ineffectively (Eslamian and Eslamian, 2017).

The study aimed to assess the WF and the economic productivity of the water used to produce cotton in SA under irrigation and used as raw materials for clothing, textile, footwear and leather industry, and feed for animals. The aim was achieved by calculating the volumetric water footprint indicator of cotton, and evaluating the economic productivity of the water footprint of cotton, as well as formulating response strategies towards more sustainable water use for cotton.

The water footprint concept is a useful tool to evaluate or assess the use of water during cotton production. The evaluation can be done using different methods, as discussed in Chapter 2. The method of Hoekstra et al. (2011) proved to be the best suited for this study. This method accounts for blue, green, and grey water footprint. Life Cycle Assessment accounts for blue water and the environmental impact of the product, while the efficient and effective allocation of scarce water resources is not sustainable, or is not included.

The method of Hoekstra et al. (2011) is mostly concerned with sustainable use of fresh water. The water footprint assessment concept has been used to assess water used by different crops. However, there are no scientific studies assessing the water footprint of cotton in South Africa. Hoekstra (2016) found that WF and LCA are both important, although they serve different purposes. LCA assesses the environmental impact of the product, and neglects the sustainability of blue and green WF. While using the Global Water Footprint Standard approach, it is possible to incorporate the economic evaluation of water used during the production of cotton. Thus, the volumetric water used during cotton production and the water footprint sustainability is crucial and needs to be addressed.

5.2 Results

Based on the results, it is concluded that the $\mathrm{WF_{b+g}}$ of irrigated cotton of early planting season in September was 1172.92$\mathrm{m^3}$/ton. Of the $\mathrm{WF_{b+g}}$, the $\mathrm{WF_{green}}$ of cotton was 685$\mathrm{m^3}$/ton and $\mathrm{WF_{blue}}$ was found to be 488$\mathrm{m^3}$. The water that evaporated during transpiration through canals and in storage dams was not considered in the water footprint of cotton from the farm level. For the early cotton crop planted in September, the $\mathrm{WF_{blue}}$ was about 40.22% and $\mathrm{WF_{green}}$ was about 59.78% of the $\mathrm{WF_{b+g}}$($\mathrm{m^3}$/ton). The results indicate that the high water volume that cotton requires during production is met through rainfall. It is important that the farmer attempts to use less irrigation as the country is experiencing water challenges. If the production of cotton can depend more on rainfall and still achieve the same yield as when under irrigation, then the water units can be allocated for other uses.

During the late planting season in October it was concluded that the $\mathrm{WF_{b+g}}$ of irrigated cotton was 1054$\mathrm{m^3}$/ton. The $\mathrm{WF_{blue}}$ of was found to be 391.67$\mathrm{m^3}$/ton while the $\mathrm{WF_{green}}$ was 662.50$\mathrm{m^3}$/ton. Of the $\mathrm{WF_{b+g}}$ of 1054$\mathrm{m^3}$/ton, 63% of the water required was contributed by rainfall, thus indicating that even in late planting time, the water that cotton requires is mostly met by water from the rainfall.

The economic value obtained per unit of water in the Loskop irrigation scheme utilised during early cotton production in September was 7.23 ZAR / $\mathrm{m^3}$(0.55USD/$\mathrm{m^3}$). The value added to cotton production of late planting time in October was 8.69ZAR /$\mathrm{m^3}$(0.66USD/$\mathrm{m^3}$). Cotton planted in September has the water productivity of 0.85$\mathrm{m^3}$/kg and that planted in October has the water productivity of $0.95\mathrm{m}^3/\mathrm{kg}$. Therefore, it takes $0.85\ \mathrm{m}^3$ of water to produce 1kg of cotton which was planted in September and $0.95\mathrm{m}^3$ of water to produce 1kg of cotton in October. The early harvesters of cotton were receiving ZAR8500/ton and late harvesters, ZAR9150/ton from the farm gate during the harvesting period beginning in May until end of July. Cotton growers planting in October for the late cotton crop, receives more value on water compared to the early cotton crop growers in September. Therefore, it is important that cotton growers consider planting their cotton in October as it has more value than those planted in September.

Cotton growers should also consider planting the late crop in October as it yields the same as those planted early, but it uses less water compared to the early cotton crop. The late cotton crop, planted in October essentially has more value than the early crop. The yield of production also affects the water footprint results. The plant breeders must perhaps breed a high yielding and more drought resistant varieties in order for the cotton growers to adapt to efficient production. Therefore, if the farmer can use more cost-effective irrigation methods, it can help reduce the usage of blue water.

5.3 Recommendations

5.3.1 Recommendations to cotton farmers as water users

1. It is important to have sufficient knowledge about the climate as it is vital when considering areas suitable for an efficient and profitable cotton production. This will help to ensure the most advantageous growing season for cotton. Cotton growers must be aware of the water required by the crop, and they need to know the rainfall contribution and how much water they have to use for irrigation.

2. Cotton growers must consider planting the late cotton crop in October as it is more profitable than the early cotton crop in September. The late cotton crop requires less water compared to the early crop in September, therefore cotton growers must consider the late production as they can save volumes of water. Cotton is a summer crop and for optimum growth the temperature must be above 25 °C.

3. Cotton can still provide a good yield under dry land conditions with approximately 500mm of rainfall annually. However, for profitability, it is advisable that the farmer supplements it with irrigation, and evenly spread the plants as required.

5.3.2 Recommendations to policymakers

Water should be allocated according to the water requirements of the crop. Policymakers should draft guidelines on sustainable water use at farm level, while considering the planting season and the irrigating time. Educational groups among the farmers should be formed in an attempt to better educate farmers on water sustainability, while maximising production and profitability under the current water scarcity state in South Africa.

5.3.3 Limitations and Recommendations for further research

Limitations

1. The grey WF was also excluded due to limited information on water used to assimilate pollution.
2. Water footprint of cotton along the value chain of a product was excluded due to lack of information as the Loskop gin was not operating.
3. EWP along the value chain was excluded as the author couldn't get hold of the volume of water used along cotton value chain.
4. The impact of the production of cotton on society was not quantified because the data was sampled from one farm.

Recommendations for further research

1. Grey water footprint must be taken into consideration, while assessing the water footprint of cotton, to better inform farmers and policymakers of the water consumed during the production on farm level.

2. Investigate the water footprint of cotton along the value chain of products produced from cotton seeds until it reaches the end user. This will provide clarity on where water is most used in the process of offering the product to the end user of the cotton final product.

3. Assess where the EWP is high along the value chain of producing end products where cotton seeds are used as raw material.

4. Conduct a study that will better explain and quantify the social sustainability of cotton production in a specific region.

5. Conduct Water footprint of a specific product using farm data of several farms in the region.

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