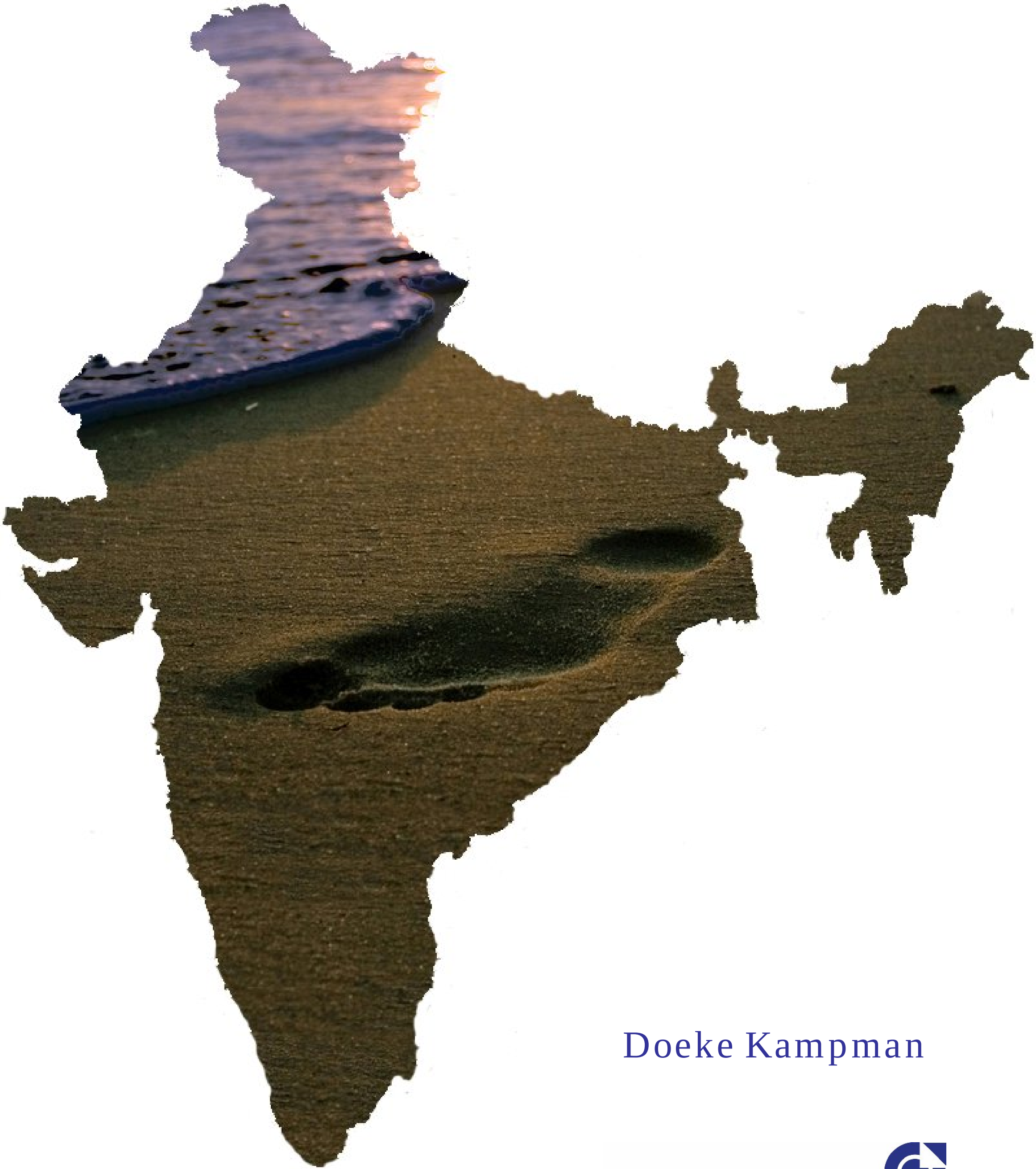
The water footprint of India



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The water footprint of India

A study on water use in relation to the consumption of agricultural goods in the Indian states

Master thesis

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“As I travel around the world, people think the only place where there is potential conflict over water is the Middle East, but they are completely wrong. We have the problem all over the world. “
(Koffi Annan)

“When the well is dry, we learn the value of water”
(Benjamin Franklin)

Preface

The completion of this study means the completion of the Master course Civil Engineering & Management at the University of Twente.

I started with the execution of this study in May 2006. After a good start, I got stuck on the many decisional crossroads this subject has to offer and I slowly realised that this study might not shake up the world as much as I had hoped. However, after making some rough decisions, I began to see the light and things started to fall into place. In the last period of this study, I have tried hard to write a comprehensible report on the subject, including a relevant link to the Indian society. And although there is still room for improvements, I am very satisfied with the current result.

I would like to thank a number of people without whom this result would not have been possible.

First of all, I would like to thank the members of my graduation committee. I would like to thank Arjen Hoekstra for his advice, criticism and ideas, for helping me with the overall direction of the study and for offering me a look in the interesting kitchen of multidisciplinary water management. I would like to thank Maarten Krol for his profound analysis of my concept reports, which undoubtedly increased the scientific value of the study. I would like to thank both Arjen Hoekstra and Maarten Krol for the pleasant collaboration during the execution of this study.

I also would like to thank Ashok Chapagain for his sharing his knowledge on the subject.

Next, I would like to thank my colleagues at the graduation chamber for their pleasant company, for the discussions in the coffee corner and for sharing the good times and *"de uren van nood en ontbering"* with me.

I also would like to thank my parents for creating a steady base in this life for me, for their advice and for their ever present support.

Finally, I would like to thank Rianne for her love, faith and encouragement. Although from a long distance during the weeks, her support has been immensely important to me.

Doeke Kampman

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Acknowledgement

This study has been executed at the University of Twente under the department of Water Engineering & Management between May 2006 and April 2007. I would like to thank the department of Water Engineering & Management for offering me the necessary facilities during this period.

Summary

The concept of the water footprint has been developed to create an indicator of water use in relation to the consumption by people. The water footprint of a country is defined as the volume of water needed for the production of the goods and services consumed by the inhabitants of the country. The water footprint is divided into a blue, a green and a gray component. The blue component refers to the evaporation of groundwater and surface water during the production of a commodity, the green component to the evaporation of rain water for crop growth, and the gray component to the water required to dilute the water pollution that is caused by the production of the commodity to acceptable levels.

In the next fifty years, India is projected to face the challenge of feeding a population of 1.6 billion people with a higher level of welfare than at present. The current view of the Indian government on food security is to hold on to the goal of food self sufficiency. Knowing that agriculture is the main consumer of water, the implied increase in food demand will increase the pressure on the renewable water resources.

In order to reduce the pressure on renewable water resources, the Indian government is considering the concept of river interlinking as the solution for water scarcity in the drier regions. This concept means that water abundant regions will provide water to water scarce regions through the connection of rivers. Whether the interlinking of rivers will provide enough water to solve the observed and future water deficit and what the side effects of the project will be is still unclear.

This study indicates why the water scarce regions have a water deficit. In the period 1997-2001, the water footprint of the inhabitants of the Indian states varied between 451 and 1357 m^3/cap/yr with an average of 777 m^3/cap/yr. Of this average, 658 m^3/cap/yr originated from local water resources and 119 m^3/cap/yr from water resources of other states or other nations. Furthermore, the blue component of the average water footprint came to 227 m^3/cap/yr, the green component to 459 m^3/cap/yr and the gray component to 92 m^3/cap/yr.

During the study period, the total virtual water flow as a result of interstate trade in agricultural commodities in India was 106 billion m^3/yr, which was 13% of the total water use in Indian agriculture. In the same period, the net international export from India was 15 billion m^3/yr. Of the total virtual water flow within India, 35% was due to the interstate trade in milled rice, 17% due the interstate trade in raw sugar and 14% due to the interstate trade in edible oils. The largest interregional net virtual water flow was 22 billion m^3/yr and flowed from North India to East India. As a result of international and interstate virtual water flows, the states Haryana, Madhya Pradesh, Punjab and Uttar Pradesh had the largest net export of virtual water and Bihar, Jharkhand and Kerala had the largest net import of virtual water.

The water scarcity from the perspective of consumption is the highest in the states of Rajasthan, Punjab, Uttar Pradesh, Tamil Nadu and Haryana. This means that the water resources of these states are closest to be exhausted in case of food self sufficiency. Because most of the states are also net exporters of virtual water, the water scarcity from production perspective is even higher in these states.

The total net global water saving as a result of the interstate trade in agricultural commodities in India was 41 billion m^3/yr. This means the total water use in Indian agriculture was 5%

lower than it would have been without interstate trade. The interstate trade in wheat alone already caused a global water saving of 23 billion m^3/yr.

Looking at the river interlinking project from the perspective of the virtual water flows as calculated in this study, it can be seen that the proposed water transfer from East to North India has a direction exactly opposite to the direction of the virtual water flow as a result of interstate trade. In this study, it is demonstrated that an increase in water productivity in the water abundant states has a better chance of reducing the national water scarcity than the proposed water transfer. The river interlinking project mainly reduces local water scarcity, while water scarcity needs to be reduced significantly at a national level in order to remain food self sufficient as a nation. The only long term option for reducing the national water scarcity and remaining food self sufficient is to increase the water productivity in India. The largest opportunity for this increase lies in East India, where there is an abundance of water and a large increase in water productivity seems possible.

Table of Contents

Appendices

1. Introduction

1.1 Background of the study

With over one billion people, India currently has the world's second largest population. The estimate of the amount of people living in India in the year 2050 is 1.6 billion (United Nations, 2004). This is an increase in population of approximately 50% in the next fifty years. Next to this population growth the total Gross Domestic Product (GDP) per capita in India is also growing rapidly (7.1% in 2005 (World Bank, 2006)). Furthermore, there currently is a net export of agricultural products from India, which has shown an increase in the past decade (FAO, 2006a), which is likely to persist. These developments will lead to a large growth in the total food demand in India in the near future.

How can India cope with this scenario? Can the production of food be increased? And if so, should India increase its food production or should India import more products from other countries?

Since most of the utilizable water supply in India is used for crop production (Hoekstra & Chapagain, 2007), an important criterion for the evaluation of a possible food supply strategy is the pressure on renewable water resources. At the moment there are regions in India that are determined as water scarce, as the water availability per is capita is less than 1000 m^3/yr, which is either caused by the lack of natural water resources or a result of over exploitation of groundwater resources for irrigation purposes (CGWB, 1989; Bobba et al., 1997).

The pressure on water resources is also increasing through the increase in water pollution caused by diffuse agricultural sources in the form of animal manure, fertilizers and pesticides. While the application of fertilizers and pesticides is currently low compared to developed countries, the intensification of agriculture is bound to cause an increase of diffuse agricultural pollution. The monitoring of groundwater and surface water have currently only resulted in the reporting of high nitrate concentrations in groundwater, which is in most cases linked directly to diffuse agricultural sources (Agrawal, 1999).

The current point of view of the Indian government on the topic of food security is to hold on to the goal of national food self sufficiency. The begging bowl image of the sixties is something that is still carved in the minds of the Indian people and is to be prevented at all cost (Gupta & Deshpande, 2004; Planning Commission, 2002).

In order to reduce the pressure on the renewable water resources, the Indian government is considering the concept of river interlinking as the solution for water scarcity in the drier regions. This concept means that water abundant regions will provide water to water scarce regions through the connection of rivers (NWDA, 2006). Whether the interlinking of rivers will provide enough water to solve the water deficit and what the side effects of the project will be is still unclear (Radhakrishna, 2003).

Since the interlinking of rivers is such an enormous project, it is useful to see to what extent another strategy can reduce the water scarcity in the drier regions.

1.2 The virtual water concept

This other water scarcity reducing strategy can be quantitatively described with the concept of virtual water. This concept defines the virtual water content of a commodity as the volume of water that is actually used to produce the commodity, measured at the place where the commodity is actually produced (Allen, 1993, 1994). The inverse of the virtual water content is known as the water productivity of a crop.

With the virtual water content, the production and the trade flow of a crop can be translated into the water use and the virtual water flow of crop. So instead of increasing local water resources by importing water, the water use in the water deficit regions can be reduced by an increase in water productivity or a change in the existing trade pattern. The water productivity of a crop can be increased when a significant gap exists between the current and potential water productivity. A change in the existing trade pattern is possible if importing states can increase their crop production and can be become less dependent, self sufficient or even exporters.

1.3 The water footprint concept

In line with the concept of virtual water, the concept of the water footprint has been introduced to create a consumption-based indicator of water use (Hoekstra & Hung, 2004; Hoekstra & Chapagain, 2007). This in contrast to the traditional production-sector-based indicators of water use, that are useful in water management but do not indicate the water that is actually needed by the inhabitants of a country in relation to their consumption pattern. The water footprint is defined as the volume of water needed for the production of the goods and services consumed by the inhabitants of a country. This concept is developed in analogy to the concept of the ecological footprint (Wackernagel & Rees, 1996).

The water footprint can be divided into an internal and an external water footprint. The internal component covers the use of domestic water resources and the external component covers the use of water resources elsewhere.

Furthermore, an agricultural, an industrial and a domestic component of the water footprint can be assessed. Here, the agricultural component corresponds with the water use in the agricultural sector (i.e. in the form of crop evapotranspiration or water pollution), the industrial component corresponds with the water use in the industrial sector and the domestic component with the water use in the domestic sector.

Finally, the water footprint can be divided into a blue, a green and a gray water footprint. The blue component covers the use of groundwater and surface water during the production of a commodity, the green component covers the use of rain water for crop growth, and the gray component covers the water required to dilute the water that is polluted during the production of the commodity. The distinction between green and blue water has been introduced by Falkenmark & Rockström (1993). The gray component has been introduced by Chapagain et al. (2006).

1.4 The water saving concept

With the current water productivity in India and the food demand scenario for the year 2050, it seems inevitable for India to become an importer of virtual water (Falkenmark, 1997; Yang et al., 2003; Falkenmark & Lannerstad, 2005). This is because the average (utilizable) water availability per capita in India will drop below the minimum amount of water needed to feed a person in the near future. This means that water scarcity is not only a local problem in India but also a national problem.

Given that the total water resources are more or less fixed, neglecting possible climatic changes, the only way to reduce the national water scarcity is to reduce the total water use with a constant or growing food production. This means that an increase in water productivity is needed together with water saving on a global scale.

Global water saving is created when a product that is traded has a higher virtual water content in the importing state than in the exporting state (Chapagain & Hoekstra, 2006). This means that the water loss in the exporting state is lower than the water saving in the importing state. If the water loss as a result of trade is larger than the water saving, there is a global loss.

1.5 Objectives

To get more insight on whether the water scarcity in the Indian states is caused by local consumption or by the export of agricultural commodities to other states or countries, the water footprints of the Indian states are assessed in this study.

The first target of this study is to assess the international and interstate virtual water flows from and to the Indian states and create a net virtual water balance for each state. In order to assess these virtual water flows, the import, export and virtual water contents of the crops need to be calculated for each Indian state. Because data on crop trade is not directly available at the state level, the trade of a crop is estimated based on the production and consumption volumes per state and the national balance of a crop.

The second target is to assess the water footprints related to the consumption of agricultural commodities of the Indian states. This is determined by the water use in the states and the virtual water flows from and to the states.

The third target is to assess the water scarcity in the Indian states. To this end, the water resources are estimated by state. Water scarcity is assessed from the production perspective by comparing water availability to the water use in a state, and from the consumption perspective by comparing water availability to the water footprint of a state.

The fourth target is to assess global water saving as a result of interstate trade in agricultural commodities. Global water saving is calculated from the difference between the virtual water content of the crop in the importing and exporting state. Global water saving gives an indication of the relative water use efficiency of interstate trade in agricultural commodities in India.

The fifth and last target of this study is to compare the river interlinking project to the outcome of the previous objectives. This might give an indication to what extent the local and national water scarcity can be reduced more by water transport through the connection of rivers or by a combination of an increase in water productivity and a change in interstate trade patterns.

The period of analysis in this study is 1997-2001, because this is the most recent five-year period for which all necessary data could be obtained. The scope of the study is limited to agricultural commodities, since they are responsible for the major part of global water use (Postel et al., 1996). Livestock products are not taken into account, because they are more difficult to assess and generally contribute a small part to the total trade in virtual water (Chapagain & Hoekstra, 2003).

2. Methodology

2.1 *Overview*

The starting point in this methodology is the calculation of the green, blue and gray virtual water content of a crop by season and by state. This calculation is derived from a method used by Chapagain et al. (2006). The following step is the estimation of the international and interstate trade of a crop by state. This estimation is based on the method used by Ma et al. (2006). With the virtual water contents, the crop production of a state is translated into the water use of a state and the interstate crop trade of a state into the virtual water flow of a state. The total water use and the gross virtual water flows of a state determine the water footprint of a state. Next, the water resources of the Indian states are estimated. Together with the water footprint, the water resources give an indication of the water scarcity in the Indian states. Finally, the global water saving as a result of interstate trade is calculated.

Throughout this chapter, independent variable *c* denotes crop, *s* state, *t* time steps of 10 days, *p* agricultural product, *rb* river basin and *us* upstream state. A summary of all used symbols in this study is presented in Appendix I.

2.2 *Calculation of virtual water content*

2.2.1 Crop water requirement

The calculation of the virtual water content of a crop starts with the calculation of the volume of water that is required for the crop growth.

Crop water requirement (*CWR*, m^3/ha) is defined as the volume of water that is required to compensate the water loss of a crop through evapotranspiration under growth conditions with no constraint by water shortage (Allen et al., 1998).

The *CWR* is calculated by accumulating the data on the crop evapotranspiration under optimal conditions ($ET_{c,opt}$, mm/day) over the complete growing period.

$$CWR[c,s] = 10 * \sum_{t=1}^{lp} ET_{c,opt}[c,s,t] \tag{1}$$

Here, the factor 10 is included to convert mm into m^3/ha and the summation is done in time steps of 10 days over the full growing period *lp*. It is worth noticing that in this calculation each month is taken to be equal to 3 time steps of 10 days, which means that all months are assumed to consist of exactly 30 days.

The $ET_{c,\,opt}$ is calculated as follows:

$$ET_{c,opt}[c,s] = K_c[c] * ET_o[s] \qquad (2)$$

In this equation, K_c is the crop coefficient (-) and ET_0 is the reference evapotranspiration in a state (mm/day). Because neither ET_0 nor K_c is constant over the growing period, $ET_{c,opt}$ is calculated for every time step of 10 days over the full growing period.

The reference evapotranspiration ET_0 is defined as the evapotranspiration rate from a hypothetical grass reference crop with specific characteristics, which has an abundance of water. Because of the abundance of water available for evapotranspiration at the reference surface, soil factors can not form a constraint for the ET_0 rate. This means that ET_0 only expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider a difference in crop characteristics and soil factors. Therefore ET_0 is computed with climatic data.

The crop coefficient K_c determines how $ET_{c,opt}$ from a certain crop field relates to ET_0 from the reference surface. The major factors that determine K_c are crop variety, climate and crop growth stage. During the various growth stages of a crop the value of K_c changes, because the ground cover, the crop height and the leaf area change as the crop develops.

The total growing period is divided into four growth stages: the initial stage, the crop development stage, the mid-season stage and the late season stage (Allen et al, 1998). The initial stage is the period from the planting date to approximately 10% ground cover. The crop development stage is the period from 10% ground cover to effective full cover. The mid-season stage is the time from effective full cover to the time the crop starts to mature. The late season is the final stage and is the time from the start of maturity to harvest. The total K_c curve of a crop is shown in Figure 2.1.

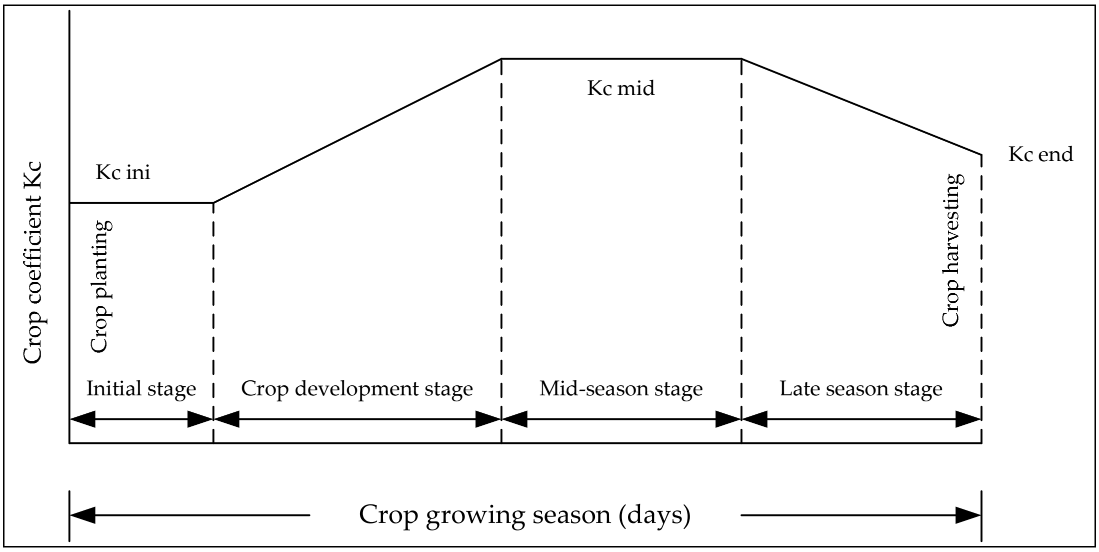

Figure 2.1: Development of Kc during the crop growing season (Chapagain & Hoekstra, 2004).

