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Water Footprint Assessment of Crop Production in Shaanxi, China

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ABSTRACT

The water footprint, introduced by professor A.Y. Hoekstra, is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use. Therefore, it gives a great insight into how and where water is used in the supply chain and helps to form a proper basis for decision making. The water footprint consists of three components. The green water footprint refers to the consumption of green water resources, such as rainwater use. The blue water footprint refers to the consumption of blue water resources, such as surface- and groundwater. The grey water footprint refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants during the process. The concept can be applied to a wide range of commodities, such as industrial products, agricultural crops and so on. Also, it can be applied at different scales, such as business scale, provincial scale or even globally.

China has the largest population of the world, over 1.3 billion people, and is still growing. Next to this projected population growth, the economy of China is developing quickly. These factors combined will lead to a rising demand for food, that China's domestic supply will not be able to meet in the future. China's agriculture has been playing an important role in guaranteeing the food safety of the country. Agricultural production has to increase due to this growing demand for food in the future. This will lead to more water use, and since water is already scarce, to even more water scarcity. In some provinces there is more water scarcity than in others. Water scarcity also differs within provinces. Here a water footprint assessment related to agricultural crop production is carried out for the year of 2008 for a key agricultural province in China; the Shaanxi province.

As a starting point the methodology of water footprints and water footprint definitions are followed as set out in Hoekstra et al. (2011). The assessment focuses on the crops related to agricultural production in the study area and the accounted crops represent 80% of cultivated land use and 77% of production of agricultural crops in the Shaanxi province. The model that has been used is the CROPWAT model and its definitions are based on Allen et al. (2008). The crop water requirement option is used, this means that adequate soil water is maintained by rainfall and/or irrigation so it does not limit plant growth or crop yield.

The water footprint of consumption within Shaanxi in the year of 2008 was 18764 $Mm^3\ yr^{-1}$ (40% green; 42% blue; 18% grey). The ten districts of the province showed a great variety concerning the water footprints, which can be ascribed to the difference in production values per district. The two major crops are Wheat (6352 $Mm^3\ yr^{-1}$) and Maize (6337 $Mm^3\ yr^{-1}$). Together they accounted for 68% of the total water footprint in the province.

Compared to other studies the water footprints per unit mass of crop were slightly higher. Besides, we see a major shift from green to blue water use, due to the fact that the year 2008 was a relatively dry year. Cotton (7285 $m^3\ ton^{-1}$) and Soybean (3785 $m^3\ ton^{-1}$) have the largest water footprint per unit mass of crop. In comparison, Wheat (1347 $m^3\ ton^{-1}$) and Maize (1157 $m^3\ ton^{-1}$) have a low water footprint per unit mass of crop but have the most influence on the total water footprint related to crop production.

The annual blue water scarcity was above 100% in the districts of Xi'an, Tongchuan, Weinan, Xianyang, Yan'an and Yulin in the middle and North Shaanxi. This could be part of the difference in climate between North and South Shaanxi, since the northern part is more arid and the southern

part more humid. Also, the districts with the higher water footprints related to crop production are located in the North and in the middle of the province. This will lead to exhaustion of the water resources of these districts, such as surface and groundwater. Severe water pollution is only occurring in the Tongchuan district. Here the water pollution level is too high concerning the volume of freshwater that is required to assimilate the load of pollutants.

PREFACE

This thesis is written in partial fulfilment of the requirements of completion of the Bachelor Civil Engineering at the University of Twente, The Netherlands.

I started my study on the water footprint concept at end of February 2014 at the Northwest A&F University, China. The start of this study was quite interesting, since it turned out that the original assignment was not feasible in the scheduled 10 weeks. An alternative assignment was offered, still with the focus on water footprints. After this exceptional start, it was searching what was possible and what was not. After gaining more insights in the concept, datasets and its possibilities, the pieces of the puzzle started to fall into place.

I would like to thank several people for helping me along the way with this project. Without their help this study would not have been possible.

I would like to thank my supervisors Arjen Hoekstra and La Zhuo for their advice, guidance and thoughts on this study. Their view has helped me to overcome obstacles, especially at times when difficult decisions had to be made.

I would like to thank my supervisor from the Northwest A&F University, dr. S. Sun for giving me new insights, advice on the study and water footprint analysis and for setting up the new assignment. Also I would like to thank the head of the Water Savings Institute, prof. P. Wu for giving me the opportunity to do my thesis at this institute.

I am thankful to Jack and ShiLijie for being excellent guides, teaching me more about China and its culture and guiding me in the daily life of China. Also, I would like to thank ShiLijie again for collecting datasets, being supportive and having a critical look on my ideas.

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Thomas de Boer

Yangling, May 2014

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1 INTRODUCTION

1.1 Background of the study

With a population of over 1.3 billion people, China has the world's largest population. Over the last 60 years the population has more than doubled and will grow to 1.5 billion by the year of 2025 (United Nations, 2013). Besides this prospected population growth in the next few years, the economy of China is growing too. The annual growth of the GDP (Gross Domestic Product) of 2013 is 7.8% and will keep on growing seen the economic statistics of the last years (The World Bank, 2014). These factors combined will lead to a rising demand for food, that China's domestic supply will not be able to meet in the future (Zhuo et al., 2012).

What will be the impact of this rising demand for food? First, if the domestic supply of China cannot meet the demand, China has to import food from other countries. This will have an economical effect on higher food prices around the globe (Zhuo et al., 2012). Next to importing food, the agricultural production has to increase even more due to this demand for food. This will have a significant impact on water resources in China. it can be problematic if water use is not managed correctly and becomes scarce (Liu & Savenije, 2008). Currently, more than 60% of freshwater withdrawals are used for agricultural productions. The irrigation water claims nearly 90% of the total agricultural water use. The agricultural irrigation districts have been playing an irreplaceable role in guaranteeing the food safety of China (Sun et al., 2012). Also, the rising demand for food can have an impact on water sustainability, due to an increase of fertilizer, irrigation water and agrochemicals to maintain high production (Meng, et al., 2012).

Apart from the increase of food demand, water scarcity is already occuring in China for a few decades. Particulary North China faces severe water scarcity (Ma et al., 2006). Resulting in over-exploitation of ground water. This overexploitation of groundwater leads to a drastic decline of groundwater levels, exhaustion of water sources and also causes sinking of ground surfaces (Ministry of Construction, 2006).

The assessment of water resource utilization during agricultural production processes is necessary to give an insight in the water use of the agricultural processes. Gathering knowledge and information about these processes, policies can be formulated to prevent, cure or decrease the described problems above. A method to quantify the water balance of crops or products is the water footprint. The water footprint has been introduced by Professor A.Y. Hoekstra in the year 2002. The water footprint is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use. The definition of a water footprint is, as Hoekstra et al. (2011) state: '*The water footprint of a product is the volume of freshwater used to produce the product, measured over the full supply chain. It is a multidimensional indicator, showing water consumption volumes by source and polluted volumes by type of pollution*' (Hoekstra et al., (2011)). This concept will unravel the hidden link between consumption and water use.

The water footprint can be divided into a green, blue and grey component. The green water component, also known as the green water footprint, refers to the consumption of green water resources, such as rainwater use (if not become runoff). The blue water footprint refers to the blue water resources, such as surface- and groundwater use. The grey water footprint refers to pollution and is defined as the volume of freshwater that is required to assimilate the load of pollutants during the crop production process.

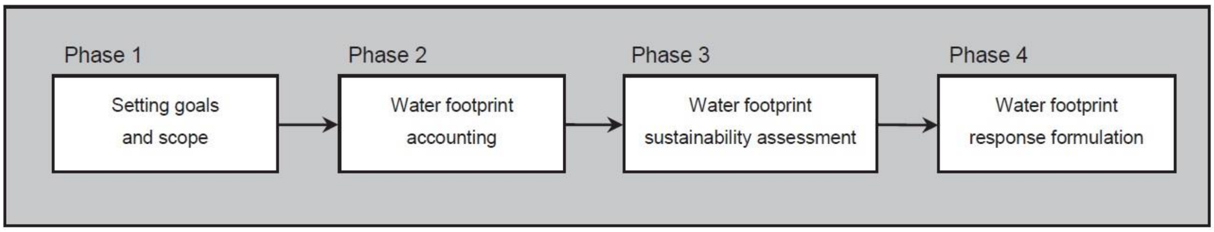

Figure 1.1: Four distinct phases in water footprint assessment (Hoekstra et al., (2011))

A full water footprint assessment consists of four distinct phases (Figure 1.1). Phase one consists of setting the goals and determining the scope of the study. Defining phase one clearly will give a transparent view on how the study is executed. In the next phase the required data is collected and the accounts for the water footprint are determined. The third phase is the sustainability assessment, in which the results from phase two will be evaluated from an environmental perspective, as well as from a social and economic perspective. The last phase consists of formulation response options, policies and strategies. A study on water footprint does not have to include all four phases. Depending on the scope and goals one can choose to stop after the accounting or sustainability assessment part (Hoekstra et al., 2011).

1.2 Scope

1.2.1 Water footprint assessment

This study focuses on the first three phases which are discussed in section 1.1. The ultimate target of this study is to quantify, map and describe the effects of the water footprints of a crop. In phase one 'setting goals and scope', described here, the scope, research objectives and research questions are discussed. Phase two focuses on quantifying the green, blue and grey water footprint of the crop. Phase three includes the primary environmental impacts of the blue and grey water footprints on respectively blue water scarcity and water pollution. The final phase of formulating a response option is not included in this study. After quantifying the water footprints of the study area, the results are spatially mapped.

1.2.2 Study area

The study area for this assessment is the Shaanxi province (35° 36′ 0″ N, 108° 24′ 0″ E), located in China. The location of the Shaanxi province is shown in Figure 1.1. The province borders 7 different provinces and one of the five autonomous region (Inner Mongolia) in China. It has an area of 205,800 km^2, which covers 2.1% of the total area of China, which is 9,630,960 km^2. It has a population of 37.3 million people, 2.8% of the total Chinese population, and its largest city, Xi'an, has a population of 6.5 million. Shaanxi stretches across basins of the Yellow River and the Yangtze River bounded by the Qinling Mountains. On the northern side of the province the Yellow River is located and on the southern side the Yangtze River. The drainage area of the Yangtze River system and the Yellow River system takes up 35% and 65% of the provincial area, respectively (Shaanxi Province, 2012).

Furthermore, the Shaanxi province can be divided into 10 districts (Figure 1.2). Each district has its own district capital city. With over 8.5 million people, the Xi'an district is the largest one concerning population. Due to the large span in latitude, the climate in Shaanxi differs a lot from North to South.

The northern part of Shaanxi is cold in the winters and hot in the summers, with dry winters, springs and autumns and can be classified as a cold arid climate. The southern part has a more humid subtropical climate (Shaanxi Province, 2012).

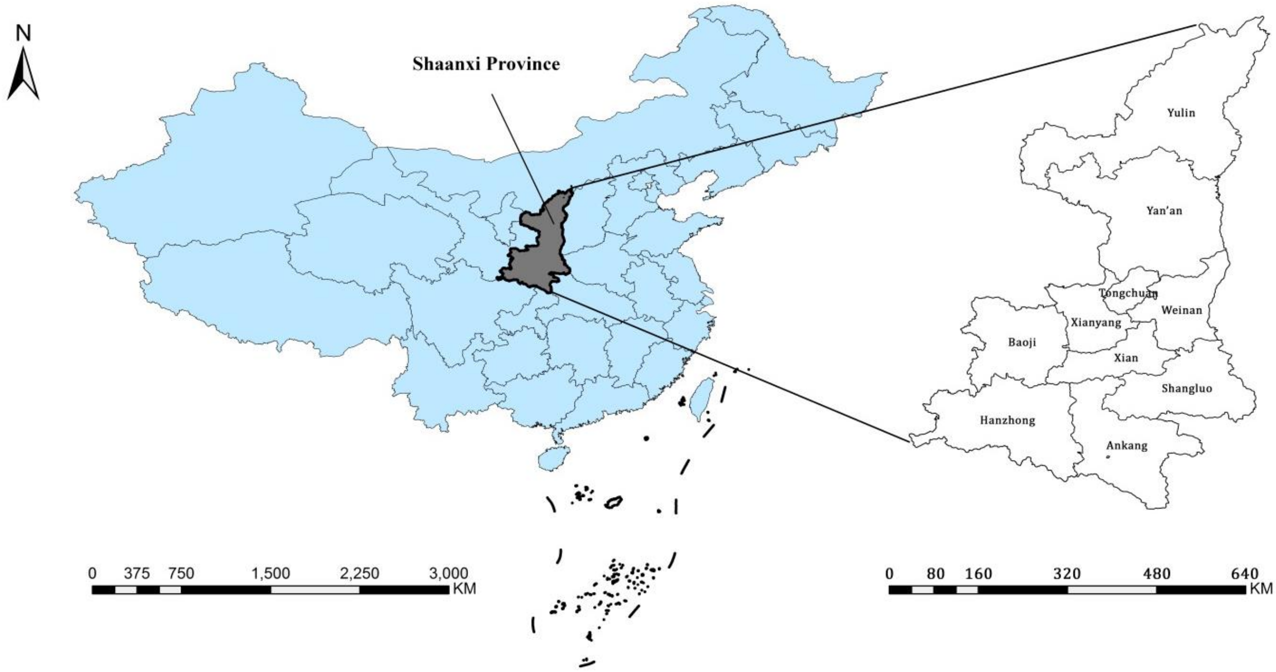

Figure 1.2: Location of the Shaanxi province in China (left) ; Location of the districts in Shaanxi province (right)

1.2.3 Research objectives

The first objective of this study is to *quantify and map the field-scale water footprints of crop production in the Shaanxi province using the CROPWAT model*. This objective corresponds to what is called 'water footprint accounting' in the Water Footprint Assessment Manual (Hoekstra et al., 2011).

The second objective is using the estimated water footprints of the first objective to determine the effects of these water footprints, in other words, *determining the environmental effects of the blue water footprint on blue water scarcity and the environmental effect of the grey water footprint on water pollution level in the Shaanxi province.* This objective corresponds to what is called 'water footprint sustainability assessment' in the Water Footprint Assessment Manual (Hoekstra et al., 2011).

The effects of the green water footprint on green water scarcity are not taken into account, because according to Hoekstra el al. (2011) the analysis of green water scarcity is largely unexplored. Further research on green water scarcity should be done before implementing this objective in this study. Therefore this study will not include green water scarcity.

1.2.4 Research questions

Three research questions have been formulated based on the research objectives. These research questions are as follows:

1. *What are the quantities of the blue water footprint, the green water footprint and the grey water footprint related to crop production of the Shaanxi province?*
2. *What is the environmental effect of the blue water footprint of the crops on the blue water scarcity in the Shaanxi province?*
3. *What is the environmental effect of the grey water footprint of the crops on the water pollution level in the Shaanxi province?*

1.2.5 Crop coverage

The assessment focuses on the crops related to agricultural production in the study area. Not all the crops related to agricultural production are taken into account due to lack of data. A selection has been made to represent crop production for the Shaanxi province.

The crop coverage is based on the size of cultivated area per crop and production values per crop. This means that the selection includes mainly the primary agricultural crops with a significant amount to the total cultivated area and production. The selection is based on the crop categories given in the Shaanxi Statistical Yearbook of 2009 (Shaanxi Provincal Bureau of Statistics & NBS Survey Office in Shaanxi Province , 2009). As shown in Table 1.1, there are 6 crop categories considered. The ‘grain’ category, with an amount of 81%, contributes the largest amount to the agricultural land use and also has the largest contribution to the production, with a value of 50%. Categories are distinguished by their own specific crops. We see that certain categories have crops named ‘other crops’; these types of crops are not defined by the Yearbook.