2.2.2 <u>Green crop water use</u>

The green crop water use (CWU_{green}) is the volume of the total rainfall that is actually used for evapotranspiration by the crop field (m^3/ha) and is calculated by accumulating the data on crop evapotranspiration under rain fed conditions ($ET_{c,rw}$, mm/day) over the complete growing period.

$$CWU_{green}\left[c,s\right]=10*\sum_{t=1}^{lp}ET_{c,rw}\left[c,s,t\right] \tag{3}$$

As in the calculation of the *CWR*, the factor 10 is included to convert mm into m^3/ha and the summation is done over the full growth period *lp* (day) in time steps of 10 days.

The $ET_{c,rw}$ is determined as follows:

$$ET_{c,rw}\left[c,s\right]=Min(ET_{c,opt}\left[c,s\right],P_{eff}\left[s\right]) \tag{4}$$

Here, P_{eff} is the effective rainfall (mm/day), which is defined as the amount of the total precipitation (P_{tot}, mm/day) that can be used for evapotranspiration by the crop and the soil surface.

Equation 4 shows that $ET_{c,rw}$ is equal to P_{eff} if P_{eff} is lower than $ET_{c,opt}$, and that $ET_{c,rw}$ is equal to $ET_{c,opt}$ if P_{eff} is higher than $ET_{c,opt}$. This is because a crop uses as much water as possible for $ET_{c,opt}$, but never uses more water than it requires for optimal growth. The fact that in some time steps a part of the P_{eff} is not used for evapotranspiration, and is thus still available as soil moisture for a following time step, is not taken into account in this study.

The effective rainfall P_{eff} is generated from P_{tot} by CROPWAT (FAO, 2006b). CROPWAT calculates with a simplified version of the USDA method. This is a simplification because the soil type and the net depth of irrigation application are not taken into account in this method (Dastane, 1978). The simplified method consists of equations 5 and 6. The factor 30 is added to these equations, because the original equations assume monthly values instead of daily values. The relation between P_{eff} and P_{tot} that is created by these equations is presented in Figure 2.2.

$$P_{tot}\leq\frac{250}{30}\rightarrow P_{eff}=P_{tot}*\frac{30}{125}*(\frac{125}{30}-0.2*P_{tot}) \tag{5}$$

$$P_{tot}>\frac{250}{30}\rightarrow P_{eff}=\frac{125}{30}+0.1*P_{tot} \tag{6}$$

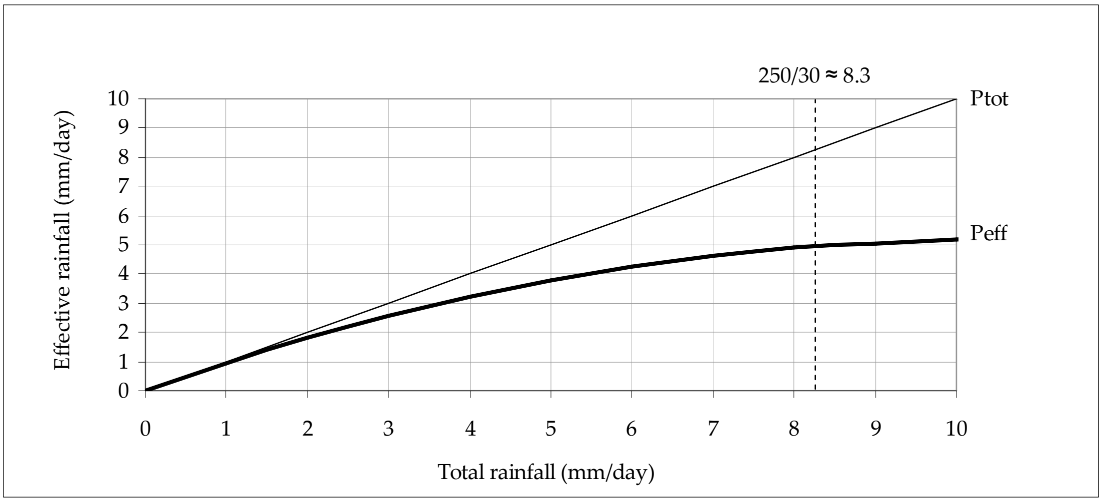

Figure 2.2: The relation between effective rainfall and total rainfall

2.2.3 Blue crop water use

The blue crop water use (CWU_{blue}, m³/ha) is the volume of irrigation water that is actually supplied to the crop field and is calculated by accumulating the data on the actual crop evapotranspiration of irrigation water ($ET_{c,iw}$, mm/day) over the complete growing period.

$$CWU_{blue}[c,s] = 10 * \sum_{t=1}^{lp} ET_{c,iw}[c,s,t] \qquad (7)$$

In equation 7, the factor 10 is again included to convert mm into m³/ha and the summation is done over the complete length of the growth period *lp* (day) in time steps of 10 days.

The $ET_{c,iw}$ (mm/day) is calculated as follows:

$$ET_{c,iw}[c,s] = IWR[c,s] * iaf \qquad (8)$$

Here, *IWR* is the irrigation water requirement (mm/day) and *iaf* is the fraction of the total area of crop *c* that is irrigated (-).

The *IWR* is calculated as follows:

$$IWR[c,s] = ET_{c,opt}[c,s] - ET_{c,rw}[c,s] \qquad (9)$$

Equation 9 shows that *IWR* represents the volume of irrigation water that is needed to meet the $ET_{c,opt}$ in case of insufficient $ET_{c,rw}$. The *iaf* determines how much of required irrigation water is actually supplied to the cropping field.

It is worth noticing that in this study only the irrigation water use on the field is taken into account, which means that the loss of irrigation water is excluded.

The actual crop evapotranspiration ($ET_{c,act}$, mm/day) during the crop growing period is found as follows:

$$ET_{c,act}[c,s] = ET_{c,rw}[c,s] + ET_{c,iw}[c,s] \qquad (10)$$

The total crop water use (CWU_{tot}, m³/ha) over the complete growing period of a crop is now calculated as follows:

$$CWU_{tot}[c,s] = 10 * \sum_{t=1}^{lp} ET_{c,act}[c,s,t] \qquad (11)$$

In equation 11, the factor 10 is again included to convert mm into m³/ha and the summation is done over the complete length of the growth period *lp* (day) in time steps of 10 days.

The water deficit (*WD*, m³/ha) that is created by insufficient irrigation water can be calculated as follows:

$$WD[c,s] = CWR[c,s] - CWU_{tot}[c,s] \qquad (12)$$

An example of the assessment of P_{eff} , $ET_{c,rw}$, $ET_{c,opt}$, $ET_{c,act}$, is given for the milled rice in the state of Kerala in Figure 2.3.

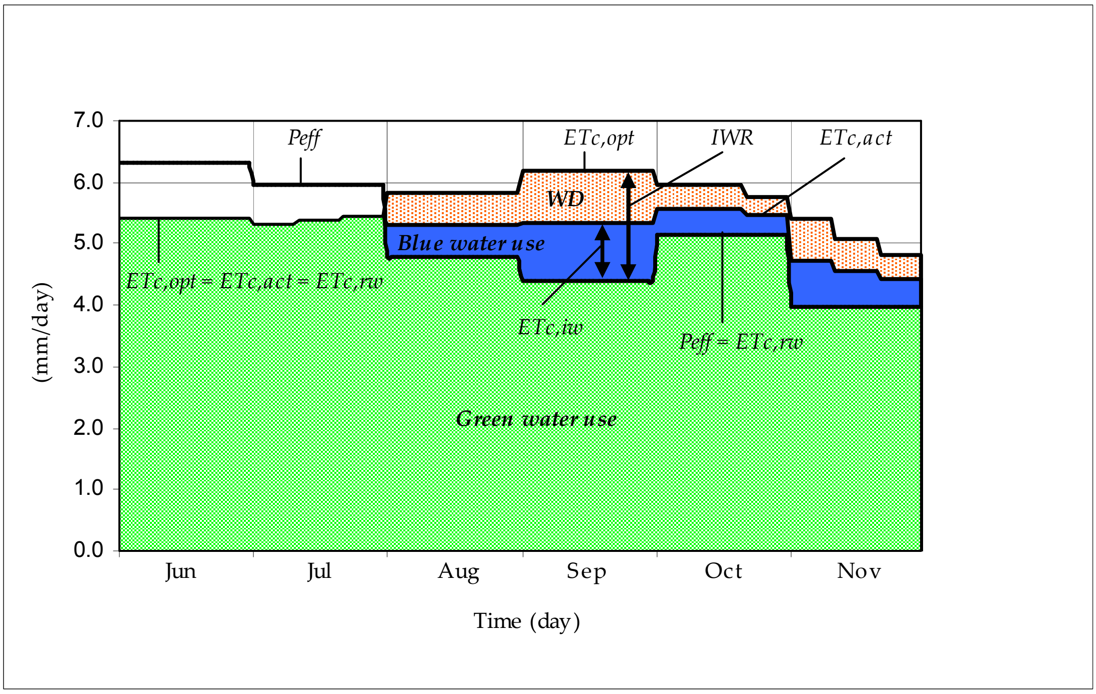

Figure 2.3: Assessment of P_{eff}, $ET_{c,rw}$, $ET_{c,act}$, $ET_{c,opt}$, IWR and $ET_{c,iw}$ for milled rice in Kerala.

2.2.4 Dilution water requirement

The dilution water requirement (*DWR*, m³/ha) is here taken to be the volume that is needed to dilute the nitrate that has leached to the groundwater to the desired level and is calculated as follows:

$$DWR[c,s] = N_{leached}[c,s] * df \tag{13}$$

Here, $N_{leached}$ is the amount of nitrate that has leached to the groundwater (ton N/ha) and *df* is the dilution factor (m³/ton).

The $N_{leached}$ is calculated as follows:

$$N_{leached}[c,s] = N_{used}[c,s] * lf \tag{14}$$

In this formula, N_{used} is the total amount of nitrate supplied to the field (ton N/ha) and *lf* is the leaching factor, which the fraction of the total supplied amount of nitrate that eventually leaches to the groundwater (-).

The dilution factor is calculated as follows:

$$df = \frac{10^6}{rl} \tag{15}$$

Here, *rl* is the recommended level of nitrogen (mg N/l). The factor 10^6 is added to the formula to convert l/mg into m³/ton.

2.2.5 Virtual water content

The total virtual water content of a crop (VWC_{tot}, m³/ton) is divided into a green component (VWC_{green}, m³/ton), a blue component (VWC_{blue}, m³/ton) and a gray component (VWC_{gray}, m³/ton).

$$VWC_{tot}[c,s] = VWC_{green}[c,s] + VWC_{blue}[c,s] + VWC_{gray}[c,s] \tag{16}$$

The VWC_{green}, VWC_{blue} and VWC_{gray} are determined as follows:

$$VWC_{green}[c,s] = \frac{CWU_{green}[c,s]}{Y_c[c,s]} \tag{17}$$

$$VWC_{blue}[c,s] = \frac{CWU_{blue}[c,s]}{Y_c[c,s]} \tag{18}$$

$$VWC_{gray}[c,s] = \frac{DWR[c,s]}{Y_c[c,s]} \tag{19}$$

Here, Y_c is the yield of a crop (ton/ha).

It is worth noticing that in contrast to the VWC_{green} and the VWC_{blue}, the VWC_{gray} may not refer to an actual water use, but to a required water use.

2.2.6 Virtual water content of processed products

The *VWC* of a processed product depends on the product fraction (*pf*, (-)) and value fraction (*vf*, (-)) of the processed product.

The product fraction (*pf*, (-)) of a processed product is the weight of the processed product (ton) divided by the weight of the primary crop (ton).

The value fraction of a processed crop is calculated as follows:

$$vf[p] = \frac{v[p] * pf[p]}{\sum (v[p] * pf[p])} \tag{20}$$

In this equation, *v* is the market value of the processed crop (US$/ton) and "$\sum(v*pf)$" the aggregated market value of all the processed crops obtained from the primary crop (US$/ton).

The virtual water content of the processed crop (VWC_{pc}, m³/ton) is now calculated as follows:

$$VWC_{pc}[c,s] = \frac{VWC[c,s] * vf[p]}{pf[p]} \tag{21}$$

Here, *VWC* refers to the virtual water content of the primary crop (m³/ton).

In the calculation of the *VWC* of processed products, the possible process water requirements are not taken into account.

2.2.7 Water productivity

The water productivity of a crop (WP, ton/m^3) is the crop production per unit of water volume and is calculated as follows:

$$WP[c,s] = \frac{1}{VWC[c,s]} \tag{22}$$

2.2.8 Water use

The total agricultural water use (AWU, m^3/yr) is the total volume of water that is used to produce crops and is calculated as follows:

$$AWU[s] = \sum_{c=1}^{n_c} \left(VWC[c,s] * P[c,s]\right) \tag{23}$$

In this equation, P represents the annual production volume (ton/yr).

The AWU can be divided into a green, a blue and a gray component as follows:

$$AWU_{green}[s] = \sum_{c=1}^{n_c} \left(VWC_{green}[c,s] * P[c,s]\right) \tag{24}$$

$$AWU_{blue}[s] = \sum_{c=1}^{n_c} \left(VWC_{blue}[c,s] * P[c,s]\right) \tag{25}$$

$$AWU_{gray}[s] = \sum_{c=1}^{n_c} \left(VWC_{gray}[c,s] * P[c,s]\right) \tag{26}$$

Here, AWU_{green} is total green agricultural water use (m^3/yr) AWU_{blue} is the total blue agricultural water use (m^3/yr) and AWU_{gray} the total gray agricultural water use (m^3/yr).

2.3 *Calculation of virtual water flows*

2.3.1 National and state crop balance

The estimation of the interstate trade flow of a crop starts with the assessment of the national crop balance for the study period 1997-2001 (FAO, 2006a). In the national crop balance, the total crop supply (S_t, ton/yr) is by definition equal to the total crop utilization (U_t, ton/yr).

$$S_t[c] = U_t[c] \tag{27}$$

The S_t and U_t are calculated as follows:

$$S_t[c] = P_t[c] + I_{t,in}[c] - SI_t[c] + SD_t[c] - E_{t,in}[c] \tag{28}$$

$$U_t[c] = Fd_t[c] + Sd_t[c] + M_t[c] + W_t[c] + Ou_t[c] + C_t[c] \tag{29}$$

Here, P_t is the total production (ton/yr), $I_{t,in}$ is the total international import (ton/yr), SI_t is the total stock increase (ton/yr), SD_t is the total stock decrease (ton/yr), $E_{t,in}$ is the total international export (ton/yr), Fd_t is the total animal feed (ton/yr), Sd_t is the total seed use (ton/yr), M_t is the total manufacture (ton/yr), W_t is the total waste (ton/yr), Ou_t is the total other use (ton/yr) and C_t is the total consumption (ton/yr).

In theory, the crop balance of a state is analogue to the national crop balance, in which the supply (S_s, ton/yr) is again equal to the utilization (U_s, ton/yr).

$$S_s[c,s] = U_s[c,s] \qquad (30)$$

The relation between the national balance and the state balance is as follows:

$$S_t[c] = \sum_{s=1}^{n} S_s[c,s] \qquad (31)$$

$$U_t[c] = \sum_{s=1}^{n} U_s[c,s] \qquad (32)$$

The S_s and U_s are calculated as follows:

$$S_s[c,s] = P_s[c,s] + I_{s,in}[c,s] + I_{s,is}[c,s] - SI_s[c,s] + SD_s[c,s] - E_{s,in}[c,s] - E_{s,is}[c,s] \qquad (33)$$

$$U_s[c,s] = Fd_s[c,s] + Sd_s[c,s] + M_s[c,s] + W_s[c,s] + Ou_s[c,s] + C_s[c,s] \qquad (34)$$

Here, P_s is the production (ton/yr), $I_{s,it}$ is the international import (ton/yr), $I_{s,is}$ is the interstate import (ton/yr), SI_s is the stock increase (ton/yr), SD_s is the stock decrease (ton/yr), $E_{s,it}$ is the international export (ton/yr), $E_{s,is}$ is the interstate export (ton/yr), Fd_s is animal feed (ton/yr), Sd_s is the seed use (ton/yr), M_s is the manufacture (ton/yr), W_s is the waste (ton/yr), Ou_s is the other use (ton/yr) and C_s is the consumption (ton/yr).

In the national balance of a crop, the interstate trade ($T_{t,is}$, ton/yr) is excluded, because the total interstate import of a country is by definition equal to the total interstate export.

The $T_{t,is}$ is calculated as follows:

$$T_{t,is}[c] = \sum_{s=1}^{n} I_{s,is}[c,s] = \sum_{s=1}^{n} E_{s,is}[c,s] \qquad (35)$$

2.3.2 <u>Interstate trade</u>

The interstate trade of a crop is calculated from the state crop balances. In the state crop balance, the production (P_s) and the consumption (C_s) are directly available. Furthermore, the crop seed use (Sd_s) and the crop waste (W_s) are calculated as fixed percentages of P_s.

The Sd_s and W_s are calculated as follows:

$$Sd_s[c,s] = \frac{Sd_t[c]}{P_t[c]} * P_s[c,s] \qquad (36)$$

$$W_s[c,s] = \frac{W_t[c]}{P_t[c]} * P_s[c,s] \qquad (37)$$

The remaining parameters in the state crop balance are calculated with the surplus of a crop in a state (Sp_s, ton/yr), which is calculated as follows:

$$Sp_s[c,s] = (P_s[c,s] - Sd_s[c,s] - W_s[c,s]) - C_s[c,s] \tag{38}$$

Next the following distinction is made:

$$Sp_{s,+} = Sp_s \quad if \quad Sp_s \geq 0 \tag{39}$$

$$Sp_{s,+} = 0 \quad if \quad Sp_s < 0 \tag{40}$$

$$Sp_{s,-} = Sp_s \quad if \quad Sp_s < 0 \tag{41}$$

$$Sp_{s,-} = 0 \quad if \quad Sp_s \geq 0 \tag{42}$$

The following assumptions are made for the calculation of the interstate export $E_{s,is}$ and interstate import $I_{s,is}$:

- Only states with a positive crop surplus ($Sp_{s,+}$, ton/yr), use a crop for other purposes than consumption (C_s), seed (Sd_s) and waste (W_s) and are therefore the only contributors to SI_t, $E_{t,in}$, $E_{t,is}$, Fd_t, M_t and Ou_t.
- Only states with a negative crop surplus ($Sp_{s,-}$, ton/yr) receive a part of SD_t, $I_{t,in}$ and $I_{t,is}$. The stock increase or the stock decrease does not contribute to interstate trade; in the case of a stock increase the crop is stored within the state of production, and in the case of a stock decrease the crop is provided within the state of consumption. This is actually incorrect, because the stock is either stored at the place of production or at the place of consumption, which means crop trade either takes place before or after storage.
- The assessed volumes of feed (Fd_s), manufacture (M_s) and other use (Ou_s) are all utilized within the state of production. Here we assume that livestock products that originate from the animals that consumed the animal feed are consumed in the state of production.

The international export $E_{s,in}$, the interstate export $E_{s,is}$, the international import $I_{s,in}$ and the interstate import $I_{s,is}$ of crop c in state s are now calculated as follows:

$$E_{s,in}[c,s] = E_{t,in}[c] * \left(\frac{Sp_{s,+}[c,s]}{\sum_{s,+=1}^{m} Sp_{s,+}[c,s]} \right) \tag{43}$$

$$E_{s,is}[c,s] = Sp_{s,+}[c,s] - E_{s,in}[c,s] - (SI_t[c] + RU_t[c]) * \left(\frac{Sp_{s,+}[c,s]}{\sum_{s,+=1}^{m} Sp_{s,+}[c,s]} \right) \tag{44}$$

$$RU_t[c] = Fd_t[c] + M_t[c] + Ou_t[c] \tag{45}$$

$$I_{s,in}[c,s] = I_{t,in}[c] * \left(\frac{Sp_{s,-}[c,s]}{\sum_{s,-=1}^{n-m} Sp_{s,-}[c,s]} \right) \tag{46}$$

$$I_{s,is}[c,s] = Sp_{s,-}[c,s] - I_{s,in}[c,s] - (SD_t[c]) * \left(\frac{Sp_{s,-}[c,s]}{\sum_{s,-=1}^{n-m} Sp_{s,-}[c,s]} \right) \tag{47}$$

In equations 43 and 46, it can be seen that a state with a large crop surplus contributes more to the total international crop export than a state with a small crop surplus.

In Figure 2.4, all parameters that determine the interstate and international crop trade are presented.

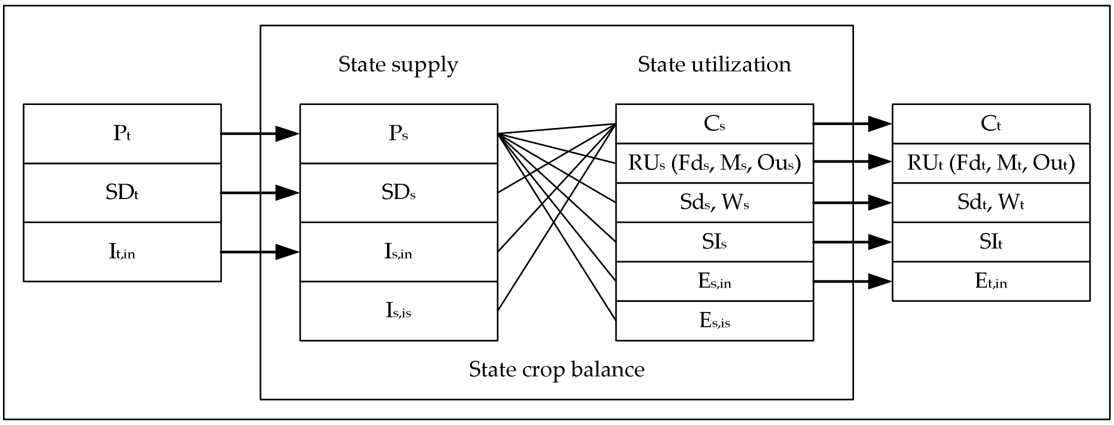

Figure 2.4: Framework of parameters that determine the interstate and international crop trade.