Table 1.1: Land use and production values per crop in the period of 2008

Crop category	Crop	Area use		Production	
		10^3 Ha	Percentage	10^4 tonne	Percentage
Grain					
	Wheat	1140	28%	391.5	17%
	Maize	1113	28%	504.3	22%
	Soybean	184	5%	24.6	1%
	Rice	119	3%	3.6	0%
	Other	678	17%	226.9	10%
Oils					
	Rape seed	178	4%	33.3	1%
	Peanut	33	1%	8.2	0%
	Other	66	2%	7.9	0%
Vegetables					
	Vegetables small*	204	5%	586.9	26%
	Potato	135	3%	202.5	9%
	Other	46	1%	277.6	12%
Fibres					
	Cotton	85	2%	10.1	0%
Other					
	Other	34	1%	7.5	0%
Total		4016	100%	2284.9	100%
Selection			**80%**		**77%**

**Area use and production of small vegetables determined using the vegetables-small vegetables ratio of China using FAOSTAT (FAO, 2014)and make the assumption this ratio is the same for Shaanxi.*

The selected crops that are assessed in this study are marked. This selection represents 80% of cultivated land use and 77% of production of agricultural crops in the Shaanxi province. Due to lack of characteristic data on certain crops and unclear definitions of other types of crops, such as 'other grains', these crops have not been included. Appendix II gives an overview of crop distribution per district.

It should be noted that the crop 'vegetables small' contains different types of small vegetables crops. However the data of small vegetable crops individually are not available. Therefore these crops are combined together to one category called 'small vegetables' that represents these crops.

1.2.6 Study period

The time period of this study is one single year, 2008. This single year was chosen because it was the most recent year that the required data could be obtained. Since this study is the first water footprint assessment (concerning the scope) of the Shaanxi province, there are no results of the years before to compare the results to. Concerning the climate we can say that 2008 was a relatively dry year compared to the years before. The annual rainfall of 2008 in Shaanxi was 592.2 millimetres. Compared to the an average annual rainfall of 656.5 millimetres, this shows a decrease of 9.8%. (Department of Water Resources, 2008)

1.2.7 Study tools

The model that is used to do the assessment is the CROPWAT 8.0 model. Its use is to generate the necessary data for the water footprint assessment. More details about the model can be found in section 2.1. The software that is used to map the accounted water footprints spatially is ArcGIS 10.0.

1.3 Outline of the report

In order to meet the research objectives and answer the research questions, this report is written in a structured way. Chapter 2 will discuss the methodology of the water footprint assessment used in this study. Chapter 3 gives an overview of the datasets used to do this assessment. Here, assumptions and model adjustments are described alongside an explanation as to why these assumptions and adjustments are made. The results of the assessment can be found in chapter 4. The results are based on the datasets used in chapter 3 and implemented in the methods showed in chapter 2. The results are presented in several visual ways, such as figures, charts and tables. A description is given on how to interpret these visual representations. Chapter 5 contains the discussion. The conclusion of this study is given in chapter 6.

2 METHODOLOGY

As a starting point the methodology of water footprint assessment is followed as set out in Hoekstra et al. (2011). The green, blue and grey water footprints accounting of a crop are explained. Also the sustainability assessment on blue water scarcity and grey water pollution are explained. The methodology of the CROPWAT model and the models definitions are based on Allen et al. (2008). The symbols discussed in this chapter are presented in Appendix I.

2.1 CROPWAT model

The model used to do the water footprint assessments is the CROPWAT 8.0 model. The CROPWAT model is developed by the Land and Water Development Division of FAO. It is a model for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data (FAO, 2013). The model approach is based on FAO publications by Allen et al. (1998).

When local data is not available, standard crop and soil data is implemented in the CROPWAT model. When local data is available, this data can be easily modified to implement it in the model. Side by side with the CROPWAT model is CLIMWAT. CLIMWAT includes a climate database obtained from over 5000 stations worldwide for the period of 1971 to 2000, which can be referred to when local climate data is not available (FAO, 2013).

The CROPWAT model offers two options to calculate the crop evapotranspiration (ET). The first option is the 'crop water requirement option' (CWR option). This option calculates the ET under 'ideal growth conditions', which means that adequate soil water is maintained by rainfall and/or irrigation so it does not limit plant growth or crop yield. The second option is the 'irrigation schedule option'. The irrigation schedule option does not work with the concept of effective precipitation as the CWR option. It includes a soil water balance to keep track of the soil moisture over time. Therefore, the model needs input data on soil. This option is recommended by Hoekstra et al. (2011) to apply whenever possible., because it is more precise. The applicability of this option depends on whether required data is available (Hoekstra et al., 2011).

In this study the <u>CWR option</u> was used, because local detailed soil data of the study area was not available.

The CWR option uses four modules for input data: the Climate/ET_0 module, the Rainfall module, the Crop module and the Soil module. The Climate/ET_0 module in CROPWAT was used to determine the reference evapotranspiration (ET_0). This program determines the average ET_0 per month and the calculation is based on the FAO Penman-Monteith Method (Allen et al., (1998)). The module is primary for data input, requiring information on the meteorological station together with climatic data. The Rain module in CROPWAT was used to implement precipitation data (*PR*) and to calculate the effective rainfall (P_{eff}). In the program, the P_{eff} is calculated using the USDA S.C. Method (Allen et al., (1998)). The Crop module in CROPWAT has two different options: non-Rice and Rice. The input parameters in the Crop module of the Rice option contains planting date, crop coefficient (K_c), length of the stages, rooting depth, puddling depth and crop height (optional). The input parameters of the Crop module in the non-Rice option contains planting date, crop coefficient (K_c), stages, rooting depth and crop height (optional). The Soil module was only used for a few Rice crops, explained in section 3.3. The parameters of the Soil module for a Rice crop include total available water (TAW), maximum infiltration rate, maximum rooting depth, initial soil moisture depletion, drainable porosity, critical depletion for puddle cracking, and water availability at planting maximum water depth.

2.2 Crop water requirement

A crop needs a certain amount of water to grow. The volume of water necessary for a crop to grow is called the crop water requirement (CWR, mm). Each type of crop has its certain level of CWR varied spatially and temporally. Two factors influence the value of the *CWR* of a certain crop, the crop coefficient (K_c) and the reference crop evapotranspiration (ET_0, mm). These factors are influenced by climate variations, such as temperature, sunshine, wind speed, and humidity.

The *CWR* is calculated by ET_0 multiplied by the K_c. The CWR is equal to the actual crop evapotranspiration (ET_c, mm), assuming there are no water limitations to crop growth, so that the crop water requirements are fully met.

$$ET_C = K_c \times ET_0 \; [mm] \tag{1}$$

$$CWR = ET_c \tag{2}$$

ET_0 is defined as the evapotranspiration rate from a reference surface, without shortage of water. The reference crop is a hypothetical grass reference crop with specific characteristics. This means that only climatic parameters will influence reference crop evapotranspiration and it does not consider a difference in crop characteristics and soil factors.

K_c is a value that distinguishes field crops from the reference crop of grass used for ET_0. Variations of the K_c occur because of difference in crop characteristics over the length of a growing period. The variations of K_c are mainly determined by crop variety, climate, and crop growth stages.

The growing period of a crop is split up into four growth stages: the initial stage, the development stage, the mid-season stage and the late season stage (Allen et al., (1998)). Three values of the K_c are implemented: one at the initial stage ($K_{c,ini}$), one at the mid-season stage ($K_{c,mid}$), and one at the end of the late season stage ($K_{c,end}$). Figure 2.1 shows a the K_c curve over the growth stages of a crop.

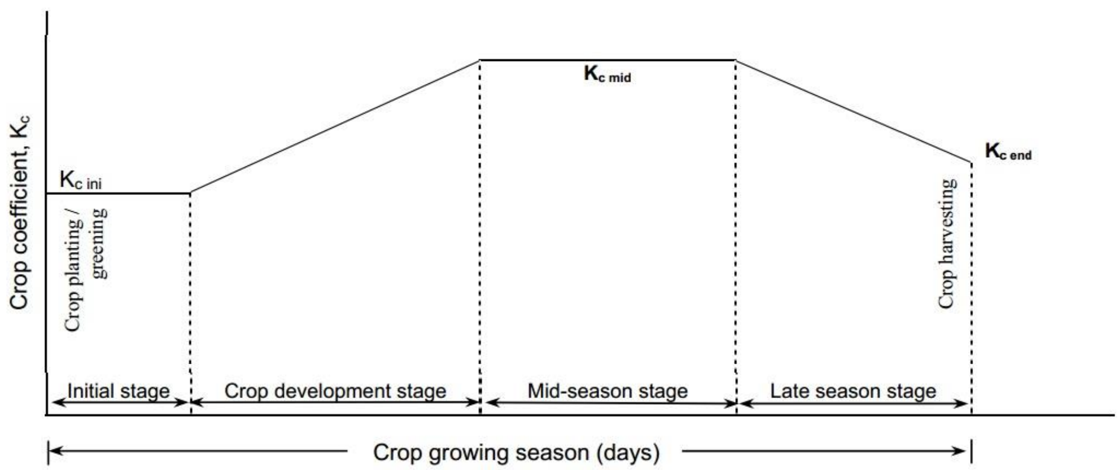

Figure 2.1: Development of Kc during the crop growing season (Chapagain & Hoekstra, 2004)

2.3 Green crop water use

The green component of crop water use (CWU_{green}, $m^3\ ha^{-1}$) is the volume of green water that is used by the crop for evapotranspiration. Green water is defined as water from rainfall. The CWU_{green} is calculated by accumulating the daily green evapotranspiration (ET_{green}, mm day^{-1}) over the complete growth period. The factor 10 is included to convert the water depths in mm into water volumes per land surface in $m^3\ ha^{-1}$. The summation is carried out in the time step of 10 days over the length of the complete growth period of a crop.

$$CWU_{green} = 10 \times \sum_{d=1}^{lgp} ET_{green}\ [volume/area] \quad (3)$$

The ET_{green} is either the ET_c or the effective precipitation (P_{eff}). If the P_{eff} is larger than the crop water requirement, the ET_{green} will be equal to the value of the ET_c, because a crop uses as much water as possible, but never uses more than required for optimal growth. If the P_{eff} is smaller than the ET_c, the ET_{green} will be the total P_{eff}.

$$ET_{green} = \min(ET_c, P_{eff})\ [length/time] \quad (4)$$

The calculation of the effective rainfall (P_{eff}) is carried out by CROPWAT using the actual rainfall (P_{act}). The calculation is based on a simplified version of the USDA method (FAO, 2013). Equations (5) and (6) show the formulas on how to calculate the effective precipitation. The choice of what equation to use, is dependent on the actual rainfall values.

$$P_{eff} = P_{act} \times \frac{125 - 0{,}2 \times P_{act}}{125}\ for\ P_{act} \leq 250mm \quad (5)$$

$$P_{eff} = 125 + 0{,}1 \times P_{act}\ for\ P_{act} > 250mm \quad (6)$$

2.4 Blue crop water use

The blue component of crop water use (CWU_{blue}, $m^3\ ha^{-1}$) is the volume of irrigation water required for crop growth and is calculated in a similar way as the green crop water use. Blue water use includes surface and ground water.

$$CWU_{blue} = 10 \times \sum_{d=1}^{lgp} ET_{blue}\ [volume/area] \quad (7)$$

The ET_{blue}, also known as the irrigation requirement (*IR*), is calculated by taking the difference between the ET_c and the P_{eff}. If the P_{eff} is larger than the ET_c, the ET_{blue} is zero, therefore no irrigation is required. If the crop water requirement is not fully met by P_{eff} then the ET_{blue} is the difference between these two values.

$$ET_{blue} = \max(0, ET_c - P_{eff})\ [length/time] \quad (8)$$

By using the approach described in this section, it should be noted that only the consumptive irrigation water use by the crop on the field is taken into account. This means that the losses of irrigation water along the way to the field and on the field are excluded.

2.5 Grey assimilation water use

The pollutants generally consist of different types of fertilizers (e.g. nitrogen (N), phosphorus (P)), pesticides and insecticides. The nitrogen (N) use was taken into account in this study. The grey assimilation water use (AWU_{grey}, m^3 ha^{-1}**)** only considers the 'waste flow' of chemicals to freshwater bodies, which is a fraction of the total application of fertilizers or pesticides to the field. In other words, the amount that is not consumed by the crop is generally considered as a surplus of fertilizer and will affect the freshwater bodies such as ground water and surface water.

AWU_{grey} is calculated by dividing the pollutant load ($L_{leached}$, ton ha^{-1}) by the difference between the ambient water quality standard for that pollutant (the maximum acceptable concentration c_{max}, mg L^{-1}) and its natural concentration in the receiving water body (c_{nat}, mg L^{-1}). The factor 10^{-6} is included to convert the units in mg L^{-1} into ton m^{-3}.

$$AWU_{grey} = \frac{L_{leached}}{(c_{max} - c_{nat}) \times 10^{-6}} \tag{9}$$

The amount of chemicals applied to the field can be measured, but the fraction of applied chemicals that is not used and reaches the ground- and surface water is hard to measure. Therefore, it is common practice to estimate the fraction of applied chemicals that enter the water system. In equation (10) the leaching fraction is called α (-). The total load applied to the field is defined as $L_{application}$ (ton ha^{-1}) and the leached load is defined as $L_{leached}$ (ton ha^{-1}).

$$L_{leached} = \alpha \times L_{application} \tag{10}$$

2.6 Water footprint per unit mass of crop

The total water footprint of a process of growing a crop (WF_{proc}) is the sum of the green ($WF_{proc,green}$, m^3 ton^{-1}), blue ($WF_{proc,blue}$, m^3 ton^{-1})and grey($WF_{proc,grey}$, m^3 ton^{-1}) water footprint components. It gives the amount of water consumed to produce a certain amount of a crop, usually in m^3 ton^{-1} for unit mass of crop.

$$WF_{proc} = WF_{proc,green} + WF_{proc,blue} + WF_{proc,grey} \quad [volume/mass] \tag{11}$$

The $WF_{proc,green}$ is calculated by dividing the green crop water use (CWU_{green}, m^3 ha^{-1}) by the crop yield (Y, ton ha^{-1}). In parallel, The $WF_{proc,blue}$ is calculated as the blue crop water use (CWU_{blue}, m^3 ha^{-1}) divided by the Y. The $WF_{proc,grey}$ is calculated by the grey water use (AWU_{grey}, m^3 ha^{-1}) divided by the Y.

$$WF_{proc,green} = \frac{CWU_{green}}{Y} \; [volume/mass] \tag{12}$$

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y} \; [volume/mass] \tag{13}$$

$$WF_{proc,grey} = \frac{AWU_{grey}}{Y} \; [volume/mass] \tag{14}$$

2.7 Water footprint of crop production

The water footprint of crop production refers to the volume of water consumed to grow the amount of crop production for a certain period. The total water footprint of a crop (WF, $m^3 yr^{-1}$) related to production is the sum of the green (WF_{green}, m^3 yr^{-1}), blue (WF_{blue}, m^3 yr^{-1}) and grey (WF_{grey}, m^3 yr^{-1}) water footprint components.

$$WF = WF_{green} + WF_{blue} + WF_{grey} \ [volume/time] \tag{15}$$

The calculations of the three components are done by multiplying the water footprint per unit mass of crop ($WF_{proc,x}$, m^3 ton^{-1}) times the annual production (P, ton yr^{-1}). By doing this the water footprint of each component will be expressed in volume of water footprint per time period (m^3 yr^{-1}).

$$WF_{green} = WF_{proc,green} \ \times P \ [volume/time] \tag{16}$$

$$WF_{blue} = WF_{proc,blue} \ \times P \ [volume/time] \tag{17}$$

$$WF_{grey} = WF_{proc,grey} \ \times P \ [volume/time] \tag{18}$$

2.8 Assessment of blue water scarcity

To calculate the environmental sustainability of the blue water footprint, the blue water availability (WA_{blue}, m^3 yr^{-1}) is necessary. In a basin or catchment the blue water availability is defined as the natural run-off in the catchment (R_{nat}) minus the 'environmental flow requirement' (*EFR*). Because this study does not include a basin or catchment, values on water availability will be used to calculate the blue water scarcity. These values will be explained in section 3.6.