Finally, the total interstate export $E_{t,is}$ is distributed over the total interstate import $I_{t,is}$. This distribution is based on the assumption that crops are traded as much as possible with neighbouring states. The first distribution step is to assess the flows between adjacent states, when no other states are directly competitive. A second step can be used for assessing the short distance trade flows that remain after the first step. In the last step the remaining crop deficits are filled up by the remaining crop surplus.

2.3.3 Virtual water flows

The virtual water flow of a crop is the trade flow of a crop expressed in the volume of water it virtually contains.

The virtual water flow as a result of crop trade between two states (VWF_s, m^3/yr) is calculated as follows:

$$VWF_s[c,s_1,s_2] = E_s[c,s_1,s_2] * VWC[c,s_1] - I_s[c,s_1,s_2] * VWC[c,s_2] \tag{48}$$

Here, E_s is the interstate export from state 1 to state 2 (tons/yr), I_s is the interstate import from state 2 into state 1 (tons/yr) and *VWC* is the virtual water content in the exporting state (m^3/ton).

The total virtual water flow as a result of all crop trade between two states ($VWF_{s,tot}$, m^3/yr) is calculated as follows:

$$VWF_{s,tot}[s_1,s_2] = \sum_{c=1}^{n} VWF_s[c,s_1,s_2] \tag{49}$$

The net virtual water balance of a state is assessed in the form of the net virtual water import (VWI_{net}, m³/yr), which is calculated as follows:

$$VWI_{net}[s_1] = -\sum_{s_2=1}^{n} VWF_{s,tot}[s_1, s_2] \tag{50}$$

2.4 *Calculation of the water footprints*

The water footprint of a country (*WFP*, m³/yr) is defined as the total volume of water used, directly or indirectly, to produce goods and service consumed by the inhabitants of the country (Hoekstra & Chapagain, 2007). In this study the total water footprint only represents the agricultural part of the footprint.

The total *WFP* is divided into an internal water footprint (WFP_i, m³/yr) and an external water footprint (WFP_e, m³/yr) as follows:

$$WFP_{tot}[s] = WFP_i[s] + WFP_e[s] \tag{51}$$

The WFP_i covers the use of internal water resources to produce crops consumed by the inhabitants of the state and is calculated as follows:

$$WFP_i[s] = AWU[s] - VWE_{gross}[s] \tag{52}$$

Here, VWE_{gross} is the gross export of virtual water from a state (m³/yr).

The WFP_e covers the use of water resources of other states or other countries to produce crops consumed by the inhabitants of the state concerned.

The WFP_e is calculated as follows:

$$WFP_e[s] = VWI_{gross}[s] \tag{53}$$

Here, VWI_{gross} is the gross import of virtual water into a state (m³/yr).

Since the water footprint is based on human consumption, it is useful to calculate the water footprint per capita (WFP_{cap}, m³/cap/yr). This gives a better view of the water use in the states and makes the water footprints better comparable.

The WFP_{cap} is calculated as follows:

$$WFP_{cap}[s] = \frac{WFP_{tot}[s]}{Pop[s]} \tag{54}$$

Here, *Pop* is the total population (capita).

The green, blue and gray water footprint can be found by calculating with the green, blue and gray component of the total virtual water content separately.

In the case of the calculation of the water footprint of a region, the import and export between states with a region are considered as a contribution to the internal water footprint.

2.5 *Estimation of water resources*

2.5.1 Water balance of a state

The assessment of the water resources in a state is based on hydrological principals. The input of the water resources in a state is formed by the precipitation within the state area and the inflow of water from outside the state. The precipitation in a state is either lost through evaporation from the soil or transpiration from plants. Because evaporation and transpiration are hard to identify separately, these two processes are combined as 'evapotranspiration'. The remaining part of the precipitation volume either percolates to the groundwater or runs off to the surface water. Groundwater and surface water are interconnected and are therefore treaded as one water system. Surface water contributes to groundwater through seepage in the river bed, while groundwater discharges into the surface water and thereby contributes to the base flow of a river.

The water balance in a state is presented in Figure 2.5.

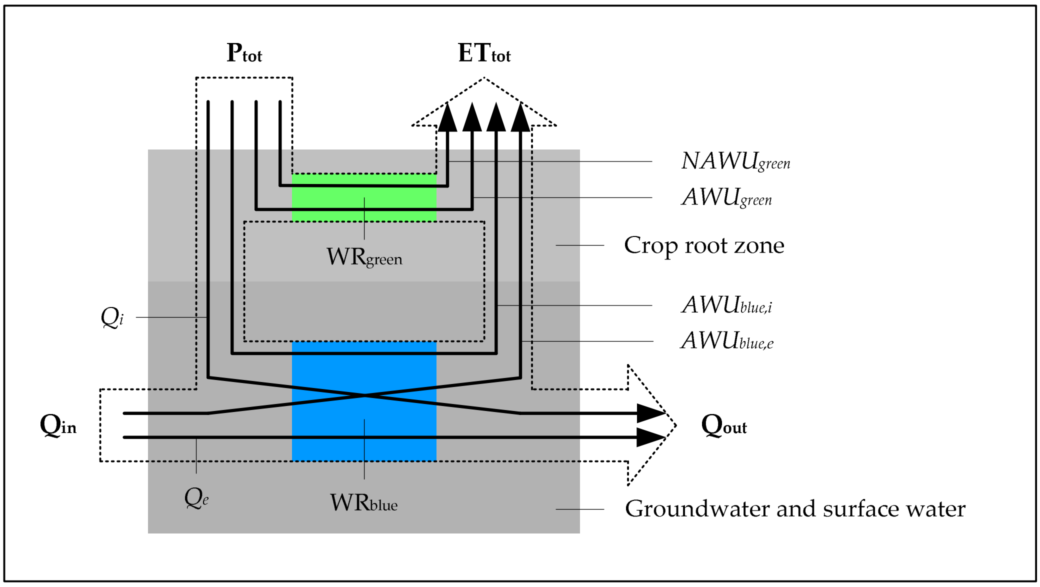

Figure 2.5: The water balance in a state

In Figure 2.5, Q_{in} is the total volume of water flowing into a state (m^3/yr), Q_{out} is the total volume of water flowing out of a state (m^3/yr), P_{tot} is total volume of precipitation that falls within the borders of a state (m^3/yr), and ET_{tot} is the total volume of evapotranspiration within the borders of a state (m^3/yr).

Q_{in}, Q_{out}, P_{tot} and ET_{tot} are calculated as follows:

$$Q_{in}[s] = AWU_{blue,e}[s] + Q_e[s] \quad (55)$$

$$Q_{out}[s] = Q_i[s] + Q_e[s] \quad (56)$$

$$P_{tot}[s] = Q_i[s] + AWU_{green}[s] + NAWU_{green}[s] + AWU_{blue,i}[s] \quad (57)$$

$$ET_{tot}[s] = AWU_{green}[s] + NAWU_{green}[s] + AWU_{blue,i}[s] + AWU_{blue,e}[s] \quad (58)$$

Here, $AWU_{blue,e}$ is the total use of external irrigation water (m^3/yr), Q_e is the outflow of external water from the state (m^3/yr), Q_i is the outflow of internal water from the state (m^3/yr), AWU_{green} is the total use of rainwater (m^3/yr), $NAWU_{green}$ is the total use of rainwater in non agricultural areas (m^3/yr), and $AWU_{blue,i}$ is the total use of internal irrigation water (m^3/yr).

As can be seen in Figure 2.5, a distinction is made between green water resources (WR_{green}, m^3/yr) and blue water resources (WR_{blue}, m^3/yr). The blue water resources can be further divided into an internal and an external component.

2.5.2 Internal water resources of a state

Green water resources (WR_{green}, m^3/yr) are by definition internal water resources and are here defined as the total volume of vapour flows from the surface area in a state under rain fed conditions.

The WR_{green} are calculated as follows:

$$WR_{green}[s] = AWU_{green}[s] + NAWU_{green}[s] \tag{59}$$

The $NAWU_{green}$ are estimated as follows:

$$NAWU_{green}[s] = Min(P_{eff}[s], ET_0[s]) * A_{non\ agric}[s] \tag{60}$$

Here, $A_{nonagric}$ is the non agricultural area in a state (ha/yr). It is worth noticing that in this study, the non agricultural area, from which $NAWU_{green}$ is calculated, also represents the agricultural area that is not taken into account.

The internal blue water resources ($WR_{blue,i}$, m^3/yr) capture the average annual flow in rivers and the recharge of groundwater generated from endogenous precipitation.

The $WR_{blue,i}$ are calculated as follows:

$$WR_{blue,i}[s] = P_{tot}[s] - WR_{green}[s] \tag{61}$$

The total outflow of internal water from a state (Q_i, m^3/yr) is calculated as follows:

$$Q_i[s] = WR_{blue,i}[s] - AWU_{blue,i}[s] \tag{62}$$

Here, $AWU_{blue,i}$ is assessed as follows:

$$AWU_{blue,i}[s] = Min(WR_{blue,i}[s], ET_{tot}[s] - WR_{green}[s]) \tag{63}$$

In equation 63, the assumption is made that blue water use in a state originates as much as possible from internal water resources. The calculated AWU_{blue} can now be separated into $AWU_{blue,i}$ and $AWU_{blue,e}$. This may lead to an underestimation of Q_i and $AWU_{blue,e}$ and to an overestimation of Q_e and $AWU_{blue,i}$, while Q_{out} remains the same. This also means that $AWU_{blue,e}$ only becomes larger than zero when Q_i becomes zero, which is the case when the Q_{out} is smaller than Q_{in}.

2.5.3 External water resources of a state

The external blue water resources of a state ($WR_{blue,e}$, m^3/yr) are defined as the total average annual flow in rivers and recharge of groundwater in a state that find their origin in other states or other countries.

The assumption is made that the volume of groundwater that crosses state borders is negligible and is therefore omitted in this assessment. Furthermore the assumption is made that the transport of surface water between across state borders is only in the form of the larger rivers in India.

The first step in the assessment of interstate river flows is the allocation of the river basin areas to the involved state areas. The total area of a state in a river basin ($A_{s,rb}$, km^2) is calculated as follows:

$$A_{s,rb}[s,rb] = A_{rb}[rb] \cap A_s[s] \tag{64}$$

Here, A_s is the total area of a state (km^2) and A_{rb} is the total area of a river basin (km^2).

The part of the outflow of internal water resources of a state that contributes to the discharge volume of a river basin ($Q_{i,rb}$, m^3/yr) is calculated as follows:

$$Q_{i,rb}[s,rb] = \frac{A_{s,rb}[s,rb] * Q_i[s]}{A_s[s]} \tag{65}$$

The total outflow of water from a state in a river basin ($Q_{out,rb}$, m^3/yr) is now calculated as follows:

$$Q_{out,rb}[s,rb] = Q_{i,rb}[s,rb] + Q_{e,rb}[s,rb] \tag{66}$$

Here, $Q_{e,rb}$ is the part of the outflow of external water resources of a state that contributes to the discharge volume of river basin *rb* (m^3/yr), which is calculated as follows:

$$Q_{e,rb}[s,rb] = Q_{in,rb}[s,rb] - AWU_{blue,e}[s] \tag{67}$$

In Equation 67, $Q_{in,rb}$ is the inflow of external water resources into a state in a river basin (m^3/yr), which is calculated as follows:

$$Q_{in,rb}[s,rb] = \sum_{us=1}^{p} Q_{i,rb}[s,rb,us] \tag{68}$$

Here, *us* denotes a state upstream of state *s*, and *p* is the amount of states upstream of state *s* in river basin *rb*. The states upstream of state *s* in river basin *rb* are determined by the flow direction of the rivers through the states in river basin *rb*.

The $WR_{blue,e}$ of state *s* are now calculated as follows:

$$WR_{blue,e}[s] = \sum_{rb}^{k} Q_{in,rb}[s,rb] \tag{69}$$

Here, *k* is the amount of river basins state *s* falls in.

The total discharge volume of river basin *rb* (Q_{rb}, m³/yr) is found as follows:

$$Q_{rb}[rb] = \sum_{s=1}^{n} Q_{out}[s, rb] \tag{70}$$

Because of climatic variations within states, this calculation method might lead to an underestimate or overestimate of the discharge volume of the river basins.

Unlike with the internal blue water resources, the external blue water resources of the states are interdependent on state scale. This means that the external water use in a state influences the external water availability downstream. The more states upstream of a state, the less accurate the calculated volume of external water resources is.

Apart from this, the spatial variations are different for internal and external resources. For the internal resources the water availability is likely to be more spread over the state area, while the water availability from the external resources is limited to the area relatively close to the river flow.

This assessment of water resources differs from other methods of assessing water resources. First of all, green water resources are taken into account. Second of all, in the assessment of internal renewable (blue) water resources, the withdrawal of irrigation water is taken into account.

2.6 *Assessment of water scarcity*

2.6.1 Water scarcity from production perspective

Traditionally, water scarcity is seen from production perspective (WS_{prod}, (-)) by comparing water use to the available water resources in a state. This water scarcity is here divided into green water scarcity ($WS_{prod,green}$, (-)) and blue water scarcity ($WS_{prod,blue}$, (-)).

The WS_{prod}, $WS_{prod,green}$ and $WS_{prod,blue}$ are calculated as follows:

$$WS_{prod}[s] = \frac{AWU_{green}[s] + AWU_{blue}[s] + AWU_{gray}[s]}{WR_{tot}[s]} \tag{71}$$

$$WS_{prod,green}[s] = \frac{AWU_{green}[s]}{WR_{green}[s]} \tag{72}$$

$$WS_{prod,blue}[s] = \frac{AWU_{blue}[s] + AWU_{gray}[s]}{WR_{blue}[s]} \tag{73}$$

By definition the water scarcity from production perspective is between 0 and 1. Because of temporal and spatial dynamics in the water resources, not all water resources can be used and therefore water scarcity from production perspective will never reach 1. At which volume of water use the water becomes "scarce" is thus determined by the volume of utilizable water resources in a state.

2.6.2 Water scarcity from consumption perspective

The green and blue water scarcity in a state can also be seen from consumption perspective (WS_{cons}, (-)) by comparing the water footprint to the available water resources in a state. Also this water scarcity can be divided into green water scarcity ($WS_{cons,green}$, (-)) and blue water scarcity ($WS_{cons,blue}$, (-)).

The WS_{cons}, $WS_{cons,green}$ and $WS_{cons,blue}$ are calculated as follows:

$$WS_{cons}[s] = \frac{WFP_{blue}[s] + WFP_{green}[s] + WFP_{gray}[s]}{WR_{tot}[s]} \quad (74)$$

$$WS_{cons,green}[s] = \frac{WFP_{green}[s]}{WR_{green}[s]} \quad (75)$$

$$WS_{cons,blue}[s] = \frac{WFP_{blue}[s] + WFP_{dilution}[s]}{WR_{blue}[s]} \quad (76)$$

In contrast to WS_{prod}, the WS_{cons} can be more than 1. This is the case when more water is needed to produce the food for the inhabitants than is available in a state, which is the case in completely urban states like Delhi.

2.7 *Calculation of water saving*

2.7.1 Global water saving

Water saving in a state is realised by a net import of a crop. The volume of water it would have taken to produce the imported amount of crop in the importing state itself is the water volume that is saved.

The water saving in a state as a result of a net import of a crop (ΔS_s, m³/yr) is calculated as follows:

$$\Delta S_s[c,s] = \left(\left(I_{s,is}[c,s] + I_{s,in}[c,s]\right) - \left(E_{s,is}[c,s] + E_{s,in}[c,s]\right)\right) * VWC[c,s] \quad (77)$$

The global water saving as a result of interstate commodity trade (ΔS_g, m³/yr) is calculated as follows:

$$\Delta S_g[c,s_e,s_i] = T[c,s_e,s_i] * \left(VWC_i[c,s_i] - VWC_e[c,s_e]\right) \quad (78)$$

It can be seen that global water saving becomes negative (global water loss) when the *VWC* in the importing state is lower than the *VWC* in the exporting state.

The total global water saving as a result of interstate commodity trade is found by summing up the global water savings of all interstate trade flows of a commodity.

The global water saving as a result of interstate trade is divided into a blue, a green and a gray component. These components are found by calculating with blue, green and gray component of *VWC* separately.

2.7.2 Water saving and the theory of comparative advantage

Based on equation 78, water is only globally saved when there is an absolute advantage in water productivity in the exporting state. This would mean that the export of crops from states with a natural absolute disadvantage in water productivity will never lead to global water saving.

However, the economic theory of comparative advantage (Ricardo, 1817) shows how two states can both gain from crop trade if they specialize in the production of crops for which they have a comparative advantage and import the crops for which they have a comparative disadvantage. In the case of water productivity, this means that the absolute water saving that is realised by focussing on the relative advantage in water productivity is higher than the absolute water saving that is realised by focussing on the absolute advantage in water productivity (Wichelns, 2007).

If we consider the states s_1 and s_2, which both produce the crops c_1 and c_2, next to the absolute advantages in water productivity, the relative advantage in water productivity can be determined.

Equations 79 and 80 present the two possible situations.

$$\frac{WP[c_1,s_1]}{WP[c_2,s_1]} < \frac{WP[c_1,s_2]}{WP[c_2,s_2]} \tag{79}$$

$$\frac{WP[c_1,s_1]}{WP[c_2,s_1]} > \frac{WP[c_1,s_2]}{WP[c_2,s_2]} \tag{80}$$

In the first situation, state s_1 has a comparative advantage in crop c_1 and a comparative disadvantage in crop c_2, while state s_2 has a comparative advantage in crop c_2 and a comparative disadvantage in crop c_1. In the second situation, state s_1 has a comparative advantage in crop c_2 and a comparative disadvantage in crop c_1, while state s_2 has a comparative advantage in crop c_1 and a comparative disadvantage in crop c_2.

State s_1 should therefore specialize in crop c_1 in the first situation and in crop c_2 in the second situation, while state s_2 should specialize in crop c_2 in the first situation and in crop c_1 in the second situation. These recommended specializations only depend on relative water productivities.

2.7.3 Relative water saving

Apart from absolute water saving, there is also relative water saving. Relative water saving is realised by increasing the part of the vapour flow that contributes to the biomass of the crop (transpiration) at the cost of the non productive part (evaporation), while the total evapotranspiration remains the same, which means there is no absolute water saving.

Figure 2.6 shows that relative water saving can be realised by increasing the agricultural productivity (Rockström, 2003). This is because with an increase in crop yield, the productive part of the water productivity of a crop increases.

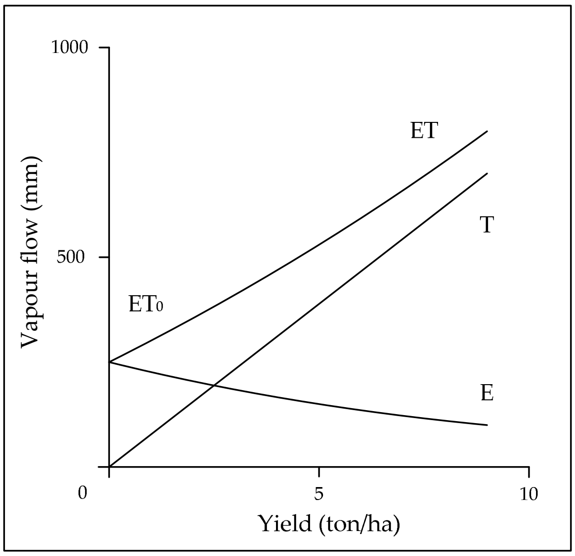

Figure 2.6: The general relationship between the crop yield and the different components of the vapour flow (Rockström, 2003)

The productive part of water productivity (WP_T, ton/m^3) is calculated as follows (Rockström, 2003):

$$WP_T[c,s] = \frac{WP_{ET}[c,s]}{\left(1 - e^{(bY[c,s])}\right)} \tag{81}$$

Here, WP_{ET} is the total water productivity of a crop (ton/m^3) as defined in equation 22, b is an empirical constant (-), and Y the crop yield (ton/ha). Depending on the climate, b fluctuates around a value of -0.3 (Rockström, 2003).

3. Study scope and data collection

3.1 Study area

India is located in South Asia bordering with Pakistan, China, Nepal, Bhutan, Myanmar and Bangladesh. In the north, along the border with China, India is situated in the Himalayan Range. Large rivers like the Indus, the Ganges and the Brahmaputra spring from this mountainous area. Below the Himalayan Range the Indo-Gangetic Plain is found, which decreases from the west to the east. In the west, against the border with South Pakistan (Latitude 25°-28°), the Thar Desert is situated. In the southern peninsular part of India the Deccan Plateau is found, with coastal hill regions (Western and Eastern Ghats). The southern part of India is surrounded by the Arabian Sea on the west side and the Bay of Bengal on the east side. Apart from the Thar Desert these geological features are all visible in the elevation map of India (Figure 3.1).