The blue water scarcity (WS_{blue}) is defined as the ratio of the total blue water footprints ($\sum WF_{blue}$) to the blue water availability.

$$WS_{blue}[x,t] = \frac{\sum WF_{blue}[x,t]}{WA_{blue}[x,t]} \ [-] \tag{19}$$

Blue water scarcity values have been classified into four levels of water scarcity (Hoekstra et al., 2012):

- Low blue water scarcity (<100%): the blue water footprint is lower than 20% of natural runoff and does not exceed blue water availability; river runoff is unmodified or slightly modified; presumed environmental flow requirements are not violated.
- Moderate blue water scarcity 100-150%): the blue water footprint is between 20 and 30% of natural runoff; runoff is moderately modified; environmental flow requirements are not met.
- Significant blue water scarcity (150-200%): the blue water footprint is between 30 and 40% of natural runoff; runoff is significantly modified; environmental flow requirements are not met.
- Severe water scarcity (>200%): the blue water footprint exceeds 40% of natural runoff; runoff is seriously modified; environmental flow requirements are not met.

2.9 Assessment of grey water pollution

The effect of the total grey water footprint depends on the runoff available to assimilate the pollutant. As a relevant local impact indicator, one can calculate the 'water pollution level' (*WPL*) which measures the degree of pollution. The water pollution level is defined as a fraction of the waste assimilation capacity consumed and calculated by taking the ratio of the total of grey water footprints ($\sum WF_{grey}$) to the actual run-off (R_{act}) in a basin or catchment. The same principle is used as the blue water availability, which is using values to represent the actual run-off. These values will be explained in section 3.6. A water pollution level of 100 per cent means that the waste assimilation capacity has been fully consumed. A water pollution level bigger than 100 per cent means the quality standards are violated (Hoekstra et al., 2011).

$$WPL[x,t] = \frac{\sum WF_{grey}[x,t]}{R_{act}[x,t]} \ [-] \tag{20}$$

3 DATA COLLECTION

As a starting point, the data had to be local wherever possible. This means local datasets were prioritized on standardized data. Where local data lacks, such as input data for CROPWAT, calculation data for the water footprint estimations, standardized datasets from databases were used. In this chapter the local data and sources where this data were obtained are described. It will be noted clearly if standardized data was used.

3.1 Climatic data

The input climate data is for estimating the ET_0 and P_{eff} in CROPWAT using the Climate/ET_0 module. Required station profile data includes country, station name, latitude, longitude, and altitude. Required climatic data for monthly ET_0 calculation includes monthly average minimal temperature (^oC), maximum temperature (^oC), humidity (%), wind speed (km day^{-1}), and sunshine length (hours). These climatic parameters were monthly values of the year 2008 and were entered per meteorological station.

The precipitation data (*PR*) was implemented to calculate the effective rainfall (P_{eff}) in CROPWAT using the Rain module. In the program, the P_{eff} is calculated using the USDA S.C. Method (Allen et al., (1998)). Like the climatic data, the rainfall parameters were monthly values of the year 2008 and were entered per meteorological station.

Table 3.1 shows the characteristics of the ten meteorological stations. The required climatic data at each meteorological station were obtained from China Meteorological Data Sharing Service System (CMDSSS, 2014). Each station individually represents the climate condition for one district of the Shaanxi province. Due to the data limitation for high intensity of stations per district, as well as the little variation of climate condition in each district, we chose one station for each district to represent its climate.

Table 3.1: The characteristics of the meteorological stations used

#	District	Station name	Latitude	Longitude	Altitude (m)
1	Xi'an	Weiyang	34^o 31'	108^o 93'	397.5
2	Ankang	Hanbin	32^o 72'	109^o 03'	290.8
3	Baoji	Weibin	34^o 35'	107^o 13'	612.4
4	Hanzhong	Hantai	33^o 07'	107^o 03'	509.5
5	Shangluo	Shangzhou	33^o 87'	109^o 97'	742.2
6	Tongchuan	Yaozhou	35^o 08'	109^o 07'	978.9
7	Weinan	Linwei	35^o 82'	109^o 50'	1159.8
8	Xianyang	Qindu	34^o 25'	108^o 22'	447.8
9	Yan’an	Baota	36^o 60'	109^o 50'	958.5
10	Yulin	Yuyang	38^o 27'	109^o 78'	1157.0

3.2 Crop data

Crop data was obtained from CROPWAT standardized crop database, data of these crops are based on Allen et al. (1998) and several FAO publications (FAO, 2013). All crops were included in this standardized database, except the crop of Rape. The data of the Rape crop was obtained from Savva et al. (2002), which is based on FAO publications.

The data on the crop calender (planting and havest dates) and K_c values for all crops per district were available. When implementing the planting date, the standardized harvest date is automatically adjusted, based on standardized crop growing length. However, there could be a difference between the local harvest date and the standardized harvest date due to growth duration differences per district or per crop. By changing the length of the stages of a crop (initial, development, mid-season, late season), this difference was settled. This was done by distributing the difference in terms of percentage to the four stages of the crop. Here, the longest stage will get more (or less if the local harvest date is earlier than the standardized harvest date) days in comparison to the shortest stage. Usually these differences were relatively small compared to the whole growing period, therefore these adjustments did not have a significant effect on the other crop parameters. The local planting and harvest dates were obtained from China Meteorological Data Sharing Service System (CMDSSS, 2014) and Department of the Ministry of Agriculture Industry (DMAI, 2014).

Next to the local planting and harvest dates, also local crop coefficients (K_c) were used per stage (initial, mid-season, late season). The crop coefficients were obtained from the book *Main crop irrigation water quota of northern China* (Duan et al., 2004). Standardized CROPWAT values were used for the other crop parameters, such as rooting depths, critical depletion factors, yield response factor, and crop height.

For the category 'vegetables small' the standarized CROPWAT values were used. Since there was no fixed planting date available for this category and these crops are planted throughout the year, an average value of the *ET* was calculated. This was done by calculating the *ET* for 6 different planting dates throughout the year (01-01, 01-03, … , 01-09 , 01-11 [dd-mm]) and using the average *ET* for the water footprint calculation.

Appendix III gives an overview per district of which crops were cultivated and the corresponding local parameters.

3.3 Soil data

The Soil module has two different options, equivalent to the Crop module: non-Rice and Rice. The parameters of the Soil module for a non-Rice crop include total available water (TAW), maximum infiltration rate, maximum rooting depth, and initial soil moisture depletion. The parameters of the Soil module for a Rice crop include total available water (TAW), maximum infiltration rate, maximum rooting depth, initial soil moisture depletion, drainable porosity, critical depletion for puddle cracking, and water availability at planting maximum water depth. Most parameters for both options were not available and general soil data per district was also missing. As stated in section 2.1, the output of the Irrigation Schedule option is highly based on soil water balance to keep track of the soil moisture contact over time. Therefore using a method based on soil data and using standardized data instead of local data can have a huge impact of the model output. Seeing that 8 out of 9 crops in the Shaanxi province were non-Rice crops (57 of 65 crop calculations are non-Rice calculations) and did not need soil data to use the Crop Water Requirement option, this option was chosen instead of the Irrigation Schedule option. For the calculation of a Rice crop soil data was necessary. As stated above, soil data per district was not available so a standardized soil was selected from the CROPWAT soil database. The output can differ from the actual values, but this was taken for granted since the small amount of Rice calculations compared to non-Rice calculations.

The CROPWAT soil database offers 7 different soil types: light soil, medium soil, heavy soil, black clay soil, red loamy soil, red sandy loam soil and red sandy soil. One soil, the medium soil, was chosen to represent the Shaanxi province. The choice of soil was based on empirical knowledge. Next to selecting a soil, the maximum water depth of Rice and the water availability at planting had to be implemented. The values of the maximum water depth and water availability at planting were 100 mm and 50 mm, respectively, and were obtained from the book *Irrigation and drainage engineering* (Wang, 2010).

3.4 Yield, agricultural production data

Data on crop yield (ton ha^{-1}) and agricultural production (ton yr^{-1}) was obtained from Shaanxi Statistical Yearbook (Shaanxi Provincal Bureau of Statistics & NBS Survey Office in Shaanxi Province , 2009). It has to be noted that all agricultural production values were obtained from this source, except for the Potato crop. The value of agricultural production of the Potato crop was obtained from Liu (2011).

3.5 Data for grey water footprint calculation

Data on grey water footprint related to Nitrogen (N) was obtained from a several different sources. Data on the nitrogen fertilizer application rates per crop was estimated based on FAO FertiStat database (FAO, 2007). We assumed that the fertilizer application rates (kg ha^{-1}) in the Shaanxi province were equal to the national average (see Appendix IV).

The assumption was made that on average 10% of the applied nitrogen fertilizer is lost through leaching. This results in a leaching factor of 0.10. This factor was based on Chapagain et al. (2006).

The maximum value of nitrogen (N) is 10 mg per litre, following US-EPA (Chapagain et al., 2006). Since there was a lack of data on natural value of nitrogen, the natural concentration (c_{nat}) was assumed zero, following Hoekstra et al. (2011) when natural concentrations are not known precisely. There has to be noted that this results in an underestimated grey water footprint when the natural concentration is not equal to zero.

3.6 Water availability data

The amount of 'available irrigation water' for crop production per district was used as reported by Shaanxi Water Resources Bulletin 2008 (Department of Water Resources, 2008). These values have been assumed here to represent the blue water availability of the province. The water for assimilating the water pollution of the grey water footprint is normally the actual run-off (R_{act}). Also, the actual run-off was not available. Instead, the amount of available water per district was used. We assume that these values represent the actual run-off of the districts.

4 RESULTS

4.1 Water footprint related to crop production

Shaanxi's total water footprint of crop production in 2008 was 18764 $Mm^3 yr^{-1}$. The green water footprint was 7543 $Mm^3 yr^{-1}$, the blue water footprint was 7836 $Mm^3 yr^{-1}$ and the grey water footprint was 3385 $Mm^3 yr^{-1}$. This converts to percentages of 40%, 42% and 18% to the green, blue and grey water footprints, respectively.

4.1.1 Water footprint per district

The water footprint per district is set out in Table 4.1. Next to the values of the water footprints, the district's relative share of the provincial water footprint is given. Also the ranking position is given, with #1 as the largest contributor and #10 as the smallest. The water footprint per district was obtained by summarizing each individual water footprint of the crops cultivated in the district. Appendix V shows the water footprint by crops per district.

As Table 4.1 shows, the largest contributor was the Weinan district (3682 $Mm^3 yr^{-1}$) and it accounts for 20% of the total water footprint for Shaanxi province. The Tongchuan district (398 $Mm^3 yr^{-1}$) is the smallest contributor to the provincial water footprint with 2%. The main causes are the amount of crops cultivated and its production values per district. Weinan is also the largest one concerning the production. For Tongchuan it is vice versa, where it has the smallest production compared with the other districts.

Table 4.1: Water footprint per district in Shaanxi province in 2008

District	Water footprint related to production ($Mm^3 yr^{-1}$)				Percentage	Position #
	Green	Blue	Grey	Total		
Xi'an	920	1103	464	2487	13%	3
Ankang	707	315	292	1315	7%	7
Baoji	1075	952	372	2399	13%	4
Hanzhong	968	380	382	1731	9%	6
Shangluo	457	388	182	1027	5%	8
Tongchuan	116	216	66	398	2%	10
Weinan	1169	1887	626	3682	20%	1
Xianyang	1073	1011	505	2589	14%	2
Yan'an	291	347	127	765	4%	9
Yulin	766	1237	369	2372	13%	5
Total	7543	7836	3385	18764	100%	
Percentage	40%	42%	18%	100%		

In Figure 4.1 a distinction is made between the green, blue and grey components of the water footprints for the districts. The ten districts differ slightly from each other concerning the green-blue water footprint ratio. This ratio for the province is about 1:1 (40%:42%). Individually the districts: Xi'an (#3),Tongchuan (#10),Weinan (#1), Yan'an (#9) and Yulin(#5) have a larger blue water footprint than the district's green water footprint. The districts: Ankang (#7),Baoji(#4),Hanzhong (#6), Shangluo (#8),Xianyang (#2) have a smaller blue water footprint compared to the district's green water footprint. The provincial grey water footprint accounts for 18% of the total water footprint. The district's grey water footprint compared to the district's total water footprint varies between 16% (Yulin) and 22% (Hanzhong and Ankang). The grey water footprint in terms of quantitative values varies between 66 $Mm^3\ yr^{-1}$ (Tongchuan) and 625 $Mm^3\ yr^{-1}$ (Weinan).

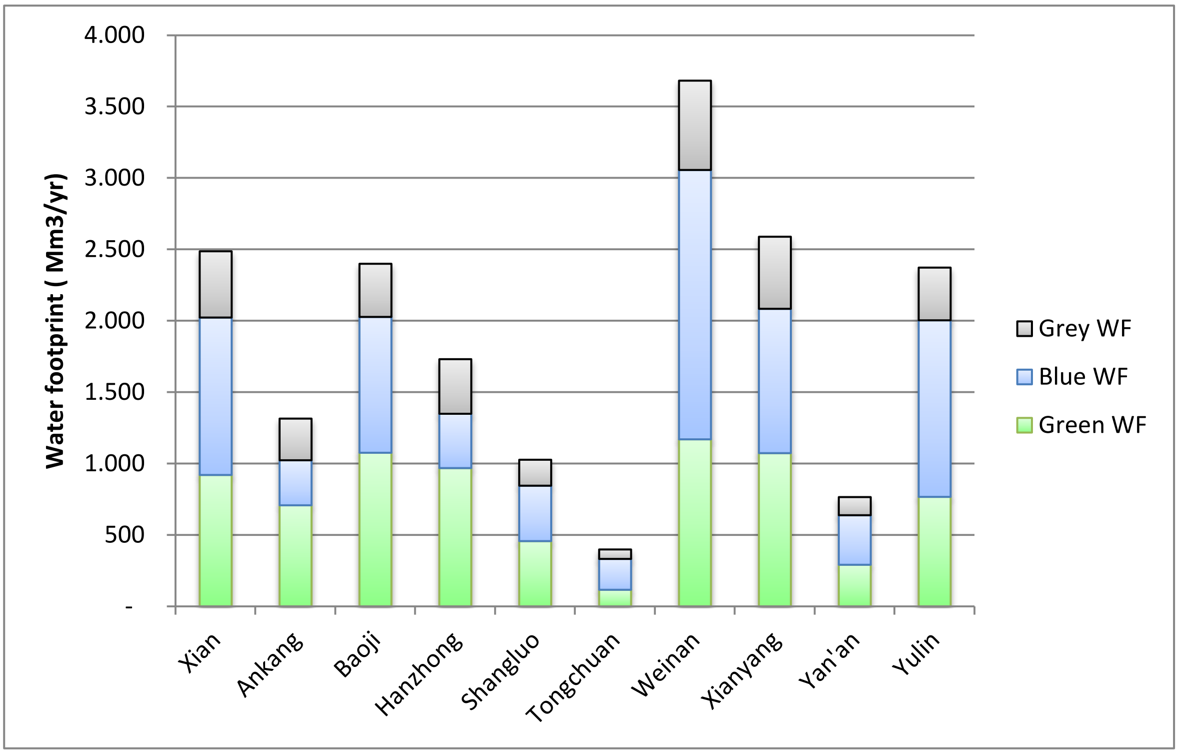

Figure 4.1: The green, blue and grey water footprint per district in Shaanxi province in 2008

The variations of the water footprints per districts are spatially mapped in Figure 4.2. The districts located in the middle of Shaanxi (Xi'an, Hanzhong, Baoji, Xianyang, Weinan) and in the North of Shaanxi (Yulin) show the largest water footprint. Looking at the water footprint components individually, we see the same phenomenon of higher water footprints in the middle and the North of Shaanxi. The main reason is that the crop production in these districts with a large water footprint are significantly larger compared to the districts with lower water footprints. Another reason, but with less impact on the size, is the water footprint per unit mass of crop. As it is higher for certain crops in some areas because of the difference in the degree of development of crop agriculture between the districts and the difference in the crop water requirements of the same crops between districts due to climatic influences. A more complete explanation is given in section 4.1.

Comparing the water footprint of districts this way will give a view on where the largest water footprint is located in the province. It is logical to say that smaller districts with less cultivated land and less production have smaller water footprints compared to districts with more cultivated land and more production. This can been seen at the Tongchuan district, a small district, versus the Yulin district, that is a number of times larger. There is a way to compare districts in another way, based on the import and export of crops for every district. In chapter 6, the discussion part, this way of comparison will be explained briefly, as this method is excluded in this study.