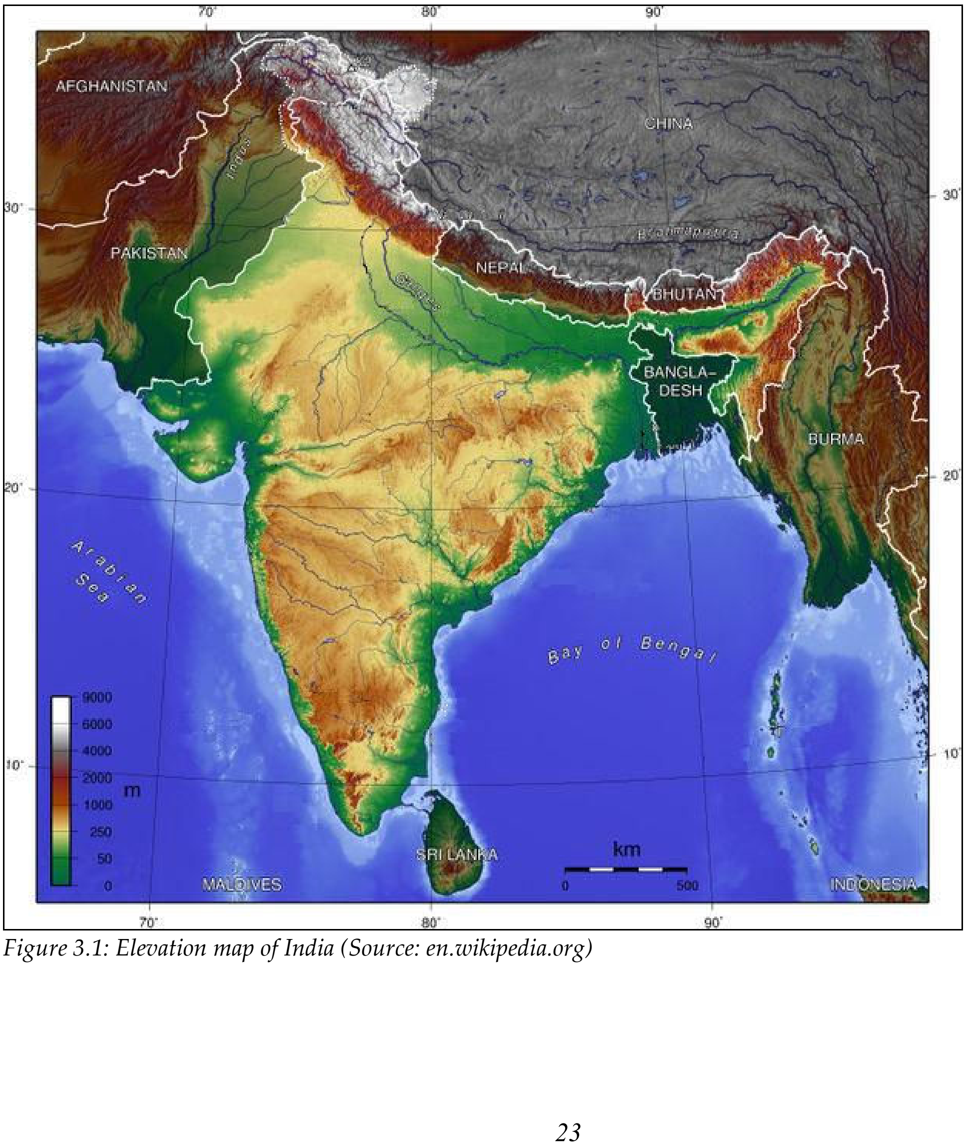

Figure 3.1: Elevation map of India (Source: en.wikipedia.org)

On a political scale India is divided into thirty-six administrative divisions; twenty-nine states, six union territories and the national capital territory Delhi (see Figure 3.2). The six union territories are Andaman & Nicobar Islands, Chandigarh (also the capital of both Punjab and Haryana), Dadra & Nagar Haveli, Daman & Diu, Lakshadweep Islands and Pondicherry. The states and the union territory of Pondicherry have an own local government. The remaining union territories are directly controlled by the national government, which is settled in Delhi.

Figure 3.2: Map of the Indian states & Union Territories (CDC, 2007)

Approximately 70 % of the Indian population is currently living in rural areas (FAO, 2006a). This percentage is decreasing as a result of an increase in urbanisation in the past decades.

In this study the following administrative divisions are excluded; Andaman & Nicobar Islands, Arunachal Pradesh, Chandigarh, Dadra & Nagar Haveli, Daman & Diu, Goa, Lakshadweep Islands, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura. These states and union territories are not taken into account, because they either have little area suitable for agriculture or have a small population (Appendix II). Therefore they are assumed to have no significant influence on the results of the study. Only in the assessment of the interstate trade, these areas are included to close the national crop balances. Another reason for the exclusion of these areas is that the precipitation is not well reported because of the small amount or even the absence of weather stations.

In November 2000, three states were split into two separate states; Uttaranchal was carved out of Uttar Pradesh, Jharkhand out of Bihar and Chhattisgarh out of Madhya Pradesh. Since this happened during the period on which this study is focused, it is worth noticing that data on the states involved prior November 2000 represent the combined performance of the split up states, which is separated by their relative individual performance after November 2000.

Finally, the India can also be divided into four larger regions; northern, western, eastern and southern India. Northern India consists of Jammu & Kashmir, Himachal Pradesh, Punjab, Haryana, Uttaranchal, Uttar Pradesh and Delhi. Western India consists of Rajasthan, Gujarat, Madhya Pradesh and Maharashtra. Eastern India consists of Bihar, Jharkhand, West Bengal, Assam, Orissa and Chhattisgarh. And southern India consists of Karnataka, Andhra Pradesh, Kerala and Tamil Nadu.

The total area considered in this study is 94% of the total territory of India and covers 98% of the population (Appendix II).

3.2 *Crop coverage*

Not all crops that are grown in India can be taken into account in this study. Therefore a selection of crops is made.

FAO distinguishes 176 primary crops in the FAOSTAT database (FAO, 2006a), of which 80 are produced in India in the period 1997-2001 (Appendix III). These 80 crops can be summarized in 12 crop categories. The 12 crop categories and their total water use, production value and land use are given in Table 3.1.

Table 3.1. Water use, production value and land use per crop category in the period 1997-2001

Crop categories	Production[1]	Water use[2]		Production value[3]		Land use[1]	
	10^6 ton/yr	10^9 m^3/yr	%	10^9 US$/yr	%	10^6 ha/yr	%
Cereals	233	581	61	30	39	101	57
Oil crops	37	154	16	10	13	35	20
Pulses	13	58	6	5	6	21	12
Sugar crops	286	46	5	5	7	4	2
Fruits	45	39	4	11	14	4	2
Spices	2	17	2	2	2	3	1
Vegetables	68	16	2	9	11	5	3
Tree nuts	1	10	1	1	1	1	1
Stimulants	1	9	1	1	1	1	0
Starchy roots	30	7	1	3	4	2	1
Vegetable fibres	2	6	1	0	0	1	0
Other	1	6	1	1	1	1	0
Total	719	949	100	77	100	178	100

*[1] Source: FAO (2006a), [2] Water use = production * Indian average virtual water content (source: Chapagain & Hoekstra, 2004), [3] Production value = production * producer price (US$ 1997-2001, source: FAO, 2006a).*

The water use of a crop is the production volume multiplied with the virtual water content of the crop (Chapagain & Hoekstra, 2004). The total crop water use in India is 949 billion m^3/yr.

The value of the annual crop production is captured in the production volume multiplied with the producer price of a crop (FAO, 2006a). The total production value is 77 billion US$/yr.

The total net area of arable land in India is approximately 145 million ha (CIA, 2006). The total gross area harvested (178 million ha/yr) is higher, because arable land can be harvested more than once in a year.

Since water use is the main focus of this study, a boundary condition is put on the water use of a crop to determine if a crop may play a significant role in the analysis of this study. The chosen **boundary level on the crop water use** is determined at **1% of the total water use**. The assumption that crops may play a significant role when they are above the chosen boundary level is more or less arbitrary. For this study, the chosen level seemed reasonable and led to a feasible amount of crops to investigate.

In the crop selection, the production value and land use of a crop are also taken into account. The excluded crops therefore have a production value that is lower than 5% of the total production value and a land use that is lower than 2% of the total agricultural area in India. These parameters are taken into account to avoid the exclusion of crops with a high economic value or a large land use.

Table 3.2 shows the 16 selected primary crops. This selection represents 80% of the total crop production, 87% of the total water use, 69% of the total production value and 86% of the total land use.

Table 3.2. Selected primary crops in the period 1997-2001 ranked by water use

Primary crops in FAOSTAT	Crop production[1]	Water use[2]		Production value		Land use	
Name	10^6 ton/yr	10^9 m^3/yr	%	10^9 US$/yr	%	10^6 ha/yr	%
Rice, Paddy	130.9	373.1	39.3	16.5	21.4	44.6	25.0
Wheat	70.6	116.8	12.3	10.4	13.5	26.7	15.0
Seed Cotton	5.7	47.2	5.0	2.9	3.8	8.9	5.0
Sugar Cane	286.0	45.6	4.8	5.1	6.7	4.1	2.3
Millet	10.2	33.2	3.5	1.0	1.3	12.6	7.0
Sorghum	8.0	32.4	3.4	0.9	1.2	10.1	5.7
Soybeans	6.4	26.2	2.8	1.5	1.9	6.3	3.5
Groundnuts in Shell	7.0	23.9	2.5	2.3	3.0	6.8	3.8
Maize	11.8	22.8	2.4	1.3	1.7	6.4	3.6
Beans, Dry	2.6	21.7	2.3	0.8	1.0	6.7	3.8
Coconuts[3]	9.3	21.1	2.2	0.8	1.1	1.8	1.0
Mangoes[3]	10.6	16.1	1.7	3.8	4.9	1.4	0.8
Chick-Peas	5.5	14.9	1.6	1.9	2.5	6.8	3.8
Rapeseed	5.4	14.1	1.5	1.7	2.2	6.1	3.4
Pimento, Allspice[3]	1.0	10.6	1.1	0.8	1.1	0.9	0.5
Pigeon Peas	2.4	9.9	1.0	0.9	1.2	3.5	1.9
Other crops[3]	145.6	119.2	12.6	24.3	31.5	24.4	13.7
Total	718.9	949.0	100.0	77.0	100.0	178.0	100.0

[1] *Source: FAO (2006a),* [2] *Source: Chapagain & Hoekstra (2004)* [3] *Shaded crops are excluded from study*

The primary crop "fresh vegetables not elsewhere specified" is omitted in table 3.2, although the production value is 5.3% of the national total. The reason for this is that this crop is already a leftover category within the category vegetables and therefore not suitable for further investigation, because data on individual crops are necessary to make an equal comparison between the states possible.

At this point, it can be seen that not all crop categories from table 3.1 are well represented in the individual crop ranking in table 3.2. Based on these two tables the decision is made that the selected crops within the crop categories cereals, oil crops, pulses and sugar crops are further investigated in this study. This means that relatively important crops like mangoes and pimento are excluded. Furthermore coconut is excluded from this study, because of the lack of trade data on the processed products of this crop (like coir) and the lack of possible changes in the location of the crop production. According to this analysis, the selection of crops now represent 77% of the total crop production, 82% of the total water use, 61% of the total production value and 84% of the total land use.

Finally, it is worth noticing that although rice is harvested as paddy rice, we only use the milled rice equivalent, which represents all the processed rice products interpolated to the equivalent of milled rice. Furthermore, it should be noted that all sugar originates from sugar cane in India and that the generic name dry beans in this study represents the crops mung bean, black gram and moth bean.

3.3 Data collection

3.3.1 Climatic parameters

The data on the reference evapotranspiration (ET_0) are calculated in CROPWAT (FAO, 2006b). In this program, the average ET_0 is calculated per month with the FAO Penman-Monteith method for 160 weather stations in India. Climatic data on these weather stations that are required as the input for this computation are taken from CLIMWAT (FAO, 2006c), which is the climatic database of CROPWAT. The available weather stations and the accompanying states are given in Appendix V. The average ET_0 in a certain state for a certain month is found by taking the mean of the ET_0 of all the weather stations situated in that state in that month. The amount of weather stations used per state varies from 1 in Himachal Pradesh and Delhi to 14 in Uttar Pradesh. In total 9 weather stations are excluded from the calculation of the average ET_0, because they are either situated in non agricultural areas like deserts and mountains or very clearly cause an uneven distribution of the weather stations over the state area. The exclusion of these particular stations (Appendix IV) still does not guarantee that the calculated average ET_0 is the "real" average ET_0 of the state. In some states there are simple too few stations to present a reliable value for the entire state.

The P_{tot} and P_{eff} data for the 160 weather stations are again taken from CLIMWAT (FAO, 2006c) and the average P_{tot} and P_{eff} per state is again found by taking the mean of the P_{tot} and P_{eff} of all the weather stations situated in that state in that month. In the calculation of the virtual water contents, the same weather stations that are excluded in the calculation of the average ET_0 per month per state are excluded here, because they are either situated in non agricultural areas like deserts and mountains or very clearly cause an uneven distribution of the weather stations over the state area. In the calculation of the internal and external blue water resources this might lead to a small underestimation in the case of the exclusion of rainy mountainous weather stations and to a small overestimation in the case of the exclusion of dry desert weather stations.

3.3.2 Crop parameters

Data on the duration of the different growing stages, sowing and harvesting periods and crop coefficients are taken from Allen et al. (1998), Directorate of Rice Development (2006a) and Directorate of Pulses Development (2006a).

Because of climatic differences and duration differences of crop varieties, the sowing and harvesting periods vary per region. To keep this study feasible a maximum of two sets of crop parameters are created for entire India; one for the wet season (kharif), which is roughly from June to December, and one for the dry season (rabi), which is roughly from December to April. For every crop the duration of these seasons is assessed, which is the same for all the Indian states. The generated parameters of the studied primary crops are presented in Appendix V.

3.3.3 Irrigated area fraction

The data on the irrigated area fraction (*iaf*, (-)) are taken from Directorate of Economics and Statistics (2003, 2004). The primary data are presented as the fraction of the total area of a crop under irrigation in a state during the agricultural years 1999-2000 and 2000-2001. The average *iaf* of these two agricultural years is taken as the total irrigated area fraction (iaf_{tot}(-)).

For the crops that are grown in one season, the *iaf* is equal to iaf_{tot}. For the crops that are grown in two seasons (kharif and rabi), the assumption is made that the *iaf* during rabi is as high as possible. The reason for this assumption is that the irrigation water is required the most during the dry season.

The *iaf* during rabi and kharif is calculated as follows:

$$iaf_{rabi} = \frac{Min\left(A_{rabi}[c,s],\left(A_{tot}[c,s]*iaf_{tot}\right)\right)}{A_{rabi}[c,s]} \qquad (82)$$

$$iaf_{kharif} = \frac{A_{tot}[c,s]*iaf_{tot} - A_{rabi}[c,s]*iaf_{rabi}}{A_{kharif}[c,s]} \qquad (83)$$

Here, A_{rabi} is the area of crop *c* in state *s* during rabi (ha/yr), A_{kharif} is the area of crop *c* in state *s* during kharif (ha/yr) and A_{tot} is the total area of crop *c* in state *s* (ha/yr).

In the case of maize in Tamil Nadu, an exception is made for the calculation of the *iaf* during kharif and rabi. The reason for this is that in this special case, the irrigation water requirement as a percentage of the total water requirement is higher during kharif than during rabi. Therefore the *iaf* of maize in Tamil Nadu during the wet season is assumed to be as high as possible.

3.3.4 Dilution water requirement

The data on the use of nitrate in fertilizers are taken from FAO (2005). FAO provides data on nitrate consumption (kg N/ha) for the most important crops in India in the agricultural year 2003-2004 for irrigated and rain fed areas, in which no distinction is made between the states. The assumption is made that the values of the year 2003-2004 also apply to the period 1997-2001.

Since the nitrate use is not given for all studied crops, the following assumptions are made:

- The nitrate use on pearl millet is taken as the nitrate use on finger millet and small millets.
- The nitrate use on pigeon peas is taken as the nitrate use on all pulses and soybean.

The total nitrate use for a crop (N_{use}, kg N/ha) is now calculated as follows:

$$N_{use}[c,s] = N_{use,ia}[c,s] * iaf[c,s] + (1 - iaf[c,s]) * N_{use,rfa}[c,s] \quad (84)$$

Here, $N_{use,ia}$ is the nitrate use on crop *c* in irrigated areas (kg N/ha), $N_{use,rfa}$ is the nitrate use on crop *c* in rain fed areas (kg/ha) and *iaf* is the irrigated area fraction (-).

The total nitrate use by states is taken from Directorate of Economics and Statistics (2003). These values are used for the comparison of the total gray water use in the different states as calculated in this study to the total gray water use in the different states as calculated from the total nitrate use.

The leaching factor of nitrate is in this study determined at 0.10. This value is taken from Chapagain et al. (2006).

The recommended level of nitrogen (N) in the groundwater is in this study taken to be 10 mg N/l (EPA, 2006; Chapagain et al., 2006), which corresponds with a nitrate (NO_3^-) level of 44 mg/l (Agrawal, 1999).

There are twelve states in India where nitrate levels are measured in the groundwater above the recommended level (Ministry of Water Resources, 2006a). The highest nitrate levels are found in Haryana and Punjab (Agrawal, 1999).

3.3.5 Product and value fractions of crops

The product fractions of the crops for India are taken from FAO (2006a, 2006d) and are based on data from the period 1992-1996. The assumption is made that these values are still accurate for our study period. The value fractions are taken from Chapagain & Hoekstra (2004). The product and value fractions of the studied crops used in this study are presented in Appendix VI.

3.3.6 Population

The urban and rural population of the states are taken from Census of India (2006) and FAO (2006a). Census of India gives detailed data for the year 2001 for every state and FAO gives the total urban and rural population for the years 1997-2001. The average population during the study period is found by combining the total number from FAO with the state distribution from Census of India. A map of the variation in the population density over the country and the total rural and urban population per state are presented in Appendix II.

Data on the average income per state in the period 1997-2001 is taken from Chandigarh Administration (2006).

3.3.7 National crop balance

In the national crop balance, the domestic supply (production, import, export, stock change) and the domestic utilization (animal feed, seed, manufacturing, waste, uses and food) of a crop are determined for the study period 1997-2001 (Appendix VII). In this study, the national balance of a crop is the average of the five annual crop balances, which are taken from the five annual food balance sheets of India (FAO, 2006a). In the cases when the primary crop is processed before consumption, the national balance is given for the primary crop and the processed crop. These annual crop balances are chosen as a base in this study, because no other balance includes other utilizations than human consumption.

In the national crop balance of sugar cane, the production, seed, feed, manufacture and food volumes for sugar cane for the years 1998 and 1999 have been adjusted to the production and utilization volumes of sugar cane as presented by the statistical database of the Indian Institute of Sugarcane Research (IISR, 2006). This is done because IISR are likely to present more reliable data.

The national crop balance of the crop category pulses is only given for dry beans, dry peas and other pulses (FAO, 2006a). Since dry peas is not taken into account in this study and the utilizations of dry beans and other pulses are of the same percentage, the national balance is only assessed for pulses as a whole.

Since there is no national balance for cotton lint, the assumption is made that all produced cotton lint that is not exported (FAO, 2006a), is used for local human consumption or exported to other states.

3.3.8 Crop area, production and yield

The production data of cereals, oil crops and pulses are taken from Directorate of Economics and Statistics (2003, 2004), Directorate of Rice Development (2006b), Directorate of Wheat Development (2006), Directorate of Pulses Development (2006b) and FAORAP (2006). The production data of sugarcane are taken from the statistical database of the Indian Institute of Sugarcane Research (IISR, 2006). The production data of oil crops for the year 1997 is not available on state level and is therefore estimated on the total national production during 1997 and the relative state production volumes during the other years of the study period.

The state production volumes are divided over the two main crop seasons in India:

- kharif (wet monsoon season), which is approximately from June to November
- rabi (dry winter season), which is approximately from November to April

Besides these two main seasons, there are also crops grown during the summer season (also known as the pre-kharif season), which is approximately from April to September, and thus overlaps the other two seasons. But since the crop production during this period is very low, this season is not taken into account in this study. The crop production during this season is either added to the crop production in the kharif season or to the crop production in the rabi season.

The primary production data are presented in agricultural years, which are from July to June, while the data in the crop balances are presented in calendar years, which are from January to December (see Figure 3.3). Therefore, the production data from 1996-1997 to 2000-2001 are used for the rabi crops and the production data from 1997-1998 to 2001-2002 are used for the kharif crops. If a crop is grown in both seasons, the season with the largest crop production determines if the crop is here considered as a rabi crop or a kharif crop. This means that, for example, in the case of milled rice, kharif is considered as the main season, which means that the rabi production of calendar year 2002 is used and the rabi production of calendar year 1997 is excluded. In this step the following crops are considered as rabi crops; wheat, sugar cane, rapeseed and chickpeas. All other crops are here considered as kharif crops.

<table>
<tr><td colspan="12">Data in calendar years</td></tr>
<tr><td>1996</td><td colspan="2">1997</td><td colspan="2">1998</td><td colspan="2">1999</td><td colspan="2">2000</td><td colspan="2">2001</td><td>2002</td></tr>
<tr><td>Kharif</td><td>Rabi</td><td>Kharif</td><td>Rabi</td><td>Kharif</td><td>Rabi</td><td>Kharif</td><td>Rabi</td><td>Kharif</td><td>Rabi</td><td>Kharif</td><td>Rabi</td></tr>
<tr><td colspan="2">1996-1997</td><td colspan="2">1997-1998</td><td colspan="2">1998-1999</td><td colspan="2">1999-2000</td><td colspan="2">2000-2001</td><td colspan="2">2001-2002</td></tr>
<tr><td colspan="12">Data in agricultural years</td></tr>
</table>

Figure 3.3: The overlap of calendar years and agricultural years

3.3.9 Crop consumption

The data on the consumption of crops in the different states are all taken from reports of NSSO. This organisation carries out socio-economic surveys throughout India on a regular basis. This means that the consumption of most commodities is estimated at least every five years. NSSO provides the state consumption per capita in rural and urban areas.