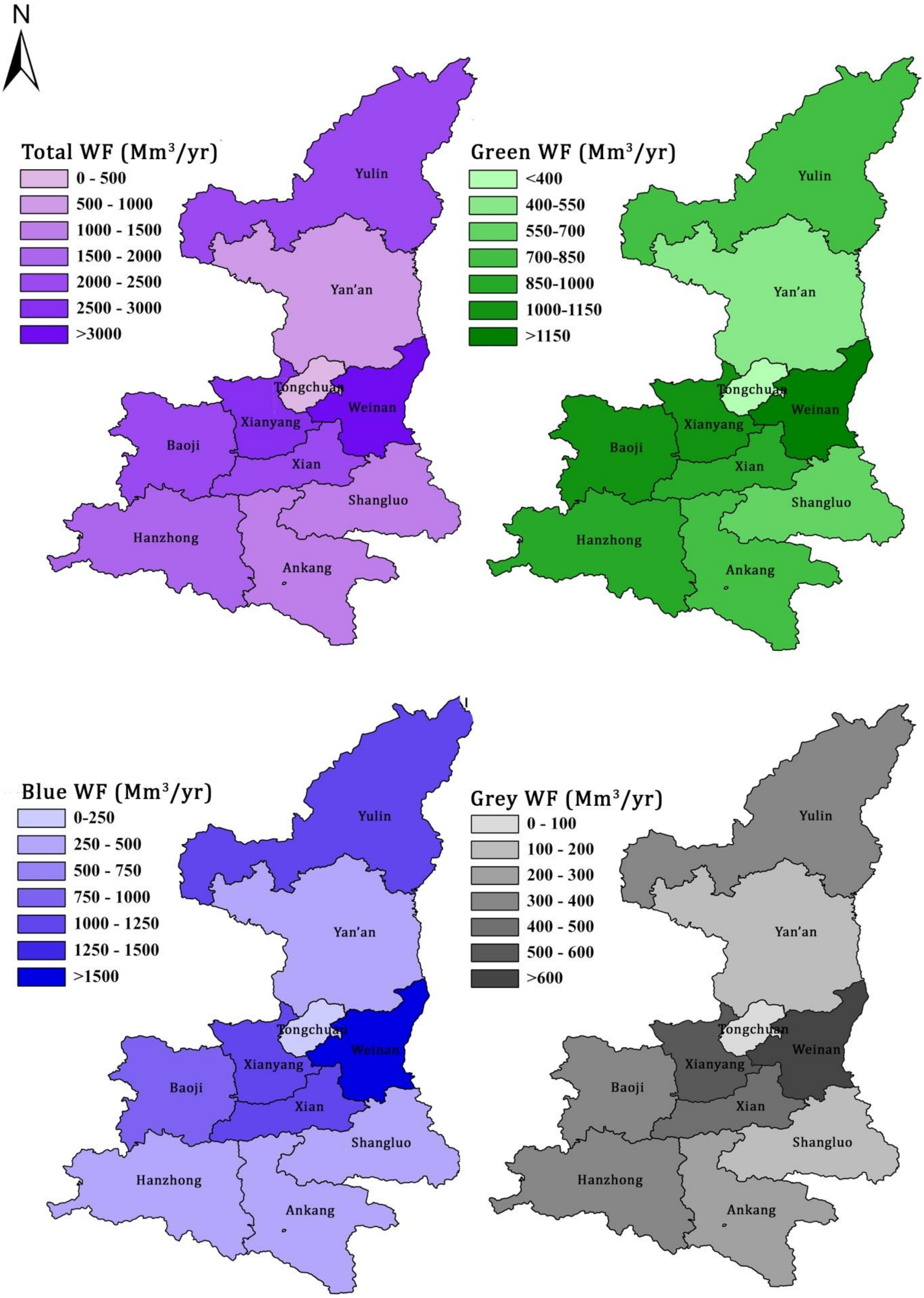

Figure 4.2: The total, green, blue and grey water footprint (WF) in Shaanxi province spatially mapped per district in 2008

4.1.2 Water footprint by crop

The contribution of the major crops to the water footprint related to crop production of Shaanxi province is presented in Figure 4.3. Wheat (6352 $Mm^3 yr^{-1}$) and Maize (6337 $Mm^3 yr^{-1}$) contribute the largest part to the total water footprint together accounting for about 68% of the province total. The other crops' water footprint is 6075 $Mm^3 yr^{-1}$ and accounts for the other 32%.

The total green water footprint was 7543 $Mm^3 yr^{-1}$. Maize (3207 $Mm^3 yr^{-1}$) has a large green water footprint and accounts for about 43% of the total green water footprint. Next to Maize, Wheat (1695 $Mm^3 yr^{-1}$) is the second largest contributor to the green water footprint and accounts for 22% of the total green water footprint. The other crops (2641 $Mm^3 yr^{-1}$) account for 35%.

The total blue water footprint was 7836 $Mm^3 yr^{-1}$. The major crops contributing to the blue water footprint are similar to the green water footprint. Here the Wheat crop (3849 $Mm^3 yr^{-1}$) is the largest contributor with 49% and is followed by Maize (1690 $Mm^3 yr^{-1}$), which accounts for 22%. Other crops (2297 $Mm^3 yr^{-1}$) contribute 29%.

The total grey water footprint related to the use of nitrogen fertilizer in crops cultivation was 3385 $Mm^3 yr^{-1}$. Maize (1439 $Mm^3 yr^{-1}$) and Wheat (808 $Mm^3 yr^{-1}$) are also the largest contributors to the grey water footprint, accounting for 42% and 24,espectively. The other crops (1138 $Mm^3 yr^{-1}$) account for 34%.The detailed information on water footprint of the other crops can be found in Appendix VI.

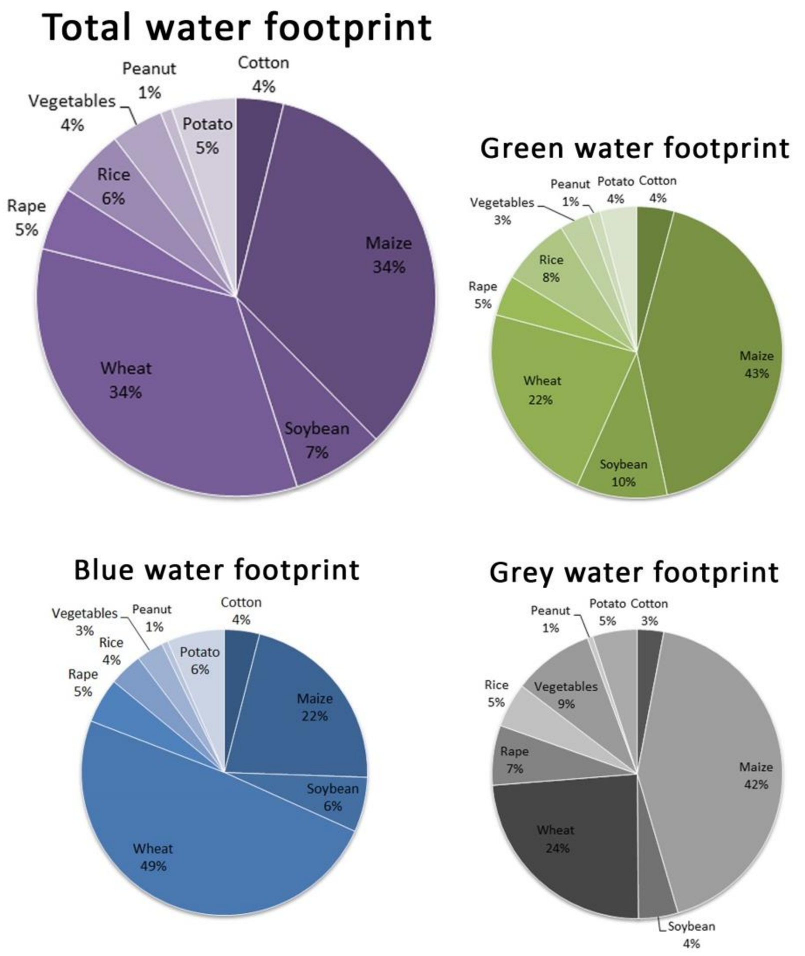

Figure 4.3: The contribution of different crops to the total, green, blue and grey water footprint of crop production in Shaanxi province in 2008

4.1.3 Water footprint of the crops per district

The contribution of the crops to the water footprint per district is presented in Figure 4.4

As shown in Figure 4.3, the size of the water footprints are mainly caused by the Maize and Wheat crops, as described in the previous subsection. Especially in the districts Xi'an, Baoji, Weinan and Xianyang, the water footprints of Maize and Wheat are large and therefore create a large water footprint for these districts.

For Cotton we see a significant share in the Weinan district, but in the other 9 districts, where Cotton is cultivated, the amount is insignificant.

The water footprints of Rape and Rice are noticeable in the Ankang and Hanzhong districts, but minimal for the other districts.

Potato has a large share in the water footprint of the Yulin district.

The water footprint of Soybean has a noticeable amount in all of the districts, especially in the districts of Xianyang, Yan'an and Yulin.

Peanut contribution is relatively small in the districts where it is cultivated. This phenomenon, where the district's size of the water footprint of Peanut is small, corresponds with the size of the water footprint of Peanut at provincial level. This is mainly caused from the low share of production compared to the other crops.

The water footprint of small vegetables is relatively small, even though the small vegetables account for 26% of the total crop coverage related to production. This can be explained due to the small amount of the water footprint to produce a ton of small vegetables (m^3 ton^{-1}). Therefore the small water footprint (m^3 ton^{-1}) compensates the large production values of these vegetables and results in a small water footprint related to production compared to the other crops.

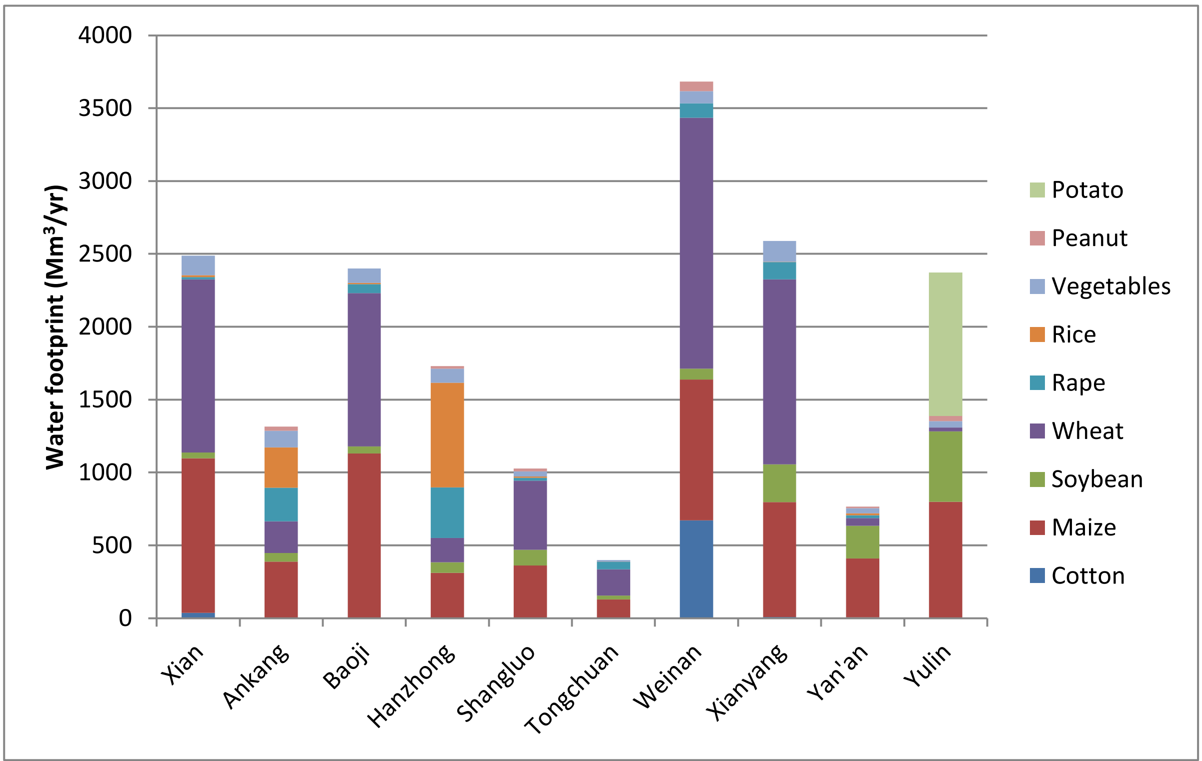

Figure 4.4: The water footprint per district in Shaanxi province with a distinction made between the crops in 2008

4.2 Water footprint per unit mass of crop

The green, blue, grey and total water footprint per unit mass of crop are given in Appendices VII and VIII.

As shown in Appendix VII, the water footprint per unit mass of crop per district are given. If we compare the blue and green water footprint per unit mass of crop, we can see a relation between the location of a district and its water footprint. In the North of Shaanxi, districts Yulin, Yan'an and Tongchuan, we see larger blue water footprints compared to the green water footprint. In the middle of Shaanxi, districts Xi'an, Boaji, Shangluo, Weinan and Xianyang, the blue and green water footprints are more in ratio with each other. In the South of Shaanxi, districts Hangzhong and Ankang, we see a larger green component compared to the blue water footprint. This phenomenon can be ascribed to the amount of precipitation in a district. A low amount of precipitation will lead to a smaller green water footprint and a higher blue water footprint, since irrigation water has to fill up the necessary amount (which the green water could not meet) to fulfil the crop water requirement. It applies the opposite way vice versa, high precipitation will lead to a large green water footprint and a small blue water footprint. As we know, the climate varies throughout the length of Shaanxi, with a more arid and dry climate in the North and a more humid and subtropical climate in the South. Since there is less precipitation in the North due to the climate, the green water footprint is smaller than the blue component (less green water, more blue water to meet CWR). In the South it the other way around, due to the climate with its high precipitation. The climate in the middle is somewhere in between these extremes and therefore the green and blue components are the same.

As we see in Appendix VIII, the magnitude of the water footprints of the same type of crop vary between districts. There are several factors that explain why the water footprint can differ so much for the same crop in different districts. Kampman (2007) showed that there are two main factors, which have large correlations with the size of a crop water footprint. The first factor is the difference in crop yield. A higher crop yield will lead to a lower water footprint and vice versa. The crop yield mainly depends on the development of agriculture. The better developed, the higher the crop yields. The degree of development can be divided in different sides of agricultural production, such as crop characteristics, fertilizer use or irrigation schedules. The second factor is the amount of the crop water requirements, which goes side by side with the evapotranspiration (*ET*). A high crop water requirement will lead to a higher water footprint at same level of crop productivity (*Y*) and vice versa. The crop water requirement is influenced by climatic parameters and crop characteristics. It has to be noted, that a higher ET rate leads not only to a higher crop water requirement but also to a higher biomass of the crop, which leads to a higher yield. However, the non-productive part of the *ET* rate (losses), that does not contribute to the biomass of the crop, is relatively higher and therefore the influence of climatic parameters on the water footprint is relatively higher.
The yields of the same crops but different districts differ a lot, so it hard to conclude which district is the most developed. Since it is possible that some crops in a district are well developed, while other crops are less developed. So there should not a conclusion be made with its focus on the district, but there should a conclusion be made by its individual crops. To see which crops are doing better than provincial average and which crops could be improved. In section 4.2.1., the water footprint unit mass of the largest crops have been examined.

4.2.1 Water footprint of the largest crops

Since a general conclusion on the water footprint of crops is hard to find, it is still interesting to see how certain crops and their corresponding water footprint are distributed spatially. As shown in Figure 4.3, Wheat and Maize have the largest contribution to the crop water footprint related to crop production in the Shaanxi province. Wheat and Maize have a share of 68% together of the total water footprint related to crop production. Therefore the water footprint per unit mass of these two crops are described in more detail.

Figure 4.5 (left) shows the spatial variation of the water footprint per unit mass of Wheat in the Shaanxi province.

The water footprint of Wheat in the Shaanxi province varies from 1125 $m^3 ton^{-1}$ to 11732 $m^3 ton^{-1}$ among districts, with an weighted average of 1347 $m^3 ton^{-1}$.