For the crop category cereals, the consumption data for the years 1997-2001 are taken from the NSSO (1998, 1999, 2001a, 2002, 2003). For the crop categories oil crops and sugar crops, the consumption data for the year 1999-2000 are taken from NSSO (2001b). For the crop category pulses, the consumption data for the year 1999-2000 are taken from NSSO (2001a). And for cotton lint, the consumption data for the year 2000-2001 are taken from NSSO (2002).

In the consumption data of oil crops, sugar crops and pulses some unrealistically high values are found for three north eastern states (Arunachal Pradesh, Manipur and Mizoram). For these states, the consumption data for year 1993-1994 are taken from NSSO (1997).

The total computed annual consumption per state ($C_{s,comp}$, ton/yr) is generated as follows:

$$C_{s,comp}[c,s] = C_{cap,rural}[c,s] * Pop_{rural} + C_{cap,urban}[c,s] * Pop_{urban} \quad (85)$$

Here, $C_{cap,rural}$ is consumption of a crop per capita in the rural area of a state (ton/cap/yr), Pop_{rural} is the rural population is a state (cap), $C_{cap,urban}$ is consumption of a crop per capita in the urban area of a state (ton/cap/yr) and Pop_{urban} is the urban population in a state (cap).

Next, the computed consumption volume of a state is interpolated to the consumption volume as given in the state crop balance (C_s, ton/yr), which is done to keep the national crop balance closed.

The C_s is now calculated as follows:

$$C_s[c,s] = \frac{\left(\frac{C_{s,comp}[c,s]}{pf}\right) * C_t[c]}{\sum_{s=1}^{n}\left(\frac{C_{s,comp}[c,s]}{pf}\right)} \quad (86)$$

Here, C_t is the consumption in the national crop balance (ton/yr) and *pf* the product fraction of the edible equivalent of crop *c* (-).

In general, the total computed crop consumption is a little lower than consumption as given in the national crop balance. But similarity between these two national crop consumption volumes can be expected, because FAO regularly uses specific information on consumption trends from household surveys for benchmarking their estimates for subsequent years. According to FAO, the difference between the two numbers reflects "waste occurring between the retail level and the kitchen and losses of edible food and nutrients in the household, e.g., during storage, in preparation and cooking (which affect vitamins and minerals to a greater extent than calories, protein and fat), as plate-waste, or as quantities fed to domestic animals and pets, or that thrown away".

Only in the case of chickpeas, non centrifugal and raw sugar, soybean and other edible oils, the computed consumption is significantly lower than the consumption as given in the national crop balance. The reason for this can be the exclusion of intermediate crop consumption in the NSSO method (NSSO, 2005). Intermediate consumption is here interpreted as the part of the crop that is used up in the process of further production (for example in factories or restaurants). The fact that there is a considerable volume of intermediate crop consumption in the case of crops involved is realistic. In the case of chickpeas, 60% is processed into a flour known as besan (Price et al., 2003), which is often mixed with flour from cereals. In the case of raw cane sugar, a large amount ends up in sweets, which are very popular in India, or other products. In the case of soybean and other edible oils, the soybean cake is processed into flour, which can again be mixed with flour from cereals, and a large part of the oil ends up in a mix of soybean oil and palm oil, which is known as vanaspati (Dohlman et al., 2003).

In the special case of pigeon peas, the computed consumption is higher than the consumption in the national balance. This overestimation seems to indicate an error in the assessment of either FAO (2006a) or NSSO (2001a).

Finally, it should be noted that the consumption data of cotton lint is presented as the average monthly expenditure on clothing per capita. Here, the assumption is made that the share of cotton lint in clothing is equal for all states. Since the consumption values are interpolated to the total value in the national balance, the unit of the consumption data does not form a problem.

3.3.10 Interstate trade

For the crops that are processed before consumption, the surplus and interstate trade are calculated in the edible equivalent. The reason for this is that the processed crop may have a by-product with a certain value that might be traded differently. An example of this is soybean which is processed into soybean oil and soybean cake. In these cases, the export, animal feed and primary crop consumption in the national balance of the primary crop are first transformed to the processed equivalent by the product fraction and then added to the crop utilizations in the national balance of the processed crop.

In the case of pulses, the surplus of pulses is only calculated for pulses as a whole and the assumption is made that the interstate trade consists of chickpeas only. The reason for this is that, apart from the individual crop balances that are lacking, the computed consumption values of the individual pulses are too dodgy. The assumption is made that summing up the individual pulse consumption before the interpolation to the national balance eventually gives a better indication of total pulse consumption in a state than summing up after interpolating to the national balance. This assumption is based on the principle that individual pulses are exchangeable, which means that locally produced pulses are consumed before imported pulses. The interstate trade of pulses is caused by the interstate export of pulses from Madhya Pradesh, Maharashtra and Rajasthan. Based on the reported consumption and production of the individual pulses in these three states (NSSO, 2001a, Directorate of Pulses, 2006b)), the assumption is made that the interstate trade of pulses exists of chickpeas only.

In the case of edible oils, the surplus is calculated for groundnut oil, rapeseed oil and remaining edible oils and the assumption is made that the interstate trade of the remaining edible oils consists of soybean oil only. The reason for this is that, apart from the traditional Indian edible oils groundnut oil and rapeseed oil, the computed consumption values of the edible oils are heavily underestimated. For the remaining edible oils (soybean oil and cottonseed oil), the same assumption is made as for pulses. The surplus of this group is therefore calculated for the remaining edible oils as a whole. In the calculation of surplus of remaining edible oils, sunflower seed oil, coconut oil and palm oil are included. These oils are included in this step, to prevent an oblique situation in the final surplus of the remaining edible oils in the Indian states. The interstate trade of the remaining edible oils is now only caused by the interstate export from Madhya Pradesh. Based on the consumption of edible oils in this state (NSSO, 2001b) and the production of soybean, the assumption is made that the interstate trade of the remaining edible oils exists of soybean only. In line with the rest of the study this would mean that Madhya Pradesh is the only state that uses the crop for other utilizations that human consumption, seed use and waste. Since the coverage of all national utilizations of all remaining edible oils would create a deficit of remaining edible oils in Madhya Pradesh, the remaining utilizations of the primary crops are in this case taken as a fixed percentage of the production (like the assessment of the seed use and waste of a crop) and the import goes to the stock increase (this is because it is unclear where the imported oils are consumed). Madhya Pradesh now only has to cover the stock increase and export of soybean.

3.3.11 Water resources

In this study, the water resources of the Indian states are not calculated from existing estimates on the water resources in India. Still a few studies on the water resources of India are analysed as a rough check for the calculated water resources in this study. These estimates on the water resources of India (Chaturvedi, 1985; FAO, 2003, 2006e; Ministry of Water Resources, 2006b) are presented in Appendix XVI.

From the previous estimates of the water resources in India, the conclusion can be made that precipitation estimates range from 3559 to 4000 km^3 (1083 to 1194 mm), blue water resources estimates range from 1272 to 1650 km^3 and green water resources estimates range from 2287 to 2350 km^3. Because precipitation is the single input of the calculation of the internal water resources, it determines a large part of the outcome of the internal blue and green water resources. Especially the blue water resources seem to be sensitive to change in precipitation. The green water resources seem to be less sensitive to change in precipitation. A map of the average annual precipitation, taken from India Meteorological Department (IMD, 2006), is shown in Appendix XVII.

As can be seen in Appendix XVII, there is an enormous spatial and temporal variation in the precipitation in India; the north eastern part and the Western Ghats receive considerably more rainfall than the central part of the Deccan plateau and most parts of north western India. The two spatial extremes are the north eastern state Meghalaya, where the hill station Cherrapunji receives the most rainfall in the world (11420 mm), and the Rajasthan desert, where some of the driest places on earth can be found. Furthermore, India receives around 75% of its annual precipitation during the monsoons. Nearly all Indian states receive most of their rainfall during the south west monsoon which takes place in India from June to the end of September.

Only Tamil Nadu receives most of its rainfall during the north east monsoon which takes place in India from October to December.

Since precipitation is of large importance for the outcome of the estimates on water resources, rainfall data are taken from IITM (2006), which collected rainfall data for India from the year 1871 and onwards. In these data four Himalayan states are excluded; Jammu & Kashmir, Himachal Pradesh, Uttaranchal and Arunachal Pradesh. These data lead to an average annual precipitation of 1088 mm.

In the calculation of the external blue water resources, the data on state areas situated in river basins and the direction of rivers through the Indian states (Appendix XIX) are taken from Ministry of Water Resources (2006c).

The total annual inflow of water from other countries (China, Nepal and Bhutan) is taken to be 636 km^3 (FAO, 2006e). This estimate is for a large part based on one rough number (347 km^3) of the Chinese government, which represents the inflow from China to Jammu & Kashmir (Indus river basin) and Arunachal Pradesh (Brahmaputra river basin). Based on data of the weather stations in Jammu & Kashmir, it seems that the eastern part of this state, where the Indus enters the country, receives very little rainfall. It is worth noticing that the highest Himalayan Range which is in India situated in the states of Himachal Pradesh and Uttaranchal seems to act as a precipitation barrier. This conclusion is based on data from weather stations in the involved states and the annual rainfall map of India. The assumption is made that the precipitation in the far western part of Tibet, where the Indus springs from, is of the same magnitude as in the eastern part of Jammu & Kashmir. This assumption lead to the estimate that 20 km^3 of water annually enters India through the Indus river basin (10 km^3 in the Indus and 10 km^3 in the Satluj tributary). This estimate means that a volume 327 km^3 of water flows from China to India through the Brahmaputra basin. The inflow from Nepal and Bhutan is estimated at 210 km^3 and 90 km^3 (FAO, 2006e). The inflow from Nepal enters India in the states Uttar Pradesh and Bihar and is thereby part of the Ganges river basin. FAO estimates that the distribution is 80 km^3 to Uttar Pradesh and 130 km^3 to Bihar. The inflow from Bhutan contributes entirely to the Brahmaputra basin though the states West Bengal and Assam. In this study the assumption is made that the distribution is 15 km^3 to West Bengal and 75 km^3 to Assam, which is based on the percentage of the total area of Bhutan that contribute to the two Indian states.

4. Virtual water content of crops

4.1 Virtual water content of the primary crops

The blue, green, gray and total virtual water content of the primary crops is tabulated by state in Appendix VIII. The virtual water content of crops that are grown during kharif (wet season) as well as rabi (dry season), is presented for kharif, rabi and the total of both seasons, which is the average of both seasons weighted by the seasonal production in a state.

In general, the virtual water content of the crops is relatively lower in the northern and southern states and relatively higher in the western and eastern states. This variation in virtual water contents is largely determined by the difference in crop yield. This difference is mainly caused by the difference in development of the agricultural areas, which can be expressed in the form of a high or low fraction of irrigated area and a high or low fertilizer use. Another reason for a variation in the virtual water content of a crop is the difference in climate. In general, the influence of climate on the magnitude of the virtual water content is not very high. On one hand, a higher evapotranspiration rate leads to a higher crop water requirement and therefore to a higher crop water use, but on the other hand, a higher evapotranspiration rate leads to a higher biomass of the crop, which leads to a higher yield. However, with a lower crop yield, the non productive part of the evapotranspiration rate (the part that does not contribute to the biomass of the crop) is relatively higher and therefore the influence of the climate on the virtual water content is relatively higher.

The blue, green and gray component of the total water use is given by crop in Figure 4.1.

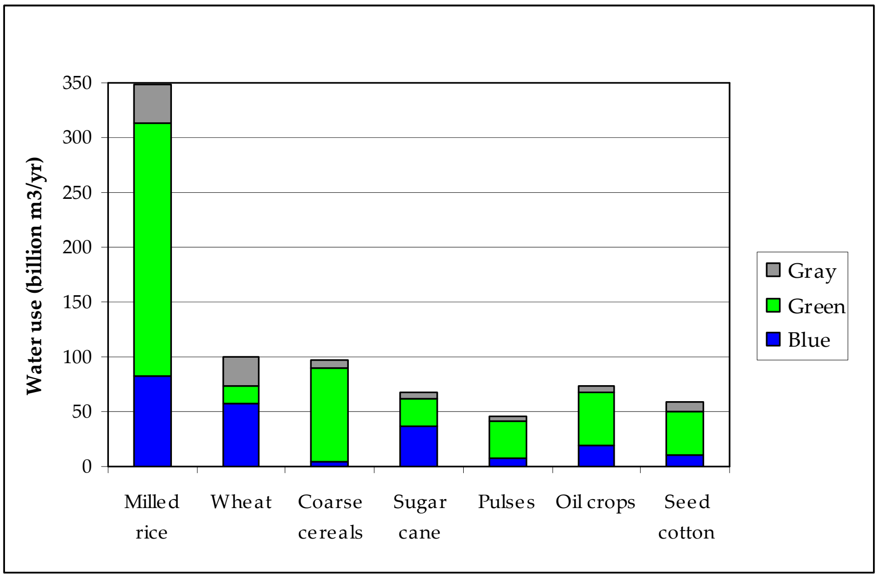

Figure 4.1: The blue, green and gray volume of water used in India for crop production in the period 1997-2001.

The total volume of water used in India for the production of the studied primary crops is 792 billion m^3/yr. The total blue water use is 219 billion m^3/yr, the total green water use 479 billion m^3/yr and the total gray water use billion 95 m^3/yr.

Figure 4.1 shows that the production of milled rice is responsible for a water use of 348 billion m^3/yr, which is 44% of the total water use, and that the production of wheat uses a water volume of 100 billion m^3/yr, which is 13% of the total water use. Furthermore Figure 4.1 shows that the water use in case of milled rice consists mainly (67%) of green water and that the water use in case of wheat consists mainly (58%) of blue water.

According to Directorate of Economics and Statistics (2003), the average nitrate use in India during the study period is 11.2 billion kg N/yr. Applying the leaching factor of 10% and a recommended level of 10 mg N/l, this translates in a total gray water use of 112 billion m^3/yr for the dilution of the total nitrate consumption in the Indian agriculture. This means that 85% of the total gray water use is represented in this study. Since this gray water use is based on the average nitrate use for crops in whole India, the calculated gray water use is compared to the total nitrate consumption per state (Directorate of Economics and Statistics, 2003). This comparison shows that the gray water use in Andhra Pradesh, Karnataka and Punjab is underestimated in this study and that the gray water use is Madhya Pradesh, Chhattisgarh, Orissa and Rajasthan is overestimated (Appendix IX).

In this study, the crops grown in the dry season (rabi) in non irrigated areas receive too little water during the growth period, which results in an underestimation of the virtual water content of a crop (Appendix VIII). The first reason for this underestimation of crop water use is the fact that a crop might be grown in a part of a state which receives more precipitation than the state average precipitation, which is used in this study. An example of this is the growth of soybean in Rajasthan under rain fed conditions, which takes place in the relatively wet south eastern part of the state. Another reason might be an incorrect assessment of the growth periods of the crops in the different states, which are in this study taken to be the same for all states. A third reason can be the fact that there might still be green water available in the soil after the monsoon, which is not taken into account in this study.

4.2 *Virtual water content of milled rice*

Because milled rice is the crop with the largest contribution to the water use in India, the virtual water content of milled rice is described here with more detail.

The virtual water content of milled rice varies from 2914 m^3/ton in Punjab to 8142 m^3/ton in Madhya Pradesh, with a national average of 4073 m^3/ton. The wide range in the virtual water content of milled rice in India is mainly caused by differences in crop yield, which has a large correlation with the fraction of the crop area under irrigation (Appendix X).

The yield of milled rice grown under rain fed conditions is considerably lower than the yield of milled rice grown under irrigated conditions, which is caused by a higher potential yield of the variety that is grown under irrigation, which requires a high level of irrigation and a high fertilizer use (Directorate of Rice Development, 2006c).

The variation of the virtual water content of milled rice over the Indian states is shown in Figure 4.2.

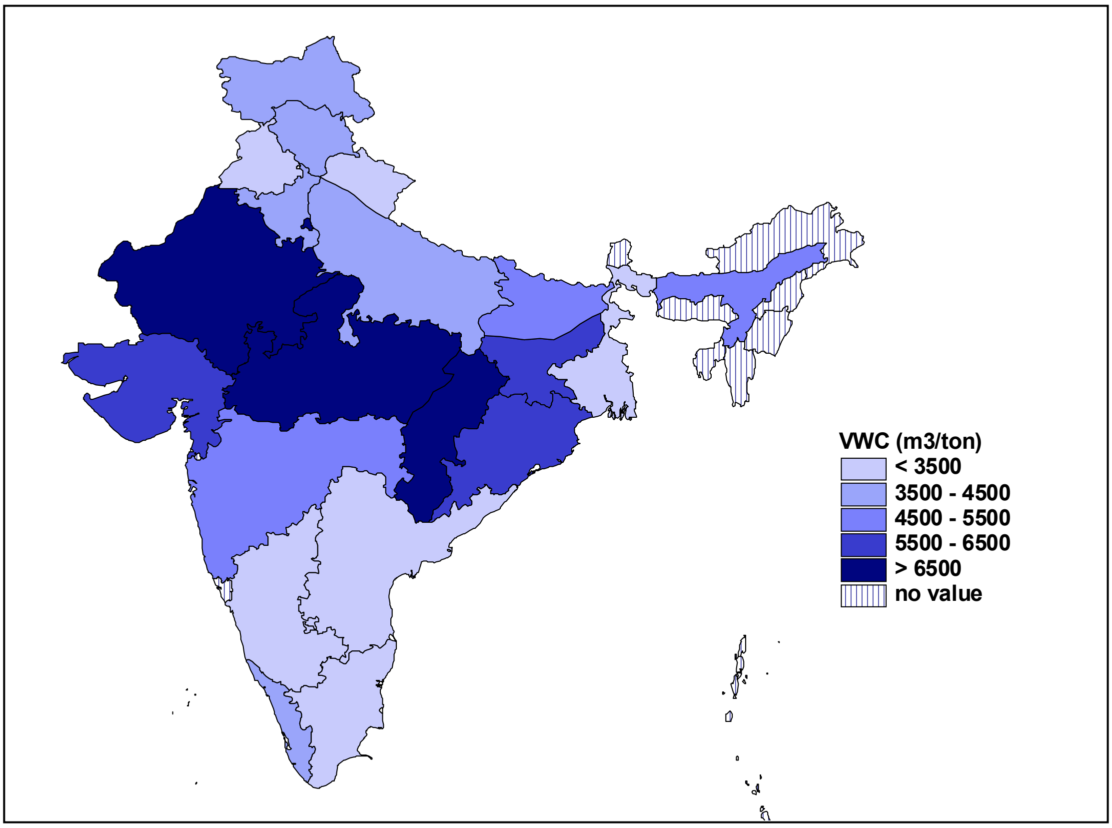

Figure 4.2: The total virtual water content of milled rice in the Indian states during the period 1997-2001.

Comparable states like Punjab and Haryana have a significant difference in the virtual water content of milled rice, because in this study no distinction is made between basmati rice and non basmati rice in the irrigated areas in North India. Basmati rice, only grown in North India, requires relatively more water than non basmati rice (Directorate of Rice Development, 2006a, 2006b) and the fraction basmati rice to the total rice production is considerably larger in Haryana than in Punjab.

Finally, it is worth noticing that milled rice is grown during two seasons in East India. In the dry season the yields are relatively higher, because milled rice is grown under irrigation in this season. With this extra season, the total virtual water content is reduced a little in the eastern states.

4.3 *Comparison with other studies*

The average virtual water content for whole India as calculated in this study (Appendix VIII) and as calculated by Chapagain & Hoekstra (2004) are presented for the studied crops in Table 4.1.

It should be noted that the values as calculated by Chapagain & Hoekstra do not include the gray component of the virtual water content and should therefore be compared with the sum of the blue and the green component as calculated in this study.

Table 4.1: Average virtual water content for the studied primary crops in India[1]

Crop	Season	Virtual water content				Chapagain & Hoekstra[2]
		Blue	Green	Gray	Total	
Unit		m³/ton				
Year		1997-2001				
Milled rice	Kharif	775	3086	430	4290	-
	Rabi	2093	330	344	2767	-
	Total	963	2692	417	4073	4113
Wheat	Rabi	822	214	376	1412	1654
Maize	Kharif	75	2281	231	2587	-
	Rabi	780	351	210	1342	-
	Total	182	1989	228	2399	1937
Millet	Kharif	56	3892	273	4222	3269
Sorghum	Kharif	27	4163	282	4473	-
	Rabi	690	1149	496	2335	-
	Total	301	2918	370	3589	4053
Sugar cane	Rabi	126	91	18	234	159
Chickpeas	Rabi	1159	598	314	2071	2712
Pigeon peas	Kharif	127	5497	297	5922	4066
Dry beans	Kharif	233	8597	662	9492	-
	Rabi	533	1484	445	2463	-
	Total	313	6706	604	7623	8335
Soybean	Kharif	23	3308	196	3526	4124
Groundnut in shell	Kharif	95	4356	243	4694	-
	Rabi	2715	381	218	3315	-
	Total	705	3430	237	4372	3420
Rapeseed	Rabi	2553	635	785	3972	2618
Seed cotton	Kharif	1887	7300	1446	10633	8264

[1] Source: Appendix VIII, [2] Total virtual water content as calculated by Chapagain & Hoekstra (2004).

From our current study results, the conclusion can be made that in the case of some crops, there is a significant difference between the values as calculated by Chapagain & Hoekstra and values as calculated in this study. It is interesting to know what assumptions in both studies caused this difference.

The following general conclusions on the differences between the two studies can be made:

- Chapagain & Hoekstra use only one set of monthly values of ET_0 for entire India. For the crops that are not grown all over India, this leads to different values. Wheat for example is mostly grown in northern India, where it can get relatively cold in the dry winter season. Therefore the average crop water requirement of wheat in India is determined at 304 mm in this study against 438 mm in the study of Chapagain & Hoekstra.
- For some crops other growth periods are used in this study, which leads to a different ET_c.
- Chapagain & Hoekstra assume the irrigated area is 100%, while in fact this is not the case, because a significant part of the crops grown in India are rain fed. This leads to lower values of the water use in this study.
- Chapagain & Hoekstra add extra water to the crop water requirement of milled rice to compensate for the high level of percolation. In this study this is not done, since percolated water does not leave the water system and is therefore not considered as lost.

Furthermore, the blue water use as calculated in this study can be compared with a study on irrigation water use (Rosegrant et al., 2002), in which the irrigation water consumption in India in 1995 is estimated at 321 billion m³/yr. This is 47% higher than the value calculated in this study. Two possible reasons for this significant difference can be the exclusion of irrigation water losses in this study and the exclusion of approximately 20% of the crops.

5. Interstate and interregional virtual water flows

5.1 *Interstate and international product trade*

The production, consumption and surplus of crops are given for the Indian states in Appendix XI. Furthermore, the distribution of the international and interstate trade of the Indian states is described in Appendix XII.

In general, a high production of a crop in a state means a high consumption of that crop in that state. For example, millets and sorghum grow well in dry areas and it no coincidence that the production and consumption of millets and sorghum is high in the dry western part of India. An exception to this rule is the production of rice in the northern states, where the production is high and the consumption relatively low.

In Table 5.1, the total production, interstate trade and net import of the crops are given. It can be seen that milled rice, wheat and sugar cause the largest interstate trade in India.

Table 5.1: National production, interstate trade and net national import of the studied crops

Crop	National production	Interstate trade	Net international import
Unit	Million ton/yr		
Year	1997-2001		
Milled rice	87.1	10.5	- 2.6
Wheat	70.6	13.3	0.1
Maize	11.7	0.3	0
Millet	10.1	1.7	0
Sorghum	7.9	0.9	0
- Total coarse cereals -	29.7	2.9	0
Raw sugar	30.1	8.7	0.1
Pulses[1]	13.4	2.2	0.8
Groundnut oil	1.6	0.3	0
Rapeseed oil	1.7	0.9	0.1
Remaining edible oils[2,3]	2.0	0.1	3.5
- Total edible oils -	5.3	1.3	3.6
Soybean cake[4]	5.0	-	- 2.5
Cotton lint	1.9	0.3	0.9

[1] Interstate trade in pulses consists of chickpeas only. [2] Remaining edible oils are soybean oil, sunflower seed oil, cottonseed oil and coconut oil. [3] Interstate trade in remaining edible oils consists of soybean oil only. [4] Trade in soybean cake consists of international trade only.

The crops with largest trade flows are milled rice, wheat and sugar. The main reason behind the magnitude of these flows is the Public Distribution System that exists for these crops. This system is controlled by the Indian government, which procures the crops mainly in northern states Punjab, Haryana, Uttar Pradesh. This is because these states have a developed trade infrastructure.

The largest interstate trade flows are created by the interstate trade in milled rice and wheat from Punjab to Bihar, Kerala and Maharashtra and from Uttar Pradesh to Bihar and Jharkhand (Appendix XII).

The largest international trade flows are caused by the export of soybean cake (from Madhya Pradesh) to South East Asia, the export of milled rice, and the international import of palm oil from Indonesia and Malaysia (FAO, 2006a).

5.2 *Interstate virtual water flows*

The net virtual water flows between the states are presented in Appendix XIII. The total interstate and international virtual water import and export from and to the Indian states together the net virtual water import is given in Table 5.2.

Table 5.2: Water use, virtual water flows and net import by state

States	Water use	Virtual water export		Virtual water import		Net VW import
		Interstate	International	Interstate	International[1]	
Unit	10^6 m^3/yr					
Year	1997-2001					
Andhra Pradesh	66652	4952	1711	569	774	-5319
Assam	17812	4	0	2304	155	2455
Bihar	38283	149	1	14469	983	15302
Chhattisgarh	27912	2835	699	2544	558	-431
Delhi	267	0	0	4026	683	4709
Gujarat	42678	3847	3120	9186	941	3160
Haryana	31956	13006	2105	638	339	-14134
Himachal Pradesh	2439	26	0	1439	212	1626
Jammu & Kashmir	4143	26	0	3101	178	3254
Jharkhand	11593	0	0	8853	430	9283
Karnataka	43358	3130	365	3699	214	418
Kerala	2897	0	2	10180	891	11069
Madhya Pradesh	64863	7671	8254	4933	162	-10831
Maharashtra	80390	5788	3949	11836	1461	3560
Orissa	37801	149	21	4552	416	4797
Punjab	43036	19351	4095	1658	914	-20874
Rajasthan	60169	9852	388	5504	512	-4224
Tamil Nadu	35496	4293	285	1397	967	-2214
Uttar Pradesh	127855	24542	2988	4777	1953	-20800
Uttaranchal	5581	1447	126	960	164	-449
West Bengal	47141	4447	1094	6238	749	1445
Total	792321	10551 6	29203	10551 6	13953	-15250

[1] *National import is blue and green water only (Chapagain & Hoekstra, 2004). Since no distinction is made between green and blue by Chapagain & Hoekstra, the total international virtual water import is contributed entirely to the blue external water footprint.*

The total virtual water flow as a result of interstate crop trade in India is 106 billion m^3/yr. This is 13% of the total water use. The export of virtual water is 29 billion m^3/yr (4% of the total water use) and the import of virtual water is 14 billion m^3/yr, which results in a net export of 15 billion m^3/yr. So in total 17% of the total volume of water used for crop production in India is exported to other states or countries.

In Table 5.2, it can be seen that the northern states Punjab, Haryana and Uttar Pradesh have a very high virtual water export and that the states Bihar, Jharkhand and Kerala have a very high virtual water import. The state with the largest net international export of virtual water is Madhya Pradesh. This is mainly caused by the international export of soybean cake from this state.

In Figure 5.1, the virtual water balances of the states are presented in the form of the net virtual water import. Furthermore, the net interstate virtual water flows larger than 2 billion m^3/yr are shown to indicate the largest interstate virtual water flows.

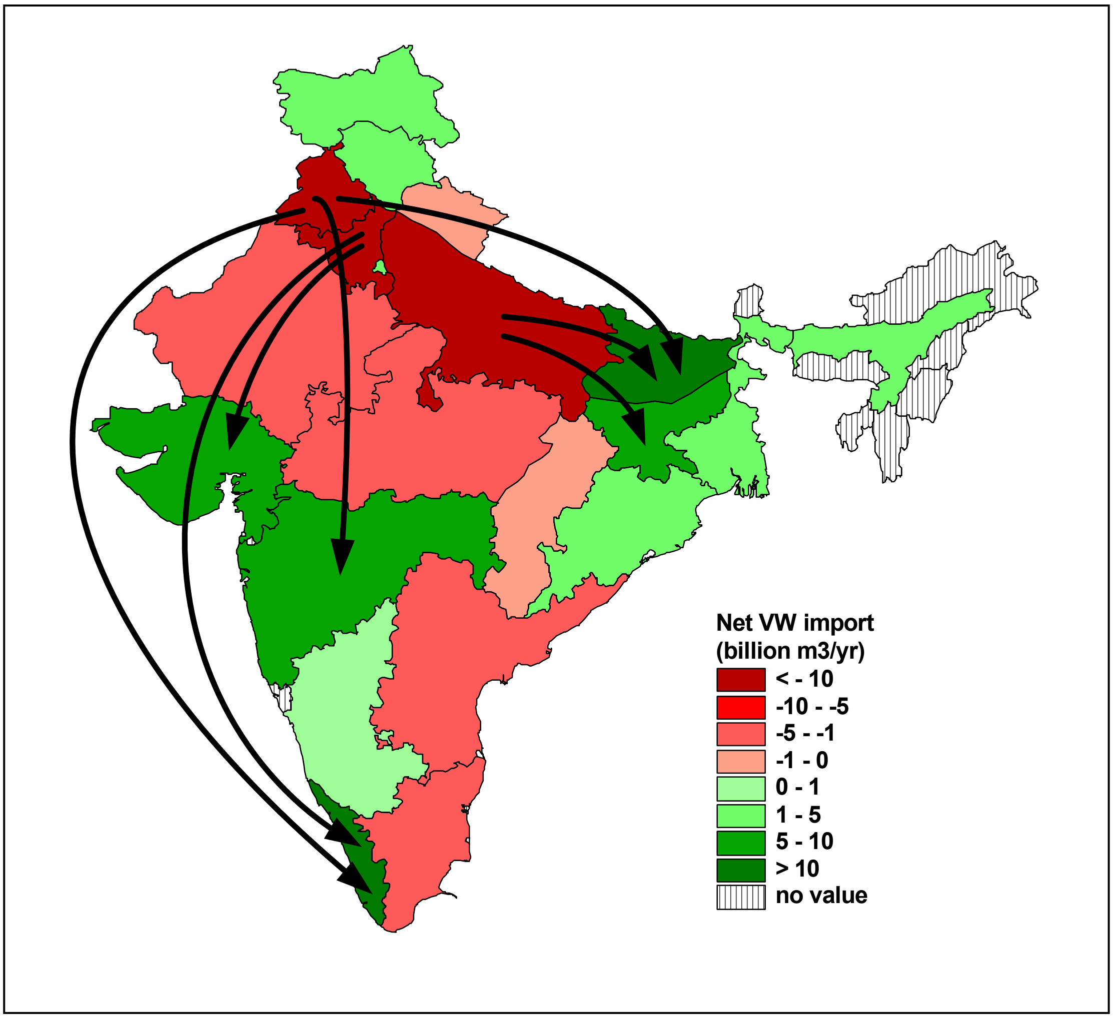

Figure 5.1: The net virtual water import of the Indian states and the largest net interstate virtual water flows (> 2 billion m^3/yr) during the period 1997-2001.

In Figure 5.1, it can be seen that the states with the highest net export of virtual water are directly connected with the states with the highest net import of virtual water by the largest net interstate virtual water flows between these states. The most striking large virtual water flows are the long distance flows from Punjab and Haryana to Bihar, Gujarat, Maharashtra and Kerala. This shows that Punjab and Haryana produce food for states all over India.

Furthermore, it is worth noticing that the states with a net virtual water export as well as the states with a net virtual water import are more or less grouped together. This may indicate a natural advantage or disadvantage through the geology, climate, population or consumption pattern of a region.

The contribution of the crops to the blue, green, gray and total interstate virtual water flow and net national virtual water import are presented in Table 5.3.

Table 5.3: Interstate virtual water flows and net national virtual water import by crop

Crop	Interstate virtual water flows				Net national
	Blue	Green	Gray	Total	VW import
Unit	Million m³/yr				
Year	1997-2001				
Milled rice	12790	20246	3829	36865	-9032
Wheat	6495	2686	3754	12936	670
Coarse cereals	313	10132	801	11245	-104
Raw sugar	9238	6895	1320	17453	100
Pulses[1]	3109	1217	724	5050	589
Edible oils[2]	7708	5107	2159	14974	8259
Soybean cake[3]	-	-	-	-	-8164
Cotton lint	1276	4762	953	6992	-7568
Total	40931	51044	13541	105516	-15250

[1] Interstate virtual water flow of pulses consists of chickpeas only. [2] Interstate trade of remaining edible oils consists of soybean oil only. [3] Trade of soybean cake consists of international trade only.

Table 5.3 shows that 35% of the interstate virtual water flow is due to interstate trade of milled rice, 17% due to interstate trade of raw sugar and 14% due to interstate trade of edible oils.

5.3 *Interregional virtual water flows*

The virtual water flows between the four large regions are calculated to show the rough direction of the virtual flows within India (Figure 5.2).

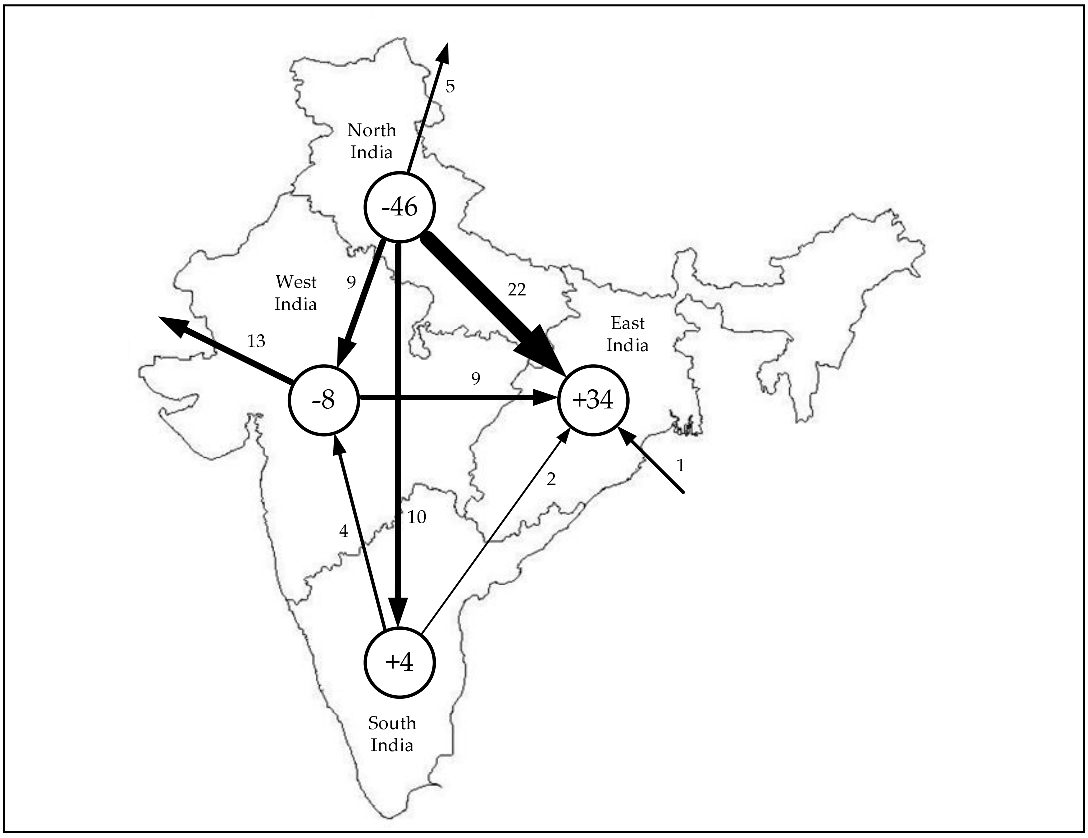

Figure 5.2: The net virtual water flows between the four regions of India in 10^9 m^3/yr during the period 1997-2001.

Figure 5.2 shows that the largest interregional virtual water flow is from North India to East India. This virtual water flow has a volume of 22 billion m^3/yr and consists for 54% of rice, for 21% of raw sugar and for 18% of wheat. Furthermore, this total water volume of 22 billion m^3/yr consists for 38% of blue water, 48% of green water and for 14% of gray water. The interregional virtual water flow from North to East India originates for 66% from Uttar Pradesh, 19% from Punjab and 13% from Haryana and is destined for 52% for Bihar, 29% for Jharkhand and 14% for West Bengal.

Table 5.2 and Figure 5.2 show a total net international export of virtual water of 15 billion m^3/yr. This shows a relatively good resemblance with the study of Chapagain & Hoekstra (2004), in which the net international export of virtual water is determined at 18 billion m^3/yr.

6. Water footprints

6.1 Water footprints of the Indian states

The total water footprint related to the consumption of agricultural commodities of India is 777 billion m^3/yr. With an average of one billion people living in India between 1997 and 2001, this leads to an average total water footprint per capita of 777 (m^3/yr).

The composition of the total water footprints of the Indian states is given in Table 6.1. Here, the use of internal and external resources is divided into blue, green and gray water use.

Table 6.1: Composition of water footprints related to the consumption of agricultural commodities of the Indian states

States	Use of internal water resources						Use of external water resources				WFP
	Blue	Green	Gray	Total	Exp[1]	SC[2]	Blue	Green	Gray	Total	
unit	10^9 m^3/yr										
year	1997-2001										
Andhra Pradesh	22	39	6	67	7	60	1	0	0	1	61
Assam	0	16	2	18	0	18	1	1	0	2	20
Bihar	9	24	5	38	0	38	7	6	2	15	54
Chhattisgarh	1	24	3	28	4	24	2	1	0	3	27
Delhi	0	0	0	0	0	0	3	1	1	5	5
Gujarat	12	26	5	43	7	36	3	6	1	10	46
Haryana	15	12	5	32	15	17	1	0	0	1	18
Himachal Pradesh	0	2	0	2	0	2	1	1	0	2	4
Jammu & Kashmir	1	3	1	4	0	4	2	1	0	3	7
Jharkhand	1	9	1	12	0	12	3	5	1	9	21
Karnataka	11	29	4	43	3	40	1	3	0	4	44
Kerala	0	2	0	3	0	3	6	4	1	11	14
Madhya Pradesh	14	42	8	65	16	49	2	3	0	5	54
Maharashtra	14	58	8	80	10	71	6	6	2	13	84
Orissa	3	31	4	38	0	38	2	3	1	5	43
Punjab	19	17	7	43	23	20	2	1	0	3	22
Rajasthan	21	31	8	60	10	50	3	3	1	6	56
Tamil Nadu	14	18	3	35	5	31	2	0	0	2	33
Uttar Pradesh	49	60	18	128	28	100	4	2	1	7	107
Uttaranchal	1	4	1	6	2	4	1	0	0	1	5
West Bengal	10	32	5	47	6	42	4	2	1	7	49
Total	219	479	95	792	135	658	55	51	14	119	777

[1] *Exp = Total use of internal water resources for export,* [2] *SC = Total use of internal water resources for state consumption.*

Table 6.2 shows the internal, external and total water footprints as a total and per capita.

Table 6.2: The internal and external water footprints of the Indian states

States	Population	Water footprint in relation to the consumption of agricultural commodities					
		Internal	External	Total	Internal	External	Total
unit	10^6	10^9 m^3/yr			m^3/cap/yr		
year	1997-2001						
Andhra Pradesh	74	60	1	61	810	18	828
Assam	26	18	2	20	687	95	782
Bihar	81	38	15	54	473	192	664
Chhattisgarh	20	24	3	27	1204	153	1357
Delhi	13	0	5	5	20	350	370
Gujarat	49	36	10	46	725	206	931
Haryana	21	17	1	18	820	48	867
Himachal Pradesh	6	2	2	4	408	280	688
Jammu & Kashmir	10	4	3	7	417	333	750
Jharkhand	26	12	9	21	443	354	797
Karnataka	51	40	4	44	776	76	852
Kerala	31	3	11	14	94	358	451
Madhya Pradesh	59	49	5	54	834	87	921
Maharashtra	94	71	13	84	750	141	891
Orissa	36	38	5	43	1052	139	1191
Punjab	24	20	3	22	827	109	936
Rajasthan	55	50	6	56	909	110	1018
Tamil Nadu	61	31	2	33	510	39	549
Uttar Pradesh	162	100	7	107	621	42	663
Uttaranchal	8	4	1	5	486	136	622
West Bengal	78	42	7	49	534	90	623
Total	1000	658	119	777	658	119	777

Table 6.2 shows that 85% of the total average water footprint is covered by the internal component and the remaining 15% is covered by the external component.

The major determinants of the magnitude of the water footprint of a state are (Chapagain & Hoekstra, 2004):

- the average consumption volume per capita, generally related to gross income per state,
- the consumption pattern of the inhabitants of the state,
- climate, in particular evaporative demand, and
- agricultural practice

The relation between the water footprint and the consumption volume is quantified by comparing the water footprint to the average income per capita per state during our study period (Appendix XV). The outcome of this comparison shows no significant relation between the two parameters.

The relation between the water footprint and the consumption pattern is quantified later on by comparing the contribution of the crops to the water footprints by state.

Next, the relation between the water footprint and the climate is quantified by comparing the water footprint to the evaporative demand in a state (Appendix XV). The outcome of this comparison shows no significant relation between the two parameters.

The relation between the water footprint and agricultural practice is already assessed in Chapter 4, where the reasons for low water productivity in a state are addressed. A low water productivity leads to a relatively high internal water footprint of a state.

The variation in water footprints per capita between the Indian states is shown in Figure 6.1.