The district with the largest water footprint of Wheat is the Yulin district (11732 $m^3 ton^{-1}$) in the most northern part of the province. The reason behind this large water footprint concerns the low production values compared to the area use, or low yield. The yield of Wheat in the Yulin district is 0,631 ton ha^{-1} compared to the average yield of 3,219 ton ha^{-1} for the whole province. Besides the low yield the crop water requirement is 37% higher in this district compared to the average value.

Next to the largest water footprints of Wheat in Yulin, the water footprints in Shangluo (2593 $m^3 ton^{-1}$), Tongchuan (1940 $m^3 ton^{-1}$) and Yan'an (2143 $m^3 ton^{-1}$) are relatively large. The size of these water footprints is a result of reasons similar to those of the Yulin district, namely lower yield and higher crop water requirements. However, they were less extreme compared to Yulin.

Medium water footprints can be found in the Hanzhong (1310 $m^3 ton^{-1}$), Weinan (1432 $m^3 ton^{-1}$) and Ankang district (1654 $m^3 ton^{-1}$). Although Ankang's water footprint is still somewhat large.

Smaller water footprints can be found in remaining districts Xi'an (1125 $m^3 ton^{-1}$), Baoji (1183 $m^3 ton^{-1}$) and Xianyang (1265 $m^3 ton^{-1}$). The reasons for smaller water footprints are higher yields and lower crop water requirements.

The crop yields in the districts can be ascribed to the degree of development of a district, described in the previous section. The Yulin district (0,631 ton ha^{-1}) differs a lot from the average yield as it is 80% smaller than the average provincial yield (3,219 ton ha^{-1}). It is obvious to say, this difference can be ascribed to harvest failure. However, comparing to the yields of the previous two years, 0,822 ton ha^{-1} (2006) and 0,480 ton ha^{-1} (2007), we see that these yields are also very low. There are either two possibilities: the cultivation of Wheat in the Yulin district is underdeveloped or the district struggles with harvest failures the last few years. These two possibilities are related to each other because underdevelopment can lead to loss of harvest due to of lack of well agricultural management.

Figure 4.5 (right) shows the variation of the water footprint of Maize in the Shaanxi province.

The water footprint of Maize in the Shaanxi province varies from 850 $m^3 ton^{-1}$ to 1748 $m^3 ton^{-1}$, with an average of 1157 $m^3 ton^{-1}$.

The district with the highest water footprint is Baoji (1748 $m^3 ton^{-1}$) caused by the high crop water requirements, since the yield is about the provincial average.

In South Shaanxi, the Ankang (1632 m^3 ton^{-1}), Hanzhong (1418 m^3 ton^{-1}) and Shangluo (1341 m^3 ton^{-1}) districts have large water footprints. The water footprint of Maize is large due to lower yields, since the crop water requirement lies under the provincial average.

Yulin (1240 m^3 ton^{-1}) is about average of the Maize water footprint. Lower water footprints can be found in the districts at middle to mid-North Shaanxi: Xi'an(1030 m^3 ton^{-1}), Tongchuan (1067 m^3 ton^{-1}), Weinan (964 m^3 ton^{-1}), Xianyang (850 m^3 ton^{-1}) and Yan'an (1060 m^3 ton^{-1}). Here the crop water requirements are average to low and yields are average to large.

As this Figure 4.5 shows the water footprint of Maize is higher in South Shaanxi. This is mainly caused by the lower yields in these districts. We can say that these districts are less developed in terms of the cultivation of Maize than the other districts. Also the climate can play part in the limitation of crop yields. However, the climate in the South is in generally more gentle than in the North. The crop water requirements are below average and therefore not responsible for the large water footprints. Except for the Baoji district, where the large crop water requirements influence the water footprint a lot.

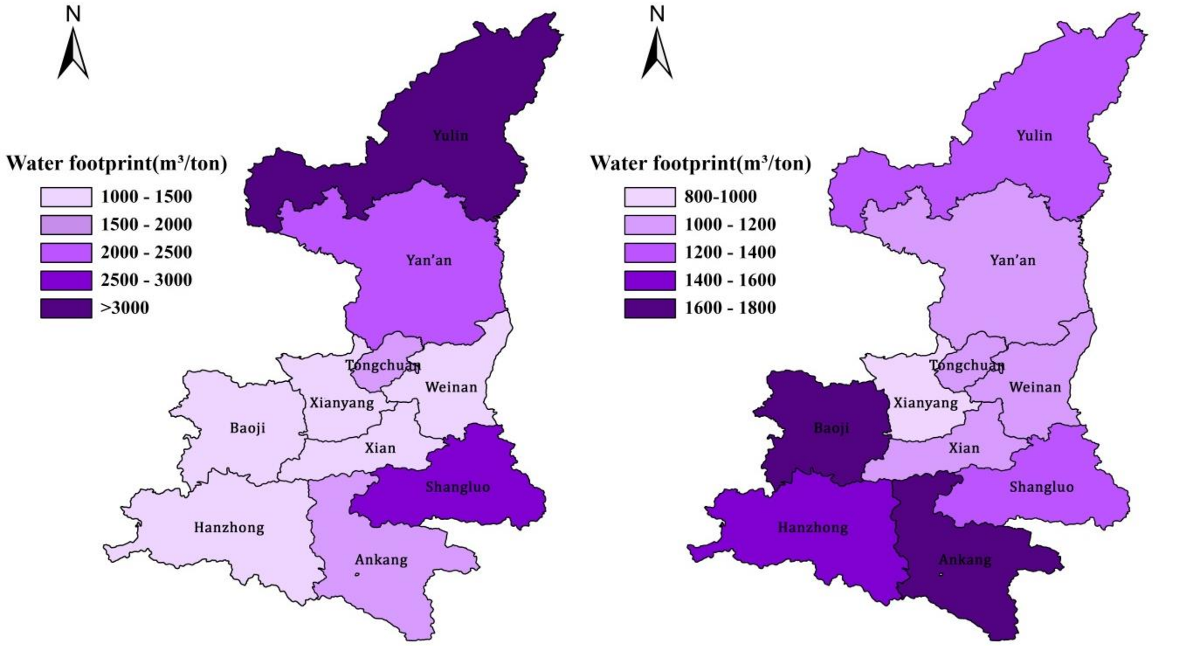

Figure 4.5: The water footprint per unit mass crop distributed spatially for wheat (left) and maize (right) in Shaanxi province in 2008

4.2.2 Comparison with other studies

The acquired water footprints (m^3 ton^{-1}) of this study can be compared to the water footprints of previous studies. A study that includes the water footprints of crops of Shaanxi is 'The green, blue and grey water footprint of crops and derived crop products' (Mekonnen & Hoekstra, 2011). It includes an assessment of the water footprints of crops and crop products around the world for the period of 1996-2005. As part of this assessment the Shaanxi province has been included and the values of the water footprints of this study are obtained from Appendix II of the report.

Table 4.2 shows the comparison of the average water footprints estimated in this study the study by Mekonnen & Hoekstra (2011).

Table 4.2: Comparison between water footprint per unit mass crop in Shaanxi province

Crop	De Boer (2014)				Mekonnen & Hoekstra (2011)				Comparison
	Water footprint (m^3 ton^{-1})				Water footprint (m^3 ton^{-1})				
	Year 2008				Average for 1996-2005				
	Green	Blue	Grey	Total	Green	Blue	Grey	Total	
Cotton	3144	3135	1006	7285	2971	371	1344	4687	55%
Maize	585	309	263	1157	713	20	290	1023	13%
Peanut	1266	718	259	2243	1190	44	257	1491	50%
Potato	151	251	83	485	202	4	97	303	60%
Rape seed	1021	1196	677	2894	1261	0	505	1766	63%
Rice	802	411	233	1446	483	297	215	995	45%
Soybean	2056	1323	406	3785	2374	253	254	2881	31%
Wheat	360	816	171	1347	720	285	312	1317	2%
Veg. small	42	41	52	135	N/A	N/A	N/A	N/A	-

We see differences between the values. The biggest difference of the total water footprint per unit mass is 63% and belongs to the Rape seed crop. The Wheat crop shows the smallest difference of 2%. As explained in the previous section 4.2, values can differ a lot due to large crop water requirements and low yields.

The main differences can be explained by the following reasons:

- Difference between study periods;
- Application of different data and area scale
- Different model approaches and assumptions.

The time period of this study includes the year of 2008 and assumes all the crop land was irrigated without consideration of soil water stress. As we examine the study of Mekonnen & Hoekstra (2011), it includes a time period of several years, ranging from 1996 to 2005. The water footprints found by Mekonnen & Hoekstra (2011) are average values for rain-fed and irrigated area under soil water stress over these years. Therefore climate variations throughout the year do not have as much impact on the water footprints. For a single year study, such as this study, climate variation can have a certain impact on the water footprints. As described in section 1.2, the year of 2008 was relatively dry. Since there was less rainfall, the shortage of water to complete the crop water requirements will be done by irrigating more. This leads to a higher blue water footprint, which we see when comparing the two studies. The blue water footprints are higher in this study than in the compared study of Mekonnen & Hoekstra (2011). This also explains why the green water footprint in this study is lower compared to Mekonnen & Hoekstra (2011).

In this study the Shaanxi province has been divided into ten districts. Therefore the calculations have been done at district level. Every district has its own climatic parameters and crop characteristics such as rainfall, growth periods, K_c, yields, and production. This will lead to different ET_c's and different water footprints per single crop. The average water footprints per unit mass of crop are taken by the weighted average water footprints per unit mass of crop per district, with its weight based on the production values. In the study of Mekonnen & Hoekstra (2011) the accounting of the water footprints of the crops has been averaged at province scale and not on district scale. Accounting the water footprints on a larger scale, details can be overlooked. Also, Mekonnen & Hoekstra (2011) state that in a global study like theirs, because of lack of data, several assumptions and expert guesses were made. Therefore the water footprint values at a smaller spatial scale should be interpreted with care.

In the study of Mekonnen & Hoekstra (2011), a grid-based water balance model was used to estimate the crop water use for 126 primary crops. For the other 20 crops, which are grown in only a few countries, the CROPWAT 8.0 model was used. Mom (2007) states that the use of different model scan have a significant impact on the outcome, since simulations and assumptions are different per model. Also, Mekonnen & Hoekstra (2011) used irrigation maps per crop to allocate where irrigation is taking place, and in those places the application of full irrigation is assumed. The method used in this study and the Mekonnen & Hoekstra (2011) method both lead to an overestimation of the blue water footprint. Because farmers may decide to irrigate below the optimal yield level, especially in places where water scarcity is occurring. However, the method of using irrigation maps will give more precise calculations because it is clear where irrigation is taking place at all. In contradiction, in this study we assumed that irrigation is taking place wherever it needed if rainfall does not cover the crop water requirement. In reality it is possible that irrigation is not possible in certain areas even though it is needed. This could lead to an overestimation of the blue water footprint.

4.3 Water footprint sustainability

4.3.1 Blue water scarcity

Figure 4.6 shows the blue water scarcity for cropland per district of the Shaanxi province. There is blue water scarcity when the blue water footprint exceeds the available blue water. Blue water availability and water scarcity values can be found in Appendix IX.

As stated in section 2.7, blue water scarcity has four different classes.

The first class is defined as 'low blue water scarcity (<1.0)'. There are four districts that could be assigned to this class: Hanzhong (0.05), Ankang (0.05), Shangluo (0.29) and Baoji (0.69). Here, the blue water footprint does not exceed blue water availability. It means the supplied blue water was enough for cropping at optimal condition in the four districts.

For the other six districts the ratio exceeds 1,0. Here, blue water scarcity might occur.

The districts Xianyang (1.48), Yan'an (1.41) and Yulin (1.22) are classified as 'moderate blue water scarcity (1.0-1.5)'. The Xi'an district and the Weinan district have ratios of 1.61 and 1.85, respectively. They belong to the class 'significant blue water scarcity (1.5-2.0)'. Tongchuan has a ratio of 4.80 and belong to 'severe water scarcity (>2.0)'. Looking at spatial distribution of the blue water scarcity, we see that the North and the middle of Shaanxi suffered from blue water scarcity for cropland. The ratios in the South are very low, so it seems that the available water is distributed unevenly according the districts. This could be part of the difference in climate between the North and the

South of Shaanxi, since the northern part is more arid and the southern part more humid. Also, the districts with higher water footprints related to production are located in in the North and in the middle of Shaanxi. The districts in the South belong to the five districts with the lowest water footprints.

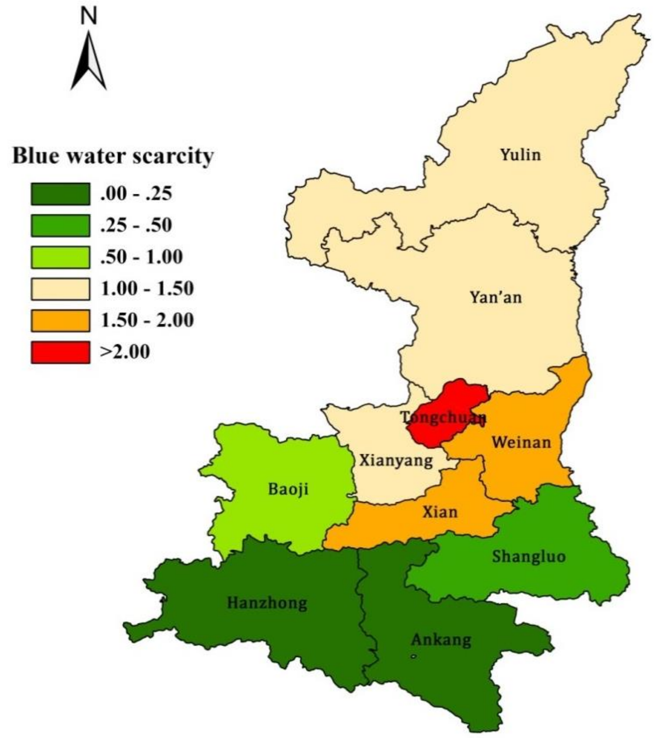

Figure 4.6: Blue water scarcity per district in Shaanxi province in 2008

The blue water scarcity assessment was done under the best condition, where we assumed all supplied irrigation water can contribute to the actual productivity without waste. In reality it could be worse, by considering the low irrigation water efficiency values (~0,5) of the districts (Appendix X). This could lead to an underestimation of the blue water scarcity of the districts.

It has to be noted that the blue water sustainability assessment is executed based on the yearly blue water scarcity. For this reason there has no distinction been made of monthly blue water scarcity. An explanation is given in the discussion part.

4.3.2 Water pollution level

Figure 4.7 shows the water pollution level per district of the Shaanxi province. The water pollution level is too high when there is not enough water to assimilate the grey water footprint.

As the figure shows, most of the districts are green (0.05-0.6). Here, there is enough water to assimilate the water pollution in the districts. We see that Tongchuan has problems concerning assimilating the water pollution, with a ratio of 1.47. This led to polluted water sources and groundwater sources in the area. For the other districts there are no high risk districts (0.8-1.0).

However, the districts in middle Shaanxi, Xi'an, Xianyang and Weinan could be risks in the future. As stated before, the same reasons of the blue water scarcity apply for these districts too.

Like the blue water scarcity analysis, the grey water pollution analysis is also done on a yearly basis. The explanation done for the blue water scarcity also applies for the grey water pollution.