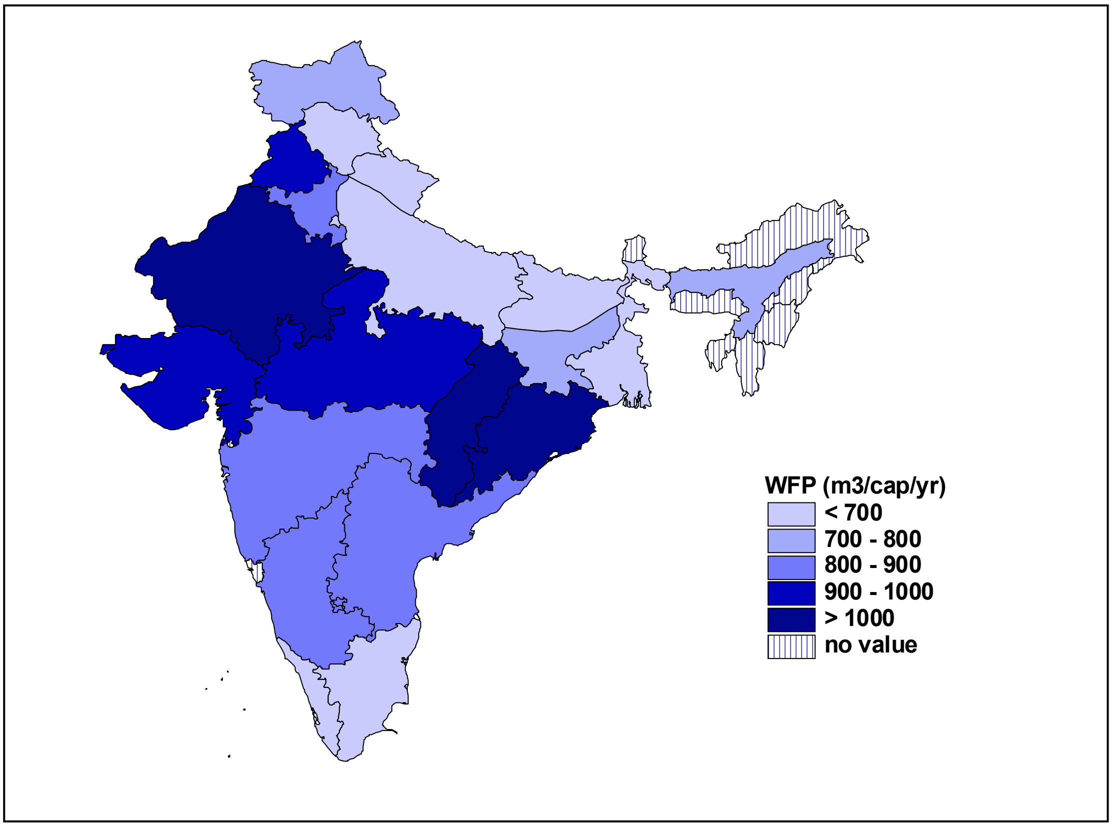

Figure 6.1: Water footprints of the Indian states per capita

The three states with the highest water footprint per capita are Chhattisgarh and Orissa in eastern India and Rajasthan in Western India. These states have a high water footprint, because the water productivity is low (Chapter 4) and the virtual water import is low (Chapter 5). In these states the water productivity is low, because of inefficient agricultural practice.

The lowest water footprints are found in the southern states Kerala and Tamil Nadu and in the national territory of Delhi. One reason for the low water footprints of Kerala and Tamil Nadu is the exclusion of coconut, which is part of the staple food in these states, in this study. Especially in the case of Kerala, this is main reason for the low internal water footprint. Kerala produces approximately half of the national coconut production (Directorate of Economics and Statistics, 2003, 2004). According to Chapagain & Hoekstra (2004) this would mean a water volume of around 10 billion m^3/yr used for the production of coconut in Kerala. Assuming that most of the coconut is consumed within Kerala, this would mean a significant increase of the internal water footprint, which is determined at 3 billion m^3/yr in this study. Furthermore, it should be noted that the water footprints of Kerala and Tamil Nadu are also relatively low as a result other local staple food, like the starchy root cassava, which has a low virtual water content. The reason for this is that a relatively large part of starchy roots is edible.

The water footprint in Delhi is low because of the large percentage of the population living in urban area. Since a large part of the crops in Delhi are consumed as processed products, the intermediate consumption is high and the reported consumption low.

6.2 Water footprint by colour

In Figure 6.2, the blue, green and gray components of the water footprints per capita are presented by state. The blue, green and gray water footprints of the states are tabulated in Appendix XIV.

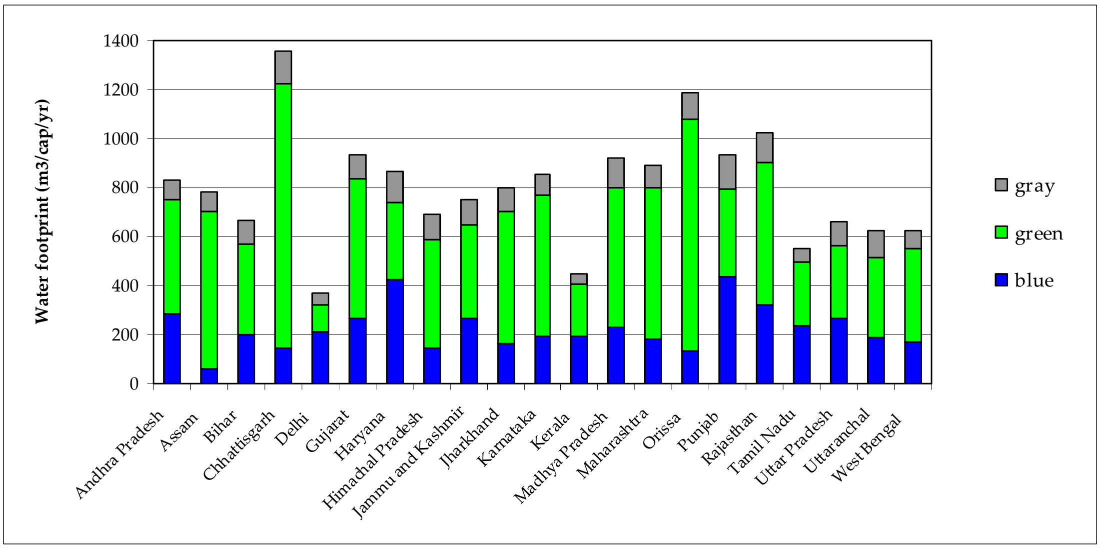

Figure 6.2: Water footprints per capita and the contribution of the water colours for the Indian states during the period 1997-2001.

Figure 6.2 shows that the two states with the highest total water footprint, Chhattisgarh and Orissa, have the highest green water footprint, but one of the lowest blue water footprint. Furthermore, Figure 6.2 shows that Punjab and Haryana have the highest blue water footprint, but have a relatively low green water footprint.

The total water footprint of India of 777 billion m^3/yr consists for 227 billion m^3/yr (29%) of blue water, for 459 billion m^3/yr (59%) of green water and for 92 billion m^3/yr (12%) of gray water.

It is worth noticing that the calculated water footprint in this study is based on the consumption of approximately 82% of the crop production (see chapter 3.2). In the study of Chapagain & Hoekstra (2004), the total water footprint of the consumption of agricultural commodities of India is assessed at 927 billion m^3/yr. 82% of this value is 760 billion m^3/yr. Since the gray component is not taken into account in the study of Chapagain & Hoekstra, this value is compared to the sum of the blue and the green component of the water footprint in this study, which is 685 billion m^3/yr. This shows that the water footprint of India in this study is 10% lower than the water footprint as calculated by Chapagain & Hoekstra (2004). A reason for this lower value in the current study can be the fact that the actual water use is calculated, while Chapagain & Hoekstra (2004) calculated the optimal water use.

6.3 *Water footprint by crop*

Besides the distinction between the blue, green and gray water footprint, the total water footprint can be divided into the water footprint of the individual crops.

The contribution of the studied crops to the water footprints of the Indian states are presented in Figure 6.3.

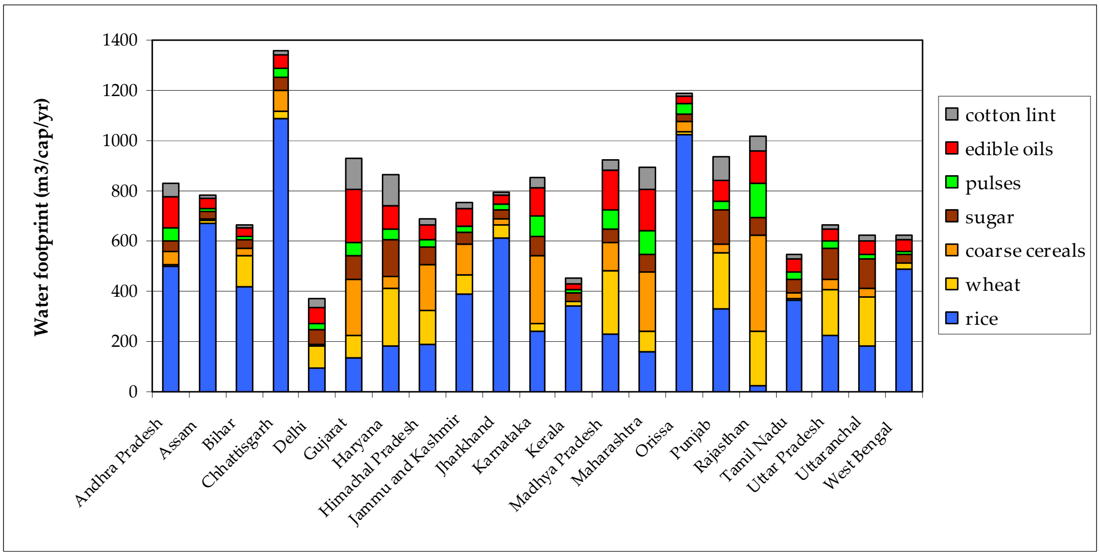

Figure 6.3: Water footprints per capita and the contribution of the different crops for the Indian states during the period 1997-2001.

Figure 6.3 shows that there is a relation between the water footprint and consumption pattern. The water footprint is significantly influenced by the fact that the staple food in a state consists of rice or wheat, or the fact that there is a high or low level of oil and sugar consumption. The magnitude of the water footprint of a state is determined by the average virtual water content of the crops that are consumed in that state.

6.4 *Water footprint by region*

The internal, external and total water footprint of the four regions of India is given as a total and per capita in Table 6.3. In the calculation of the water footprint of a region, the interstate virtual water flows within a region are considered as part of the internal water footprint.

Table 6.3: Water footprints of the consumption of agricultural commodities of the Indian regions

States	Total state region footprint			Water footprint per capita		
	Internal	External	Total	Internal	External	Total
unit	10^9 m^3/yr			m^3/cap/yr		
year	1997-2001					
North	154	15	169	632	62	694
East	175	41	215	655	153	808
West	211	29	240	820	113	933
South	137	16	153	629	75	704
Total	658	119	777	658	119	777

The region with the highest water footprint is West India. This is mainly because of the combination of a low water productivity, a low development of agricultural practice and a high evapotranspiration rate in this region.

6.5 Water scarcity

The total water resources of the Indian states are given in Appendix XVIII as a state total and by capita. The interstate water flows are given by river basin in Appendix XIX.

Figure 6.4 shows the current total water scarcity per capita from consumption perspective, which is the total water footprint divided by the total water resources.

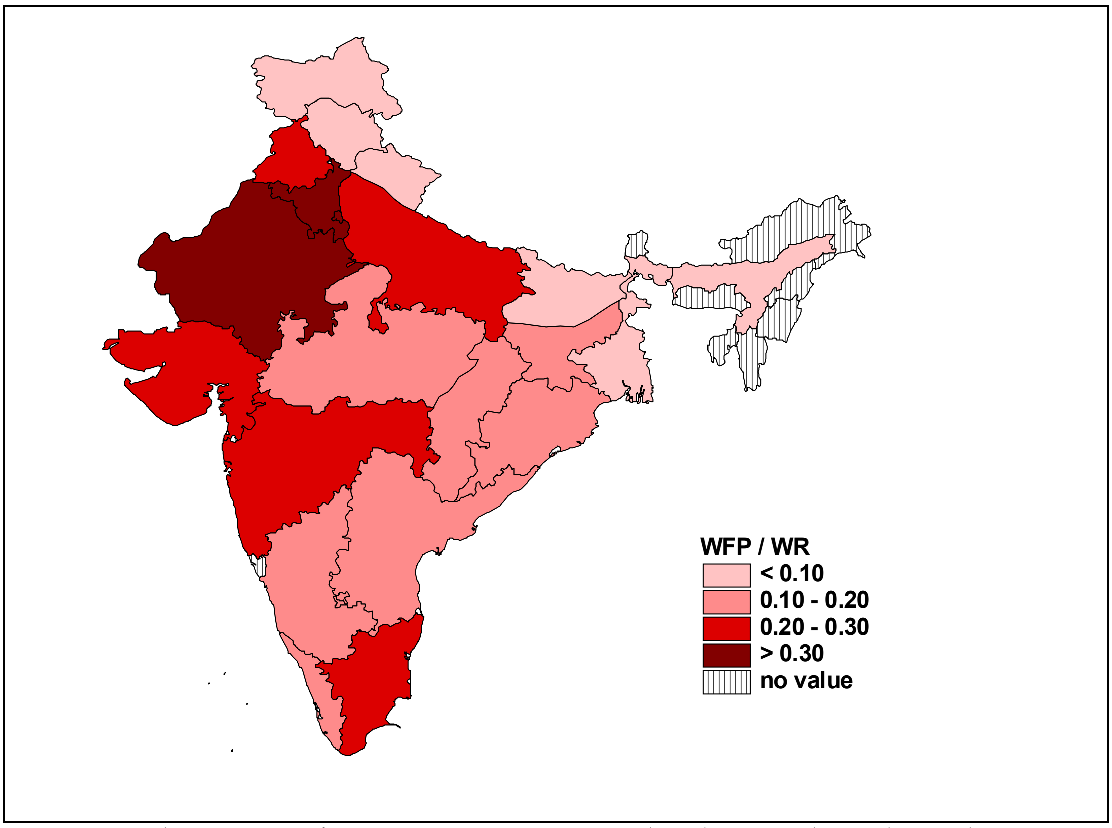

Figure 6.4: Total water scarcity from consumption perspective in the Indian states during the period 1997-2001.

Figure 6.4 shows that the total water scarcity from a consumption perspective is the highest is Rajasthan and Haryana. Furthermore the water scarcity is relatively high is Punjab, Uttar Pradesh, Gujarat, Maharashtra and Tamil Nadu. Since the water productivity is relatively high in most of these areas, these states can be considered as naturally scarce.

The lowest water scarcity from consumption perspective can be found in the mountainous areas and in Bihar and West Bengal. The utilizable percentage of the water resources is relatively low in these states. In the mountainous areas this is due to a lack of storage and agricultural area and in Bihar and West Bengal, most of the water resources consist of external water in the form of the discharge of Ganges. The discharge in the Ganges is the highest during the monsoon season, in which often flooding occurs in Bihar and West Bengal and the additional water is not usable.

The green, blue and total water scarcity from a production and consumption perspective is given by state in Table 6.4.

Table 6.4: blue and green water scarcity from consumption and production perspective

	Water scarcity					
	Consumption perspective			Production perspective		
States	Blue	Green	Total	Blue	Green	Total
unit	—					
year	1997-2001					
Andhra Pradesh	0.10	0.18	0.13	0.10	0.21	0.14
Assam	0.01	0.22	0.03	0.00	0.21	0.02
Bihar	0.05	0.47	0.10	0.03	0.38	0.07
Chhattisgarh	0.05	0.24	0.13	0.04	0.26	0.14
Delhi	14.37	1.89	4.85	0.70	0.12	0.26
Gujarat	0.13	0.32	0.20	0.12	0.29	0.19
Haryana	0.52	0.28	0.40	0.90	0.54	0.71
Himachal Pradesh	0.02	0.07	0.04	0.01	0.05	0.02
Jammu & Kashmir	0.07	0.04	0.05	0.03	0.03	0.03
Jharkhand	0.10	0.26	0.17	0.03	0.17	0.10
Karnataka	0.10	0.21	0.15	0.10	0.20	0.15
Kerala	0.11	0.17	0.13	0.01	0.06	0.03
Madhya Pradesh	0.11	0.20	0.15	0.12	0.25	0.18
Maharashtra	0.17	0.32	0.25	0.15	0.33	0.24
Orissa	0.05	0.27	0.14	0.03	0.25	0.12
Punjab	0.24	0.32	0.26	0.45	0.65	0.51
Rajasthan	0.54	0.24	0.32	0.63	0.24	0.35
Tamil Nadu	0.29	0.17	0.22	0.29	0.19	0.23
Uttar Pradesh	0.18	0.34	0.23	0.20	0.43	0.27
Uttaranchal	0.05	0.07	0.06	0.04	0.10	0.07
West Bengal	0.03	0.41	0.07	0.03	0.43	0.07
Total India	0.14	0.22	0.18	0.13	0.23	0.18

Table 6.4 shows that the national blue, green and total water scarcity from consumption perspective closely matches the national blue, green and total water scarcity from production perspective. This is because the net international export of virtual water is relatively small in India.

The high blue water scarcity from production perspective in Punjab, Haryana, Rajasthan and Tamil Nadu is line with the current status on water scarcity in the Indus, Luni and Cauvery river basins (Bobba et al., 1997; Rosegrant et al., 2002; Gupta & Deshpande, 2004; Falkenmark, 2005).

In Table 6.4, it can be seen that the states with a high water scarcity from production perspective, Haryana, Punjab and Rajasthan, also have a relatively high water scarcity from consumption perspective.

6.6 *Global water saving as a result of interstate trade*

The global water saving as a result of interstate trade in crops during the study period is given for the Indian states by colour and as a net total in Table 6.5.

Table 6.4: Net blue, green, gray and total global water saving as a result of interstate trade by crop

Crop	Blue	Green	Gray	Total
Unit		million m³/yr		
Year		1997-2001		
Milled rice	-2490	14108	1339	12957
Wheat	17241	1235	4349	22824
Maize	-18	363	33	378
Millet	10	1536	135	1680
Sorghum	106	-2816	-86	-2796
Raw sugar	3795	1972	492	6259
Pulses	-1238	428	-63	-872
Groundnut oil	196	-18	6	184
Rapeseed oil	-2495	2661	765	931
Remaining edible oil	5	-71	-2	-68
Cotton lint	-38	31	-4	-11
Total	15074	19429	6964	41466

In total, a net water volume of 41 billion m^3/yr is globally saved as a result of interstate trade in agricultural commodities in India. This means the total water use in Indian agriculture is 5% lower than it would have been without interstate trade. The total global water saving consists for 36% of blue water, 47% of green water and 17% of gray water.

The interstate trade in wheat is responsible for a net total global water saving of 23 billion m^3/yr. An example of this is shown in Figure 6.5, in which the water saving is given as a total and by colour.

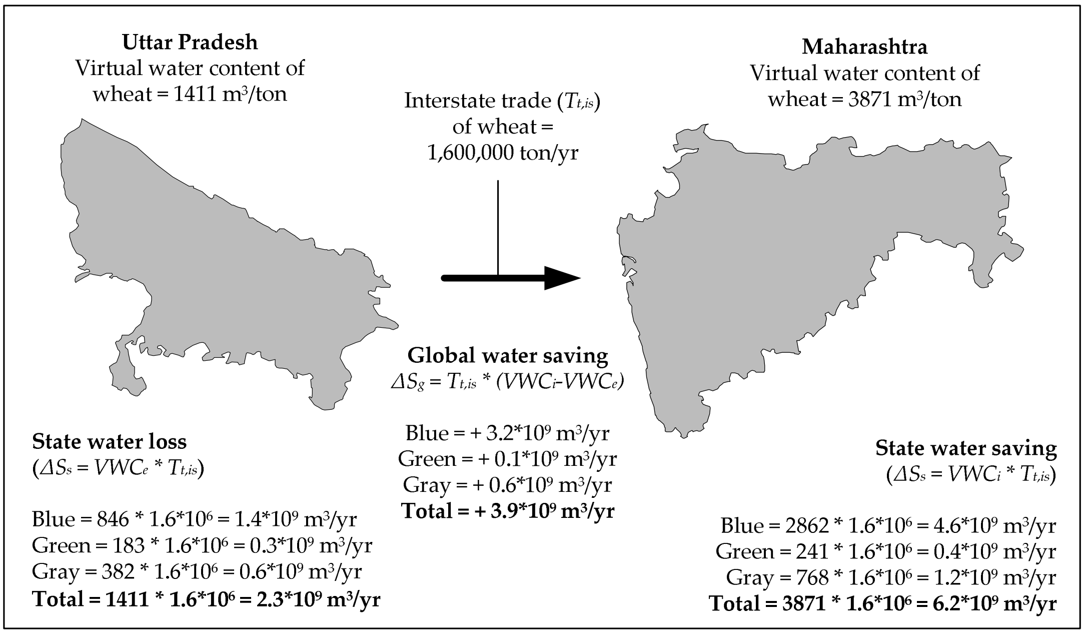

Figure 6.5: Global water saving as a result of interstate trade in wheat between Uttar Pradesh and Maharashtra during the period 1997-2001.

In Figure 6.5, it can be seen that the global water saving as a result of the interstate trade in wheat between Uttar Pradesh and Maharashtra is 3.9 billion m^3/yr. This total water saving consists mainly of global blue water saving, which corresponds with the findings presented in Table 6.5. The reason for the large blue component is simply because wheat is grown during the dry season, when the green water availability is low.

The interstate trade in milled rice is responsible for a net total global water saving of 13 billion m^3/yr. An example of this is shown in Figure 6.6, in which the global water saving is given as a total and by colour.