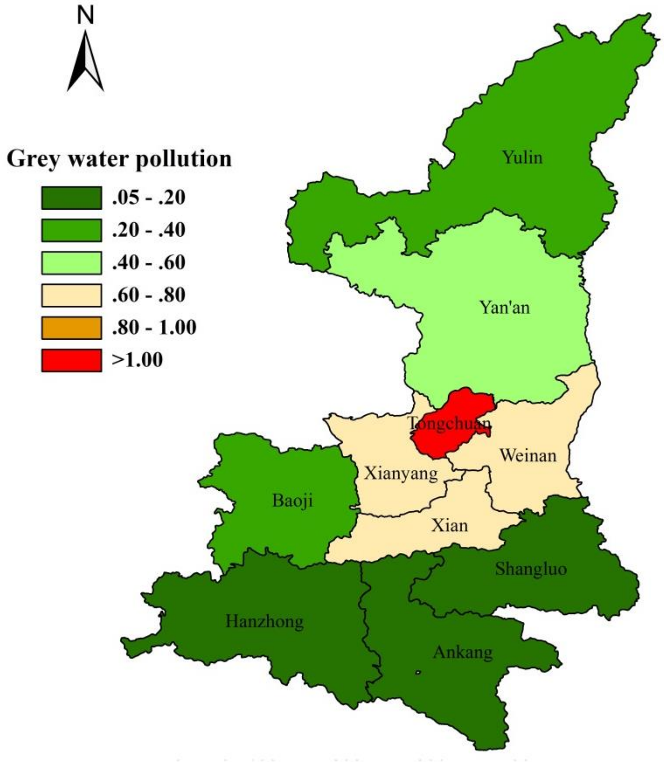

Figure 4.7: Grey water pollution per district in Shaanxi province in 2008

5 DISCUSSION

The blue water footprint has been underestimated, due to excluding irrigation losses, such as *ET* losses in the canals. However, these losses are difficult to measure and no clear method is given to include these losses. On the other hand, using the crop water requirement option of CROPWAT may lead to an overestimation of the blue water footprint. This option calculates the ET under 'ideal growth conditions', this means that adequate soil water is maintained by rainfall and/or irrigation so it does not limit plant growth or crop yield. In other words, every single crop is assumed to be fully irrigated to their needs, even in places where in reality it is not possible to irrigate fully. Whereas, Mekonnen & Hoekstra (2011) used irrigation maps per crop to allocate where irrigation is taking place, and in those places the application of full irrigation is assumed. The method used in this study and the Mekonnen & Hoekstra (2011) method both lead to an overestimation of the blue water footprint. Because farmers may decide to irrigate below the optimal yield level, especially in places where water scarcity is occurring. However, the method of using irrigation maps will give more precise calculations because it is clear where irrigation is taking place at all.

In this study we aimed to quantify the water footprints of crops in the Shaanxi province. In this study there was no 100% crop coverage, but a crop coverage of 80% related to land use and 77% related to production. Due to incompleteness of crop coverage, the water footprint found in this study was therefore underestimated. The actual water footprint of the Shaanxi province will be larger than claimed.

There was only one climate station used for each district. Therefore the data was rough because it represents a large area. For crop data we used the standardized CROPWAT values, with adjusted dates, growth stages, and *Kc* values. However, other standardized data such as rooting depths and crop height have not been adjusted for this region study. For the crop category 'small vegetables' we used the standardized CROPWAT data to represent this crop category. This category included a lot of different crops. It would be better to split this category up into individual crops, however available data did not allow that. For soil data we also used standardized CROPWAT values, based on the fact that there was no reliable soil data and the amount of calculations including soil data was limited compared with the total amount of calculations. Using the standardized CROPWAT values can lead to different outcomes. For fertilizer data we used the FertiStat database. This data base includes the fertilizer use of the whole country instead of provincial data. The assumption was made that the country's data represents Shaanxi in a similar way. Furthermore, the data was relatively old, since it was retrieved from the year 1997.

In this study the water footprints were based on the total production of a district, excluding import or export. Since the districts differ in size and agriculture, it is hard to make conclusions based on these water footprints. The water footprint per capita could be used to compare the districts' water use. However, this includes import, export values and virtual trade flows. Since our scope was not to determine the water footprint per capita, but the total water footprint, it was excluded from this study.

For the blue water availability the natural run-off was not available for the whole province, nor district. Similar for the grey water availability the actual run-off was not available for the province, nor district. Therefore the amount of 'available irrigation water' per district was used as reported by Shaanxi Water Resources Bulletin 2008 (Department of Water Resources, 2008). The assumption of using the reported ‘available irrigation water’ as blue WA and grey WA is rough, since it is unclear what type of irrigation waters these values of ‘available irrigation water’ comprehend. This can lead to an over- or underestimation of the values used. The blue water scarcity assessment was done under the best condition, where we assumed all supplied irrigation water can contribute to the actual productivity without waste. Seeing the low irrigation water efficiency values (~0,5) of the districts, it could be the case that a lot of irrigation water will become waste (not be able to use for crop production). This could lead to an underestimation of the blue water scarcity of the districts. It should be noted that the blue water scarcity values found should be interpreted with care.

The blue water scarcity analysis was done on yearly basis, which means that no study was made of blue water scarcity variations within the year. This has not been done because of a lack of data on blue water availability per month. A yearly blue water sustainability assessment will give a general view on blue water scarcity in the area. However, this gives a rather rough image on blue water scarcity, because details are overseen. When doing an assessment on a more detailed scale, like a monthly assessment, the outcome could be different. For example, severe blue water scarcity occuring in certain months in a district, but with an overall yearly low blue water scarcity. Therefore, we have to be cautious with jumping to conclusions based on blue water scarcity with results on yearly basis. This explanation also applies to the water pollution level which was done on a yearly basis.

6 CONCLUSION

The total water footprint related to Shaanxi's crop production in the year of 2008 was 18764 $Mm^3\ yr^{-1}$ (40% green; 42% blue; 18% grey).

The Shaanxi province consists of ten districts, for each of which the water footprint was estimated. The Weinan district (3692 $Mm^3\ yr^{-1}$) was the largest contributor and it accounted for 20% of the total water footprint of Shaanxi province. The Tongchuan district (398 $Mm^3\ yr^{-1}$) was the smallest contributor to the provincial water footprint with a contribution of 2%. The districts located in the middle of Shaanxi (Xi'an, Hanzhong, Baoji, Xianyang and Weinan) and in the North of Shaanxi (Yulin) showed larger total water footprints. This spatial distribution also applied for the three water footprint components. The main reason of the larger water footprints in these districts relates to the high production values the crops cultivated in these districts compared to the other districts with smaller water footprints.

Wheat (6352 $Mm^3\ yr^{-1}$) and Maize (6337 $Mm^3\ yr^{-1}$) contributed the largest part to the total water footprint, together accounting for about 68%. For the green, blue and grey water footprint, the same two crops, Wheat and Maize had the upper hand, concerning the contribution to each water footprint. Wheat and Maize had a large share of the provincial water footprint for each district individually as well. These two crops were usually the largest shareholders of a district's water footprint.

There is a relation between the location of a district and the individual components of a water footprint unit mass of the crops (grey excluded). In the North the blue water footprint was larger than the green water footprint, in the middle the green and blue water footprints were about the same ratio and in the South the green water footprint was larger than the blue water footprint. This due to the climatic difference over the length of Shaanxi. Looking at the total water footprint per unit mass of all the crops, we found no clear connection between the size of the water footprints and its location. The main reason for the size of the water footprint was the development of the agriculture in a district. A more developed district could achieve higher yields than an underdeveloped district and could therefore achieve a smaller water footprint. However, the water footprint unit mass of crop per district vary too much to conclude that certain districts are under or well developed. So there should not a conclusion be made with its focus on the district, but there should a conclusion be made by its individual crops. To see which crops are doing better than provincial average and which crops could be improved. Comparing the two largest crops (related to production) individually, we found for Wheat larger water footprints unit mass of crop in the North and in the east of Shaanxi compared to the other districts that cultivate Wheat. Regarding Maize we found larger water footprints unit mass of crop in the South of Shaanxi.

The water footprints per unit mass of crop estimated in this study were larger compared to the study of Mekonnen & Hoekstra (2011). The latter study gave average water footprints over a period of 1996-2005, while this study is done for the year of 2008. Since 2008 was a dry year, we see larger blue water footprints and smaller green water footprints. Furthermore, this study was done in more detail by doing the assessment per district, where mostly local datasets from local organisations per district were used, while in the Mekonnen & Hoekstra (2011) study was done on higher resolution, where the water footprints were calculated for the province as a whole, and where mostly datasets from global organisations were used. Also Mekonnen & Hoekstra (2011) state that a global study like theirs the water footprint values at a smaller spatial scale should be interpreted with care.

Blue water scarcity on a yearly scale was above 100% in six (Xianyang, Yan'an, Yulin, Xi'an, Weinan and Tongchuan) of the ten districts in 2008. Where the blue water footprint exceeded the amount of available blue water. This can lead to exhaustion of the water resources of these districts, such as surface and groundwater. The blue water scarcity was the highest in the Tongchuan district (480%) and lowest in the Hanzhong district (5%). Also severe water pollution was occurring in one district. Here the runoff could not assimilate the amount of pollution produced by the fertilizer used in the agricultural section. This can lead to polluted water sources and groundwater sources in the area. Both cases occurred in the North and in the middle Shaanxi. In these districts the water footprint was larger than in South Shaanxi. Since blue water scarcity and water pollution was low in the South, it seemed that the water was distributed unevenly in the province. The different climates between North (arid) and South (humid) could be the cause.

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APPENDICES

APPENDIX I: LIST OF SYMBOLS

Symbol	Unit	Explanation
α	-	leaching-run-off fraction, i.e. fraction of applied chemicals reaching freshwater bodies
AR	mass/area	application rate of a chemical (fertilizer or pesticide) per unit of land
AWU_{grey}		
C_{max}	mass/volume	maximum acceptable concentration of a chemical in a receiving water body
C_{nat}	mass/volume	natural concentration of a chemical in the receiving water body
CWR	length/time	crop water requirement
CWU_{blue}	volume/area	blue crop water use
CWU_{green}	volume/area	green crop water use
EFR	volume/time	environmental flow requirement
ET_{blue}	length/time	blue water evapotranspiration
ETc	length/time	crop evapotranspiration (under optimal conditions)
ET_{green}	length/time	green water evapotranspiration
ET_0	length/time	reference crop evapotranspiration
K_c	-	crop coefficient
$L_{leached}$	mass/area	Leached pollutant load
P	mass/time	Production quantity
P_{act}	length/time	
P_{eff}	length/time	effective rainfall
R_{act}	volume/time	actual run-off from a catchment
R_{nat}	volume/time	natural run-off from a catchment (without blue water footprint within the catchment)
WA_{blue}	volume/time	blue water availability
WF_{proc}	volume/mass	water footprint of a process
$WF_{proc,blue}$	volume/mass	blue water footprint of a process
$WF_{proc,green}$	volume/mass	green water footprint of a process
$WF_{proc,grey}$	volume/mass	grey water footprint of a process
WF_{blue}	volume/time	blue water footprint of a process

WF_{green}	volume/time	green water footprint of a process
WF_{grey}	volume/time	grey water footprint of a process
WF	volume/time	water footprint of a process
WS_{blue}	-	blue water scarcity in a catchment area in a specific period within the year
Y	mass/area	crop yield

APPENDIX II: CROPS CULTIVATION IN SHAANXI PROVINCE IN 2008 PER DISTRICT

	1. Xi'an	**2. Ankang**	**3. Baoji**	**4. Hangzhong**
I.	Cotton	Cotton	Cotton	Cotton
II.	Maize	Maize	Maize	Maize
III.	Soybean	Soybean	Soybean	Soybean
IV.	Wheat	Wheat	Wheat	Wheat
V.	Rape	Rape	Rape	Rape
VI.	Rice	Rice	Rice	Rice
VII.	Vegetables	Vegetables	Vegetables	Vegetables
VIII.		Peanut		Peanut
	5. Shangluo	**6. Tongchuan**	**7. Weinan**	**8. Xianyang**
I.	Cotton	Maize	Cotton	Cotton
II.	Maize	Soybean	Maize	Maize
III.	Soybean	Wheat	Soybean	Soybean
IV.	Wheat	Rape	Wheat	Wheat
V.	Rape	Vegetables	Rape	Rape
VI.	Rice	Rice	Vegetables	Rice
VII.	Vegetables		Peanut	Vegetables
VIII.	Peanut			
	9. Yan'an	**10. Yulin**		
I.	Cotton	Patato		
II.	Maize	Maize		
III.	Soybean	Soybean		
IV.	Wheat	Wheat		
V.	Rape	Vegetables		
VI.	Rice	Peanut		
VII.	Vegetables			
VIII.	Peanut			

APPENDIX III: CROP YIELD & PRODUCTION IN SHAANXI PROVINCE IN 2008 PER DISTRICT

District		Crop	Yield (2008)	Prod. (2008)	District		Crop	Yield (2008)	Prod. (2008)
			ton/ha	ton				ton/ha	ton
1.Xi'an	I	Cotton	1.459	6,173	**6. Tongchuan**	I	Maize	6.096	121,500
	II	Maize	5.391	1,030,300		II	Soybean	1.490	7,400
	III	Soybean	1.630	12,400		III	Wheat	2.927	92,600
	IV	Wheat	4.960	1,056,200		IV	Rape	1.134	10,369
	V	Rape	2.057	9,540		V	Vegetables	21.155	54,010
	VI	Rice	6.999	8,600		VI	Rice	6.545	200
	VII	Vegetables	7.074	1,218,417	**7. Weinan**	I	Cotton	1.190	91,711
2. Ankang	I	Cotton	0.920	23		II	Maize	5.096	1,002,600
	II	Maize	2.916	237,000		III	Soybean	1.325	20,000
	III	Soybean	1.478	18,700		IV	Wheat	4.009	1,203,000
	IV	Wheat	2.554	131,500		V	Rape	1.798	29,249
	V	Rape	1.741	73,366		VI	Vegetables	26.205	528,049
	VI	Rice	6.622	192,900		VII	Peanut	2.940	34,491
	VII	Vegetables	15.852	466,083	**8. Xianyang**	I	Cotton	0.653	682
	VIII	Peanut	2.197	11,801		II	Maize	5.358	927,100
3. Baoji	I	Cotton	1.185	109		III	Soybean	1.828	111,100
	II	Maize	4.797	646,500		IV	Wheat	4.507	1,003,800
	III	Soybean	1.400	13,800		V	Rape	2.014	41,976
	IV	Wheat	4.502	889,400		VI	Rice	4.670	1,100
	V	Rape	1.908	20,713		VII	Vegetables	39.459	1,575,769
	VI	Rice	6.947	6,600	**9. Yan'an**	I	Cotton	0.706	411
	VII	Vegetables	20.490	515,046		II	Maize	6.203	382,000
4. Hanzhong	I	Cotton	1.074	29		III	Soybean	1.325	46,000
	II	Maize	3.145	219,500		IV	Wheat	3.065	24,800
	III	Soybean	1.069	17,500		V	Rape	1.710	4,987
	IV	Wheat	2.759	127,400		VI	Rice	8.323	10,300
	V	Rape	1.977	139,662		VII	Vegetables	38.398	336,361
	VI	Rice	6.040	494,900		VIII	Peanut	1.625	2,916
	VII	Vegetables	28.527	761,968	**10. Yulin**	I	Patato	15.000	2,025,000
	VIII	Peanut	2.387	8,317		II	Maize	5.917	643,700
5. Shangluo	I	Cotton	1.429	20		III	Soybean	1.286	82,400
	II	Maize	3.835	269,300		IV	Wheat	0.631	2,300
	III	Soybean	1.708	38,700		V	Vegetables	23.242	223,969
	IV	Wheat	2.280	183,500		VI	Peanut	2.183	11,978
	V	Rape	1.134	3,591					
	VI	Rice	6.545	5,400					
	VII	Vegetables	19.920	171,583					
	VIII	Peanut	2.620	10,016					

				Length of stages					Crop coefficients		
District	Crop	Planting date	Harvest date	I	D	M	L		Kc_ini	Kc_mid	Kc_end
		dd/mm	dd/mm	d	d	d	d	d			
1. Xi'an	Cotton	03/04	24/10	32	53	63	57	205	0.57	1.15	0.63
	Maize	06/06	02/10	19	33	38	29	119	0.50	1.14	0.53
	Soybean	09/06	10/10	22	22	58	22	124	0.57	1.14	0.53
	Wheat	13/10	04/06	29	138	39	29	235	0.60	1.12	0.40
	Rape	15/09	10/05	39	39	59	99	236	0.70	1.00	0.95
	Rice**	07/04	15/09	-	-	-	-	-	-	-	-
	Vegetables	N.F.*	N.F.*	20	30	30	15	95	0.70	1.05	0.95
2. Ankang	Cotton	03/04	24/10	32	53	63	57	205	0.55	1.13	0.60
	Maize	16/06	02/10	17	31	35	26	109	0.58	1.11	0.50
	Soybean	09/06	10/10	22	22	58	22	124	0.71	1.08	0.42
	Wheat	26/10	15/05	25	118	34	25	202	0.60	1.11	0.40
	Rape	17/09	10/05	39	39	59	99	236	0.70	1.00	0.95
	Rice**	07/04	15/09	-	-	-	-	-	-	-	-
	Vegetables	N.F.*	N.F.*	20	30	30	15	95	0.70	1.05	0.95
	Peanut	07/05	13/09	25	35	45	25	130	0.40	1.15	0.60
3. Baoji	Cotton	04/03	24/10	32	53	63	57	205	0.55	1.13	0.60
	Maize	13/06	02/10	17	32	36	27	112	0.58	1.11	0.50
	Soybean	10/06	13/10	22	22	60	22	126	0.71	1.08	0.42
	Wheat	08/10	05/06	30	141	40	30	241	0.60	1.11	0.40
	Rape	15/09	10/05	39	39	59	99	236	0.70	1.00	0.95
	Rice**	07/04	15/09	-	-	-	-	-	-	-	-
	Vegetables	N.F.*	N.F.*	20	30	30	15	95	0.70	1.05	0.95
4. Hanzhong	Cotton	03/04	24/10	32	53	63	57	205	0.55	1.13	0.60
	Maize	16/06	02/10	17	31	35	26	109	0.58	1.11	0.50
	Soybean	09/06	10/10	22	22	58	22	124	0.71	1.08	0.42
	Wheat	26/10	15/05	25	118	34	25	202	0.60	1.11	0.40
	Rape	05/09	15/05	39	39	59	99	236	0.70	1.00	0.95
	Rice**	07/04	15/09	-	-	-	-	-	-	-	-
	Vegetables	N.F.*	N.F.*	20	30	30	15	95	0.70	1.05	0.95
	Peanut	07/05	13/09	25	35	45	25	130	0.40	1.15	0.60
5. Shangluo	Cotton	03/04	24/10	32	53	63	57	205	0.55	1.13	0.60
	Maize	08/06	09/10	20	35	39	30	124	0.58	1.11	0.50
	Soybean	09/06	10/10	22	22	58	22	124	0.71	1.08	0.42
	Wheat	19/10	03/06	28	133	38	29	228	0.60	1.11	0.40
	Rape	17/09	10/05	39	39	59	99	236	0.70	1.00	0.95
	Rice**	07/04	15/09	-	-	-	-	-	-	-	-
	Vegetables	N.F.*	N.F.*	20	30	30	15	95	0.70	1.05	0.95
	Peanut	07/05	13/09	25	35	45	25	130	0.40	1.15	0.60
6. Tongchuan	Maize	01/05	08/09	21	37	42	31	131	0.55	1.13	0.35
	Soybean	09/06	10/10	22	22	58	22	124	0.57	1.10	0.44
	Wheat	13/10	04/06	29	138	39	29	235	0.60	1.10	0.40

	Rape	15/09	10/05	39	39	59	99	236	0.70	1.00	0.95
	Vegetables	N.F.*	N.F.*	20	30	30	15	95	0.70	1.05	0.95
	Rice	07/04	15/09	-	-	-	-	-	-	-	-
7. Weinan	Cotton	03/03	24/10	32	53	63	57	205	0.57	1.15	0.63
	Maize	08/06	20/09	17	29	34	25	105	0.50	1.14	0.53
	Soybean	09/06	10/10	22	22	58	22	124	0.57	1.10	0.44
	Wheat	02/10	27/05	30	138	40	30	238	0.60	1.11	0.40
	Rape	15/09	10/05	39	39	59	99	236	0.70	1.00	0.95
	Vegetables	N.F.*	N.F.*	20	30	30	15	95	0.70	1.05	0.95
	Peanut	07/05	13/09	25	35	45	25	130	0.40	1.15	0.60
8. Xianyang	Cotton	03/04	24/10	32	53	63	57	205	0.57	1.15	0.63
	Maize	12/06	02/10	18	32	36	27	113	0.50	1.14	0.53
	Soybean	09/06	10/10	22	22	58	22	124	0.57	1.10	0.44
	Wheat	19/09	24/06	35	163	46	35	279	0.60	1.12	0.40
	Rape	08/09	28/05	39	39	59	99	236	0.70	1.00	0.95
	Rice**	07/04	15/09	-	-	-	-	-	-	-	-
	Vegetables	N.F.*	N.F.*	20	30	30	15	95	0.70	1.05	0.95
9. Yan'an	Cotton	03/04	24/10	32	53	63	57	205	0.57	1.15	0.63
	Maize	03/05	22/09	23	40	46	34	143	0.33	1.18	0.35
	Soybean	03/05	02/10	27	27	72	27	153	0.38	1.14	0.49
	Wheat	24/09	15/06	33	155	44	33	265	0.60	1.11	0.40
	Rape	05/09	15/05	39	39	59	99	236	0.70	1.00	0.95
	Rice**	07/04	15/09	-	-	-	-	-	-	-	-
	Vegetables	N.F.*	N.F.*	20	30	30	15	95	0.70	1.05	0.95
	Peanut	07/05	13/09	25	35	45	25	130	0.40	1.15	0.60
10. Yulin	Potato	01/05	08/09	25	30	46	30	131	0.31	1.14	0.74
	Maize	01/05	08/09	21	37	42	31	131	0.33	1.18	0.35
	Soybean	07/05	20/10	29	29	79	30	167	0.38	1.14	0.49
	Wheat	24/09	15/06	33	155	44	33	265	0.60	1.11	0.40
	Peanut	07/05	20/10	32	45	58	32	167	0.28	1.13	0.59
	Vegetables	N.F.*	N.F.*	20	30	30	15	95	0.70	1.05	0.95

*N.F. = not fixed

**CROPWAT standardized crop parameters for Rice

APPENDIX IV: NATIONAL AVERAGE FERTILIZER APPLICATION

	Crop	Rate N*
		kg/ha
I.	Cotton	120
II.	Maize	130
III.	Soybean	60
IV.	Wheat	70
V.	Rape	125
VI.	Rice	145
VII.	Vegetables	150
VIII.	Peanut	65
IX.	Potato	125

*Retrieved from Fertistat database (FAO, 2007)

APPENDIX V: WATER FOOTPRINT IN SHAANXI PROVINCE IN 2008 PER DISTRICT

1. Xi'an				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Cotton	15887,33	15,87	5,08	36,84
Maize summer	499,38	313,43	248,45	1061,26
Soybean	20,92	13,08	4,56	38,56
Wheat winter	337,30	701,65	149,06	1188,01
Rape	4,52	5,48	5,80	15,80
Rice	3,72	6,88	1,78	12,38
Vegetables	38,24	46,27	49,30	133,80
Total	919,97	1102,66	464,03	2486,65
2. Ankang				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Cotton	0.14	0.02	0.03	0.20
Maize summer	279.43	1.63	105.66	386.71
Soybean	52.49	0.44	7.59	60.53
Wheat winter	68.53	112.91	36.04	217.48
Rape	78.25	100.42	52.68	231.35
Rice	157.83	76.67	42.24	276.74
Vegetables	47.38	22.16	44.10	113.64
Peanut	23.45	1.12	3.49	28.06
Total	707.50	315.38	291.83	1314.71
3 Baoji				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Cotton	0.36	0.27	0.11	0.74
Maize summer	732.08	222.51	175.20	1129.79
Soybean	30.58	11.96	5.91	48.45
Wheat winter	263.34	650.36	138.29	1051.99
Rape	17.62	29.60	13.57	60.79
Rice	3.16	4.72	1.38	9.26
Vegetables	28.21	32.19	37.70	98.10
Total	1075.35	951.61	372.17	2399.13
4 Hanzhong				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Cotton	0.14	0.03	0.03	0.20
Maize summer	216.92	3.70	90.73	311.35
Soybean	59.08	3.90	9.82	72.80
Wheat winter	75.91	58.60	32.32	166.83
Rape	156.76	101.37	88.30	346.44

Rice	404.77	195.58	118.81	719.16
Vegetables	41.26	14.65	40.07	95.97
Peanut	13.20	2.62	2.26	18.08
Total	968.03	380.45	382.35	1730.83
5 Shangluo				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Cotton	0.06	0.04	0.02	0.11
Maize summer	205.96	63.83	91.29	361.08
Soybean	67.11	26.28	13.59	106.99
Wheat winter	150.74	268.81	56.34	475.89
Rape	6.72	8.83	3.96	19.51
Rice	3.06	3.85	1.20	8.11
Vegetables	11.78	10.32	12.92	35.02
Peanut	11.17	6.14	2.48	19.79
Total	456.60	388.11	181.80	1026.51
6 Tongchuan				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Maize summer	47.54	56.25	25.91	129.69
Soybean	13.35	8.45	2.98	24.78
Wheat winter	37.87	119.59	22.15	179.60
Rape	14.15	27.77	11.43	53.34
Rice	0.09	0.18	0.04	0.32
Vegetables	2.66	3.95	3.83	10.44
Total	115.65	216.18	66.34	398.17
7 Weinan				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Cotton	289.62	289.31	92.48	671.42
Maize summer	406.08	304.16	255.77	966.01
Soybean	43.22	21.72	9.06	73.99
Winter Wheat	354.09	1158.29	210.05	1722.43
Rape	23.44	55.62	20.33	99.39
Vegetables	21.87	31.28	30.23	83.38
Peanut	31.11	26.41	7.63	65.15
Total	1169.42	1886.80	625.54	3681.76
8 Xianyang				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Cotton	3.59	2.78	1.25	7.63
Maize summer	434.31	128.91	224.94	788.16
Soybean	167.20	55.12	36.47	258.79
Wheat winter	391.76	722.28	155.90	1269.95
Rape	34.93	58.65	26.05	119.63
Rice	0.71	0.98	0.34	2.04

Vegetables	40.35	42.13	59.90	142.39
Total	1072.86	1010.85	504.86	2588.58
9 Yan’an				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Cotton	1.98	2.51	0.70	5.18
Maize summer	158.39	166.58	80.06	405.03
Soybean	99.15	103.91	20.83	223.89
Winter Wheat	11.34	36.14	5.66	53.14
Rape	4.01	10.91	3.65	18.56
Rice	3.80	7.35	1.79	12.95
Vegetables	7.90	15.00	13.14	36.04
Peanut	4.34	4.71	1.17	10.22
Total	290.90	347.11	127.00	765.01
10 Yulin				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Patato	306.05	508.14	168.75	982.94
Maize summer	227.26	429.50	141.42	798.18
Soybean	203.50	241.95	38.44	483.89
Winter Wheat	4.11	20.32	2.55	26.98
Peanut	17.40	16.13	3.57	37.09
Vegetables	8.04	20.81	14.45	43.31
Total	766.36	1236.84	369.19	2372.39

APPENDIX VI: WATER FOOTPRINT IN SHAANXI PROVINCE IN 2008 BY CROP

Cotton				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Xi'an	15.89	15.87	5.08	36.84
Ankang	0.14	0.02	0.03	0.20
Baoji	0.36	0.27	0.11	0.74
Hanzhong	0.14	0.03	0.03	0.20
Shangluo	0.06	0.04	0.02	0.11
Tongchuan	-	-	-	-
Weinan	289.62	289.31	92.48	671.42
Xianyang	3.59	2.78	1.25	7.63
Yan'an	1.98	2.51	0.70	5.18
Yulin	-	-	-	-
Total	311.77	310.84	99.70	722.31
Average	38.97	38.85	12.46	90.29
Maize				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Xi'an	499.38	313.43	248.45	1061.26
Ankang	279.43	1.63	105.66	386.71
Baoji	732.08	222.51	175.20	1129.79
Hanzhong	216.92	3.70	90.73	311.35
Shangluo	205.96	63.83	91.29	361.08
Tongchuan	47.54	56.25	25.91	129.69
Weinan	406.08	304.16	255.77	966.01
Xianyang	434.31	128.91	224.94	788.16
Yan'an	158.39	166.58	80.06	405.03
Yulin	227.26	429.50	141.42	798.18
Total	3207.34	1690.49	1439.43	6337.25
Average	320.73	169.05	143.94	633.73
Soybean				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Xi'an	20.92	13.08	4.56	38.56
Ankang	52.49	0.44	7.59	60.53
Baoji	30.58	11.96	5.91	48.45
Hanzhong	59.08	3.90	9.82	72.80
Shangluo	67.11	26.28	13.59	106.99
Tongchuan	13.35	8.45	2.98	24.78
Weinan	43.22	21.72	9.06	73.99
Xianyang	167.20	55.12	36.47	258.79

Yan'an	99.15	103.91	20.83	223.89
Yulin	203.50	241.95	38.44	483.89
Total	756.60	486.81	149.26	1392.67
Average	75.66	48.68	14.93	139.27
Wheat				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Xi'an	337.30	701.65	149.06	1188.01
Ankang	68.53	112.91	36.04	217.48
Baoji	263.34	650.36	138.29	1051.99
Hanzhong	75.91	58.60	32.32	166.83
Shangluo	150.74	268.81	56.34	475.89
Tongchuan	37.87	119.59	22.15	179.60
Weinan	354.09	1158.29	210.05	1722.43
Xianyang	391.76	722.28	155.90	1269.95
Yan'an	11.34	36.14	5.66	53.14
Yulin	4.11	20.32	2.55	26.98
Total	1695.00	3848.95	808.37	6352.32
Average	169.50	384.89	80.84	635.23
Rape				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Xi'an	4.52	5.48	5.80	15.80
Ankang	78.25	100.42	52.68	231.35
Baoji	17.62	29.60	13.57	60.79
Hanzhong	156.76	101.37	88.30	346.44
Shangluo	6.72	8.83	3.96	19.51
Tongchuan	14.15	27.77	11.43	53.34
Weinan	23.44	55.62	20.33	99.39
Xianyang	34.93	58.65	26.05	119.63
Yan'an	4.01	10.91	3.65	18.56
Yulin	-	-	-	-
Total	340.39	398.66	225.77	964.82
Average	37.82	44.30	25.09	107.20
Rice				
Crop	WF green	WF blue	WF grey	WF total
	Mm^3/yr			
Xi'an	3.72	6.88	1.78	12.38
Ankang	157.83	76.67	42.24	276.74
Baoji	3.16	4.72	1.38	9.26
Hanzhong	404.77	195.58	118.81	719.16
Shangluo	3.06	3.85	1.20	8.11
Tongchuan	0.09	0.18	0.04	0.32
Weinan	-	-	-	-
Xianyang	0.71	0.98	0.34	2.04

Yan'an	3.80	7.35	1.79	12.95
Yulin	-	-	-	-
Total	577.14	296.22	167.58	1040.95
Average	72.14	37.03	20.95	130.12
Vegetables				
Crop	WF green	WF blue	WF grey	WF total
	Mm³/yr			
Xi'an	38.24	46.27	49.30	133.80
Ankang	47.38	22.16	44.10	113.64
Baoji	28.21	32.19	37.70	98.10
Hanzhong	41.26	14.65	40.07	95.97
Shangluo	11.78	10.32	12.92	35.02
Tongchuan	2.66	3.95	3.83	10.44
Weinan	21.87	31.28	30.23	83.38
Xianyang	40.35	42.13	59.90	142.39
Yan'an	7.90	15.00	13.14	36.04
Yulin	8.04	20.81	14.45	43.31
Total	247.68	238.76	305.64	792.09
Average	24.77	23.88	30.56	79.21
Peanut				
Crop	WF green	WF blue	WF grey	WF total
	Mm³/yr			
Xi'an	-	-	-	-
Ankang	23.45	1.12	3.49	28.06
Baoji	0.00	0.00	0.00	0.00
Hanzhong	13.20	2.62	2.26	18.08
Shangluo	11.17	6.14	2.48	19.79
Tongchuan	-	-	-	-
Weinan	31.11	26.41	7.63	65.15
Xianyang	-	-	-	-
Yan'an	4.34	4.71	1.17	10.22
Yulin	17.40	16.13	3.57	37.09
Total	100.67	57.13	20.60	178.39
Average	16.78	9.52	3.43	29.73
Potato				
Crop	WF green	WF blue	WF grey	WF total
	Mm³/yr			
Yulin	306.05	508.14	168.75	982.94
Total	306.05	508.14	168.75	982.94
Average	306.05	508.14	168.75	982.94

APPENDIX VII: WATER FOOTPRINT PER UNIT MASS OF CROP IN SHAANXI PROVINCE IN 2008 PER DISTRICT

1. Xi'an											
Crop	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Cotton	376	375	751	3755	3752	7507	1.459	2574	2572	822	5968
Maize	261	164	425	2613	1640	4253	5.391	485	304	241	1030
Soybean	275	172	447	2750	1719	4469	1.630	1687	1055	368	3110
Wheat	158	330	488	1584	3295	4879	4.960	319	664	141	1125
Rape	97	118	216	974	1182	2156	2.057	474	575	608	1656
Rice	303	560	863	3025	5603	8628	6.999	432	801	207	1440
Vegetables	116	141	257	1164	1408	2571	37.074	31	38	40	110
2. Ankang											
Crop	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Cotton	569	91	661	5693	912	6605	0.920	6188	991	1304	8484
Maize	344	2	346	3438	20	3458	2.916	1179	7	446	1632
Soybean	415	4	418	4149	35	4184	1.478	2807	24	406	3237
Wheat	133	219	352	1331	2193	3524	2.554	521	859	274	1654
Rape	186	238	424	1857	2383	4240	1.741	1067	1369	718	3153
Rice	542	263	805	5418	2632	8050	6.622	818	397	219	1435
Vegetables	161	75	237	1611	754	2365	15.852	102	48	95	244
Peanut	437	21	457	4365	209	4574	2.197	1987	95	296	2378
3. Boaji											
Crop	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Cotton	389	299	688	3893	2988	6881	1.185	3285	2522	1013	6819
Maize	543	165	708	5432	1651	7083	4.797	1132	344	271	1748
Soybean	310	121	432	3102	1213	4315	1.400	2216	866	429	3511
Wheat	133	329	463	1333	3292	4625	4.502	296	731	155	1183
Rape	162	273	435	1623	2727	4350	1.908	851	1429	655	2935
Rice	333	497	830	3331	4968	8299	6.947	479	715	209	1403
Vegetables	112	128	240	1122	1281	2403	20.490	55	62	73	190
4. Hanzhong											
Crop	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Cotton	506	98	604	5060	977	6037	1.074	4711	910	1117	6738
Maize	311	5	316	3108	53	3161	3.145	988	17	413	1418

Soybean	361	24	385	3609	238	3847	1.069	3376	223	561	4160
Wheat	164	127	291	1644	1269	2913	2.759	596	460	254	1310
Rape	222	144	365	2219	1435	3654	1.977	1122	726	632	2481
Rice	494	239	733	4940	2387	7327	6.040	818	395	240	1453
Vegetables	154	55	209	1545	549	2093	28.527	54	19	53	126
Peanut	379	75	454	3788	752	4540	2.387	1587	315	272	2174
5. Shangluo											
Crop	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Cotton	410	272	682	4102	2716	6818	1.429	2871	1901	840	5611
Maize	293	91	384	2933	909	3842	3.835	765	237	339	1341
Soybean	296	116	412	2962	1160	4122	1.708	1734	679	351	2765
Wheat	187	334	521	1873	3340	5213	2.280	821	1465	307	2593
Rape	212	279	491	2122	2788	4910	1.134	1871	2459	1102	5432
Rice	371	467	838	3707	4670	8377	6.545	566	714	222	1501
Vegetables	137	120	257	1368	1198	2566	19.920	69	60	75	204
Peanut	292	161	453	2921	1607	4528	2.620	1115	613	248	1976
6. Tongchuan											
Crop	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Maize	239	282	521	2385	2822	5207	6.096	391	463	213	1067
Soybean	269	170	439	2688	1702	4390	1.490	1804	1142	403	3349
Wheat	120	378	498	1197	3780	4977	2.927	409	1291	239	1940
Rape	155	304	458	1547	3037	4584	1.134	1364	2678	1102	5145
Rice	306	584	890	3057	5844	8901	6.545	467	893	222	1582
Vegetables	104	155	259	1042	1546	2588	21.155	49	73	71	193
7. Weinan											
Crop	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Cotton	376	375	751	3758	3754	7512	1.190	3158	3155	1008	7321
Maize	206	155	361	2064	1546	3610	5.096	405	303	255	964
Soybean	286	144	430	2863	1439	4302	1.325	2161	1086	453	3700
Wheat	118	386	504	1180	3860	5040	4.009	294	963	175	1432
Rape	144	342	486	1441	3419	4860	1.798	801	1902	695	3398
Vegetables	109	155	264	1085	1553	2638	26.205	41	59	57	158
Peanut	265	225	490	2652	2251	4903	2.940	902	766	221	1889
8. Xianyang											
Crop	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			

Cotton	344	266	610	3442	2659	6101	0.653	5271	4072	1838	11181
Maize	251	75	326	2510	745	3255	5.358	468	139	243	850
Soybean	275	91	366	2751	907	3658	1.828	1505	496	328	2329
Wheat	176	324	500	1759	3243	5002	4.507	390	720	155	1265
Rape	168	281	449	1676	2814	4490	2.014	832	1397	621	2850
Rice	303	417	720	3032	4170	7202	4.670	649	893	310	1853
Vegetables	101	106	207	1011	1055	2066	39.459	26	27	38	90
9. Yan'an											
Crop	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Cotton	339	431	770	3393	4311	7704	0.706	4806	6106	1700	12612
Maize	257	271	528	2572	2705	5277	6.203	415	436	210	1060
Soybean	286	299	585	2856	2993	5849	1.325	2155	2259	453	4867
Wheat	140	447	587	1401	4467	5868	3.065	457	1457	228	2143
Rape	137	374	512	1374	3741	5115	1.710	804	2188	731	3722
Rice	307	594	901	3070	5941	9011	8.323	369	714	174	1257
Vegetables	90	171	261	902	1713	2614	38.398	23	45	39	107
Peanut	242	262	504	2420	2623	5043	1.625	1489	1614	400	3503
10. Yulin											
Crop	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Patato	227	376	603	2267	3764	6031	15.000	151	251	83	485
Maize	209	395	604	2089	3948	6037	5.917	353	667	220	1240
Soybean	318	378	695	3176	3776	6952	1.286	2470	2936	467	5872
Wheat	113	558	670	1128	5575	6703	0.631	1788	8835	1109	11732
Peanut	317	294	611	3171	2939	6110	2.183	1453	1346	298	3097
Vegetables	83	216	299	835	2160	2994	23.242	36	93	65	193

APPENDIX VIII: WATER FOOTPRINT UNIT MASS OF CROP IN SHAANXI PROVINCE IN 2008 BY CROP

Cotton											
District	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Xi'an	376	375	751	3755	3752	7507	1.459	2574	2572	822	5968
Ankang	569	91	661	5693	912	6605	0.920	6188	991	1304	8484
Baoji	389	299	688	3893	2988	6881	1.185	3285	2522	1013	6819
Hanzhong	506	98	604	5060	977	6037	1.074	4711	910	1117	6738
Shangluo	410	272	682	4102	2716	6818	1.429	2871	1901	840	5611
Tongchuan	-	-	-	-	-	-	-	-	-	-	-
Weinan	376	375	751	3758	3754	7512	1.190	3158	3155	1008	7321
Xianyang	344	266	610	3442	2659	6101	0.653	5271	4072	1838	11181
Yan'an	339	431	770	3393	4311	7704	0.706	4806	6106	1700	12612
Yulin	-	-	-	-	-	-	-	-	-	-	-
Total	3310	2207	5517	33096	22069	55165	8.616	32864	22228	9642	64734
Average	414	276	690	4137	2759	6896	1.077	4108	2778	1205	8092
Maize											
District	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Xi'an	261	164	425	2613	1640	4253	5.391	485	304	241	1030
Ankang	344	2	346	3438	20	3458	2.916	1179	7	446	1632
Baoji	543	165	708	5432	1651	7083	4.797	1132	344	271	1748
Hanzhong	311	5	316	3108	53	3161	3.145	988	17	413	1418
Shangluo	293	91	384	2933	909	3842	3.835	765	237	339	1341
Tongchuan	239	282	521	2385	2822	5207	6.096	391	463	213	1067
Weinan	206	155	361	2064	1546	3610	5.096	405	303	255	964
Xianyang	251	75	326	2510	745	3255	5.358	468	139	243	850
Yan'an	257	271	528	2572	2705	5277	6.203	415	436	210	1060
Yulin	209	395	604	2089	3948	6037	5.917	353	667	220	1240
Total	2914	1604	4518	29144	16039	45183	48.754	6582	2918	2851	12350
Average	291	160	452	2914	1604	4518	4.875	658	292	285	1235
Soybean											
District	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Xi'an	275	172	447	2750	1719	4469	1.630	1687	1055	368	3110
Ankang	415	4	418	4149	35	4184	1.478	2807	24	406	3237
Baoji	310	121	432	3102	1213	4315	1.400	2216	866	429	3511
Hanzhong	361	24	385	3609	238	3847	1.069	3376	223	561	4160

Shangluo	296	116	412	2962	1160	4122	1.708	1734	679	351	2765
Tongchuan	269	170	439	2688	1702	4390	1.490	1804	1142	403	3349
Weinan	286	144	430	2863	1439	4302	1.325	2161	1086	453	3700
Xianyang	275	91	366	2751	907	3658	1.828	1505	496	328	2329
Yan'an	286	299	585	2856	2993	5849	1.325	2155	2259	453	4867
Yulin	318	378	695	3176	3776	6952	1.286	2470	2936	467	5872
Total	3091	1518	4609	30906	15182	46088	14.539	21915	10766	4218	36900
Average	309	152	461	3091	1518	4609	1.454	2192	1077	422	3690
Wheat											
District	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Xi’an	158	330	488	1584	3295	4879	4.960	319	664	141	1125
Ankang	133	219	352	1331	2193	3524	2.554	521	859	274	1654
Baoji	133	329	463	1333	3292	4625	4.502	296	731	155	1183
Hanzhong	164	127	291	1644	1269	2913	2.759	596	460	254	1310
Shangluo	187	334	521	1873	3340	5213	2.280	821	1465	307	2593
Tongchuan	120	378	498	1197	3780	4977	2.927	409	1291	239	1940
Weinan	118	386	504	1180	3860	5040	4.009	294	963	175	1432
Xianyang	176	324	500	1759	3243	5002	4.507	390	720	155	1265
Yan'an	140	447	587	1401	4467	5868	3.065	457	1457	228	2143
Yulin	113	558	670	1128	5575	6703	0.631	1788	8835	1109	11732
Total	1443	3431	4874	14430	34314	48744	32.194	5892	17445	3038	26376
Average	144	343	487	1443	3431	4874	3.219	589	1745	304	2638
Rape											
District	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF Total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Xi’an	97	118	216	974	1182	2156	2.057	474	575	608	1656
Ankang	186	238	424	1857	2383	4240	1.741	1067	1369	718	3153
Baoji	162	273	435	1623	2727	4350	1.908	851	1429	655	2935
Hanzhong	222	144	365	2219	1435	3654	1.977	1122	726	632	2481
Shangluo	212	279	491	2122	2788	4910	1.134	1871	2459	1102	5432
Tongchuan	155	304	458	1547	3037	4584	1.134	1364	2678	1102	5145
Weinan	144	342	486	1441	3419	4860	1.798	801	1902	695	3398
Xianyang	168	281	449	1676	2814	4490	2.014	832	1397	621	2850
Yan'an	137	374	512	1374	3741	5115	1.710	804	2188	731	3722
Yulin	-	-	-	-	-	-	-	-	-	-	-
Total	1483	2353	3836	14833	23526	38359	15.473	9186	14722	6865	30772
Average	165	261	426	1648	2614	4262	1.719	1021	1636	763	3419
Rice											
District	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF Total

	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Xi'an	303	560	863	3025	5603	8628	6.999	432	801	207	1440
Ankang	542	263	805	5418	2632	8050	6.622	818	397	219	1435
Baoji	333	497	830	3331	4968	8299	6.947	479	715	209	1403
Hanzhong	494	239	733	4940	2387	7327	6.040	818	395	240	1453
Shangluo	371	467	838	3707	4670	8377	6.545	566	714	222	1501
Tongchuan	306	584	890	3057	5844	8901	6.545	467	893	222	1582
Weinan	-	-	-	-	-	-	-	-	-	-	-
Xianyang	303	417	720	3032	4170	7202	4.670	649	893	310	1853
Yan'an	307	594	901	3070	5941	9011	8.323	369	714	174	1257
Yulin	-	-	-	-	-	-	-	-	-	-	-
Total	2958	3622	6580	29580	36215	65795	52.691	4599	5521	1803	11924
Average	370	453	822	3698	4527	8224	6.586	575	690	225	1490
Vegetables											
District	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF Total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Xi'an	116	141	257	1164	1408	2571	37.074	31	38	40	110
Ankang	161	75	237	1611	754	2365	15.852	102	48	95	244
Baoji	112	128	240	1122	1281	2403	20.490	55	62	73	190
Hanzhong	154	55	209	1545	549	2093	28.527	54	19	53	126
Shangluo	137	120	257	1368	1198	2566	19.920	69	60	75	204
Tongchuan	104	155	259	1042	1546	2588	21.155	49	73	71	193
Weinan	109	155	264	1085	1553	2638	26.205	41	59	57	158
Xianyang	101	106	207	1011	1055	2066	39.459	26	27	38	90
Yan'an	90	171	261	902	1713	2614	38.398	23	45	39	107
Yulin	83	216	299	835	2160	2994	23.242	36	93	65	193
Total	1168	1321	2490	11683	13215	24898	270.32	486	524	606	1616
Average	117	132	249	1168	1321	2490	27.032	49	52	61	162
Peanut											
District	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF Total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Xi'an	-	-	-	-	-	-	-	-	-	-	-
Ankang	437	21	457	4365	209	4574	2.197	1987	95	296	2378
Baoji	-	-	-	-	-	-	-	-	-	-	-
Hanzhong	379	75	454	3788	752	4540	2.387	1587	315	272	2174
Shangluo	292	161	453	2921	1607	4528	2.620	1115	613	248	1976
Tongchuan	-	-	-	-	-	-	-	-	-	-	-
Weinan	265	225	490	2652	2251	4903	2.940	902	766	221	1889
Xianyang	-	-	-	-	-	-	-	-	-	-	-
Yan'an	242	262	504	2420	2623	5043	1.625	1489	1614	400	3503
Yulin	317	294	611	3171	2939	6110	2.183	1453	1346	298	3097
Total	1932	1038	2970	19317	10381	2969	13.952	8532	4750	1735	15017

						8					
Average	322	173	495	3220	1730	4950	2.325	1422	792	289	2503
Potato											
District	ET green	ET blue	ET_a	CWU green	CWU blue	CWU total	Yield (2008)	WF green	WF blue	WF grey	WF Total
	mm / growing period			m^3/ha			ton/ha	m^3/ton			
Yulin	227	376	603	2267	3764	6031	15.000	151	251	83	485
Total	227	376	603	2267	3764	6031	15.000	151	251	83	485
Average	227	376	603	2267	3764	6031	15.000	151	251	83	485

APPENDIX IX: WATER AVAILABILITY, BWS & WPL IN SHAANXI PROVINCE IN 2008 PER DISTRICT

	District	Water availability	Blue water scarcity	Grey water pollution level
		m3		
1.	Xi’an	687,000,000	1.61	0.68
2.	Ankang	5,980,000,000	0.05	0.05
3.	Baoji	1,380,000,000	0.69	0.27
4.	Hanzhong	8,420,000,000	0.05	0.05
5.	Shangluo	1,338,000,000	0.29	0.14
6.	Tongchuan	45,000,000	4.80	1.47
7.	Weinan	1,021,000,000	1.85	0.61
8.	Xianyang	683,000,000	1.48	0.74
9.	Yan'an	247,000,000	1.41	0.51
10.	Yulin	1,014,000,000	1.22	0.36

APPENDIX X: IRRIGATION EFFICIENCIES IN SHAANXI PROVINCE IN 2008 PER DISTRICT

	District	Irrigation efficiency
1.	Xi'an	0.54
2.	Ankang	0.52
3.	Baoji	0.52
4.	Hanzhong	0.53
5.	Shangluo	0.50
6.	Tongchuan	0.44
7.	Weinan	0.50
8.	Xianyang	0.50
9.	Yan'an	0.47
10.	Yulin	0.51