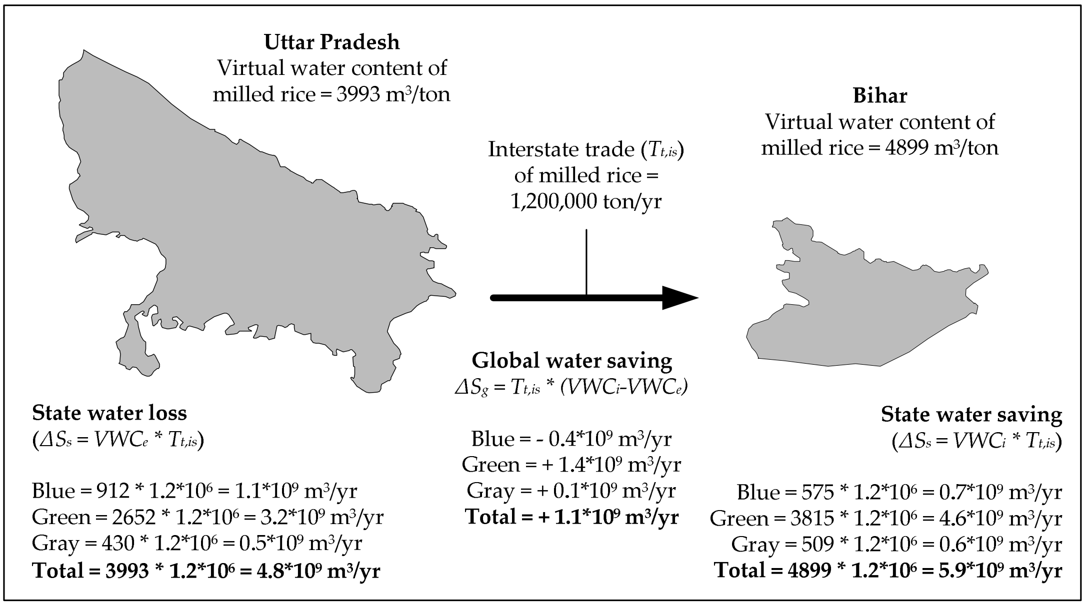

Figure 6.6: Global water saving as a result of interstate trade in milled rice between Uttar Pradesh and Bihar during the period 1997-2001.

Figure 6.6 shows that the global water saving as a result of the interstate trade in milled rice from Uttar Pradesh to Bihar is 1.1 billion m^3/yr. Figure 6.6 and Table 6.5 show that interstate trade in milled rice leads to global green and gray water saving, but to global blue water loss.

The interstate trade in raw cane sugar is responsible for a net total global water saving of 6 billion m^3/yr. In Figure 6.7 shows an example of water saving by colour and as a total, in which the interstate trade in raw cane sugar leads to global water loss.

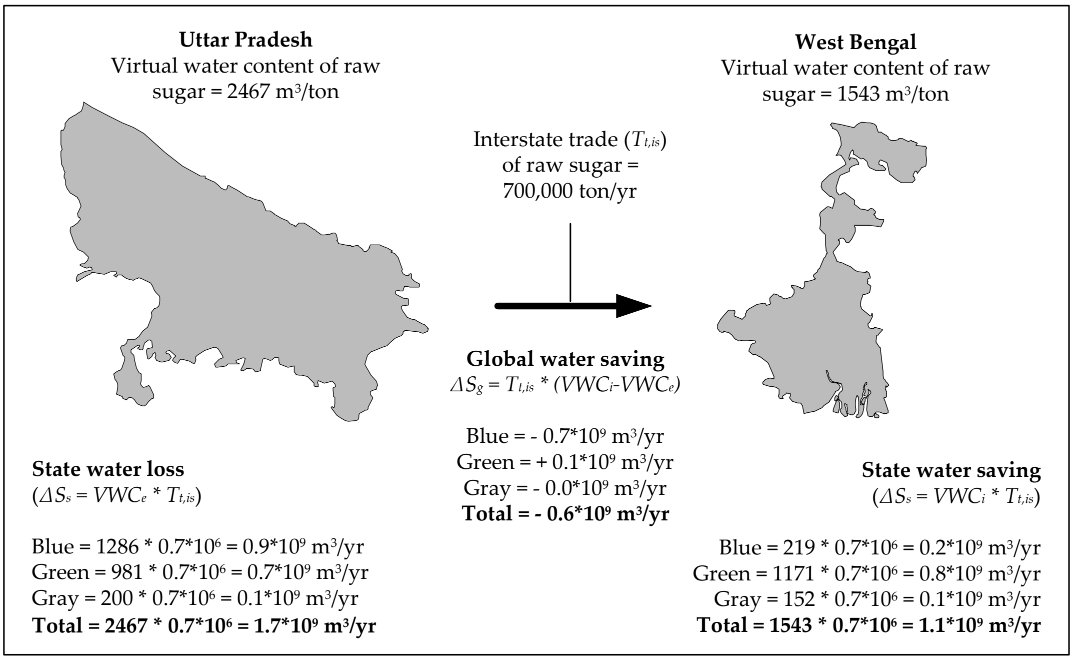

Figure 6.7: Global water saving as a result of interstate trade in raw cane sugar between Uttar Pradesh and West Bengal during the period 1997-2001.

In Figure 6.7, it can be seen that the interstate trade in raw cane sugar between Uttar Pradesh and West Bengal leads to a global water loss of 0.6 billion m^3/yr. Figure 6.7 and Table 6.4 show that interstate trade in raw cane sugar leads to global blue water saving, but to a green and gray global blue water loss.

In the case of sorghum and pulses, the interstate trade leads to considerable net global water loss. The interstate trade in sorghum is responsible for a net total global water loss of 3 billion m^3/yr. An example of this is shown in Figure 6.8, in which the global water saving is given as a total and by colour.

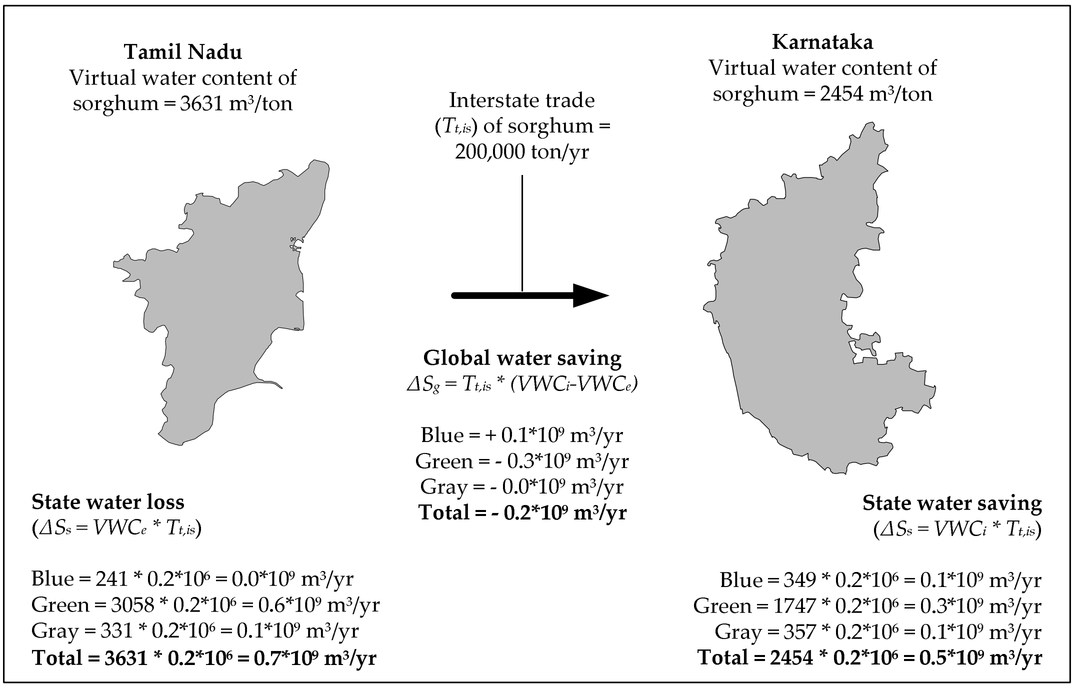

Figure 6.8: Global water loss as a result of interstate trade in sorghum between Tamil Nadu and Karnataka during the period 1997-2001.

Figure 6.8 shows that the interstate trade in sorghum between Tamil Nadu and Karnataka leads to a global water loss of 0.2 billion m^3/yr. Figure 6.8 and Table 6.4 show that interstate trade in sorghum leads to global green and gray water loss, but to global blue water saving.

6.7 Water saving as a result of comparative advantage in water productivity

The interstate trade in crops that leads to a global water loss can still be justified from a water management perspective with the theory of comparative advantage.

The state of Rajasthan has an absolute disadvantage in the water productivity of most of its crops. This is because of a dry hot climate in combination with a low development of agricultural practice. When only absolute advantages in water productivity are observed, the conclusion would be that the export of most crops leads to global water loss and that water will be saved when this export of virtual water from Rajasthan is stopped.

The theory of comparative advantage shows that the elimination of export of virtual water from Rajasthan does not necessarily lead to water saving. This is because the theory of comparative advantage focuses on relative advantages in water productivity instead of absolute advantages in water productivity. The logic behind this theory is that when a state has an absolute disadvantage in water productivity of all crops, the maximum global benefit from the state water resources is created when these water resources are used to produce the crop, of which the water productivity has the least absolute disadvantage.

In the period 1997-2001, Rajasthan exported 0.10 million ton/yr of chickpeas to Punjab and 0.12 million ton/yr of rapeseed oil to Uttar Pradesh and imported 0.40 million ton/yr of wheat from Punjab and 0.50 million ton/yr of raw sugar from Uttar Pradesh.

The global water saving as a result of interstate trade in chickpeas and wheat between Rajasthan and Punjab is shown in Figure 6.9.

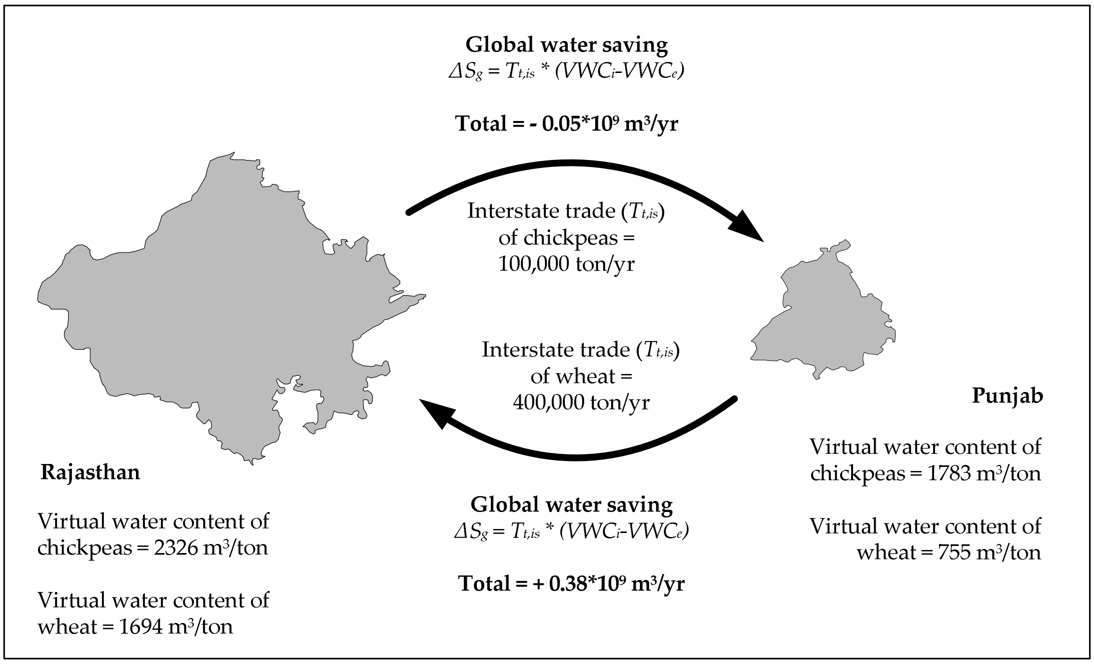

Figure 6.9: Global water savings as a result of interstate trade in chickpeas and wheat between Rajasthan and Punjab the period 1997-2001.

Figure 6.9 shows that the interstate trade in wheat from Punjab to Rajasthan leads to global water saving and that the interstate trade in chickpeas from Rajasthan to Punjab leads to global water loss.

The global water saving as a result of interstate trade in rapeseed oil and raw sugar between Rajasthan and Uttar Pradesh is shown in Figure 6.10.

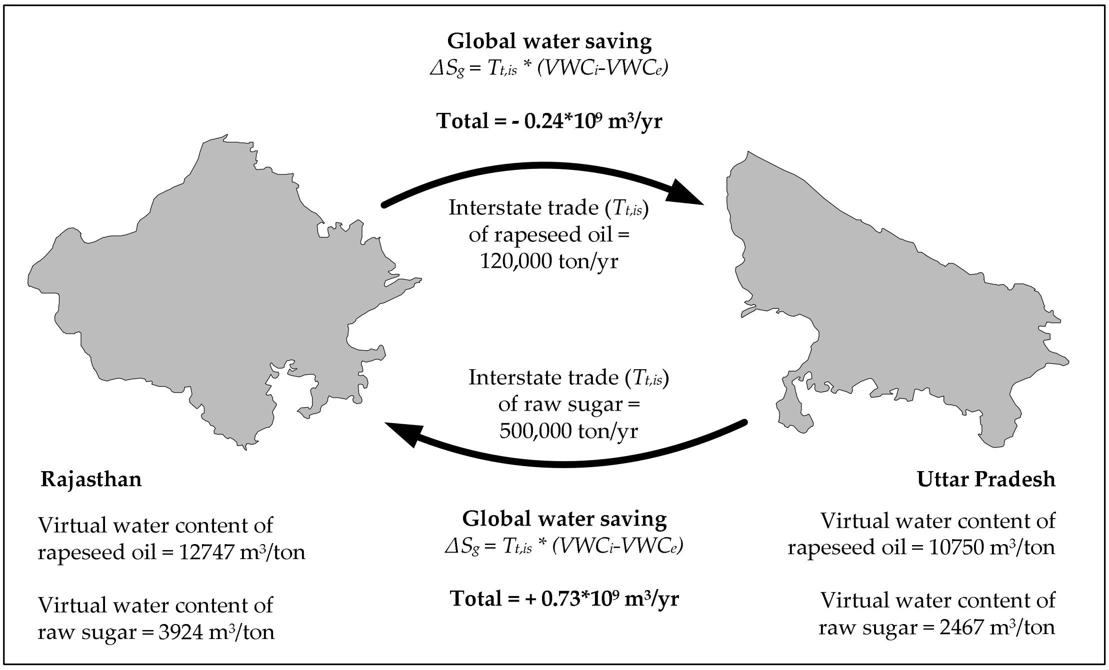

Figure 6.10: Global water savings as a result of interstate trade in rapeseed oil and raw sugar between Rajasthan and Uttar Pradesh during the period 1997-2001.

Figure 6.10 shows that the interstate trade in raw sugar from Uttar Pradesh to Rajasthan leads to global water saving and that the interstate trade in rapeseed oil from Rajasthan to Uttar Pradesh leads to global water loss.

In Table 6.5 the opportunity cost of chickpeas, wheat, rapeseed oil and raw sugar are given for the states Rajasthan, Punjab and Uttar Pradesh. These opportunity costs are found by comparing the water productivity of the competitive crops in the states involved. In this case, all the crops that are involved are grown in the dry season and are therefore considered as competitive.

Table 6.5: Opportunity costs of chickpeas, wheat, rapeseed oil and raw sugar in the states Rajasthan, Punjab and Uttar Pradesh during the period 1997-2001

Crops	Opportunity costs		
	Rajasthan	Punjab	Uttar Pradesh
Unit		-	
1.00 ton of chickpeas	0.73 ton of wheat	0.42 ton of wheat	-
1.00 ton of wheat	1.37 ton of chickpeas	2.36 ton of chickpeas	-
1.00 ton of rapeseed oil	0.31 ton of raw sugar	-	0.23 ton of raw sugar
1.00 ton of raw sugar	3.25 ton of rapeseed oil	-	4.37 ton of rapeseed oil

Table 6.5 shows that the opportunity cost of chickpeas is higher in Rajasthan than in Punjab, that the opportunity cost of wheat is higher in Punjab than in Rajasthan, that the opportunity cost of rapeseed oil is higher Rajasthan than in Uttar Pradesh and that the opportunity cost of raw sugar is higher in Uttar Pradesh than in Rajasthan.

Table 6.6 now shows the change in the production of the crops involved when the virtual water flows from Rajasthan are eliminated and the total water use in the importing and exporting states remains equal. In Table 6.6, the assumption is made that Punjab and Uttar Pradesh will produce the previously imported amount of chickpeas and rapeseed oil themselves and will reduce the production and export of wheat and raw sugar to keep the water use equal. Rajasthan will consequently produce the amount of wheat and raw sugar that is no longer imported from Punjab and Uttar Pradesh and will reduce the production of chickpeas and rapeseed oil to keep the water use equal.

Table 6.6: The change in crop production with the elimination of the export of chickpeas from Rajasthan to Punjab and the export of rapeseed oil from Rajasthan to Uttar Pradesh in the period 1997-2001 when the total water use in the states remains equal

	Rajasthan	Punjab	Uttar Pradesh	Total
Unit		Million ton/yr		
Chickpeas	- 0.17	+ 0.10	-	**- 0.07**
Wheat	+ 0.24	- 0.24	-	**0**
Rapeseed oil	- 0.16	-	+ 0.12	**- 0.04**
Raw sugar	+ 0.52	-	- 0.52	**0**

Table 6.6 shows that the elimination of export of chickpeas and rapeseed oil from Rajasthan to Punjab and Uttar Pradesh, leads to a decrease in crop production, while the water use remains equal. This means that although this export of chickpeas and rapeseed oil leads to global water loss, the water loss would be even larger when these export flows are eliminated.

Another state that has an absolute disadvantage in the water productivity of most its crops is Madhya Pradesh. This is mainly because of the low development of agricultural practice. The theory of comparative advantage again shows that the export of some crops can still be justified from water management perspective in Madhya Pradesh.

In the period 1997-2001, Madhya Pradesh exported 0.12 million ton/yr of soybean oil and 0.40 million ton/yr of wheat to the rest of India and imported 1.30 million ton/yr of raw sugar and 0.40 million ton/yr of milled rice from the rest of India.

The global water saving as a result of the interstate export of soybean oil and wheat from Madhya Pradesh and the interstate import of raw sugar and milled rice into Madhya Pradesh is shown in Figure 6.10.

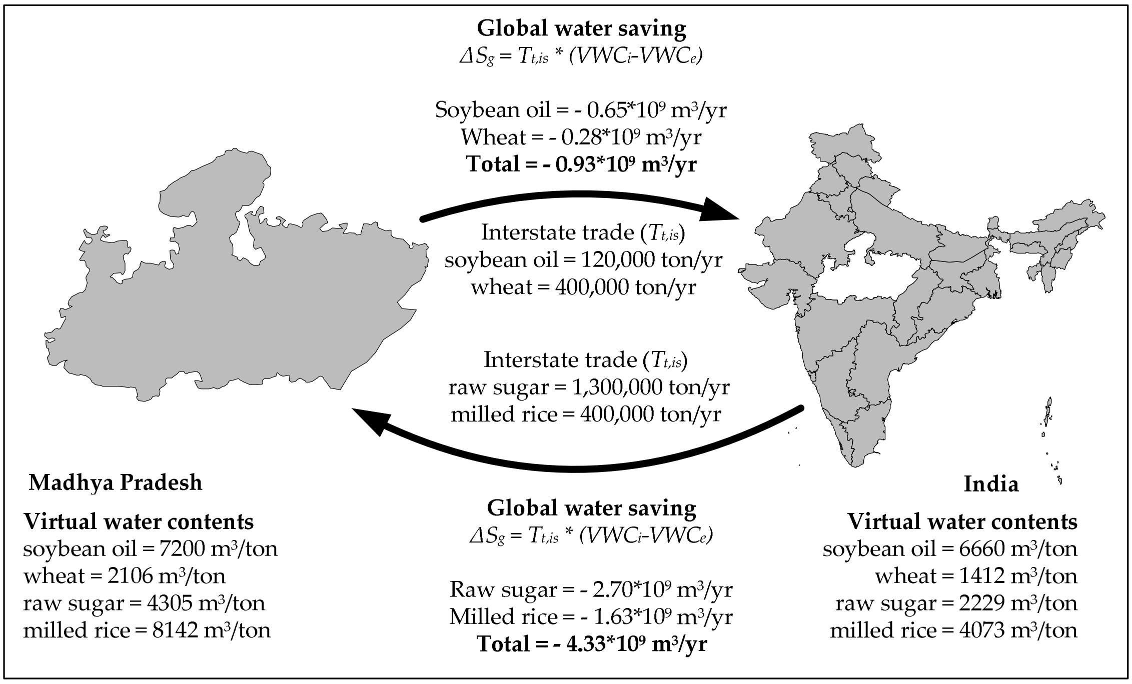

Figure 6.11: Global water saving as a result of interstate trade in soybean oil, wheat, raw sugar and milled rice between Madhya Pradesh and the rest of India during the period 1997-2001.

Figure 6.11 shows that the interstate export of soybean oil and wheat from Madhya Pradesh leads to global water loss and that the interstate import of raw sugar and milled rice into Madhya Pradesh leads to global water saving.

Table 6.7 shows the opportunity cost of soybean oil, milled rice, wheat and raw sugar for Madhya Pradesh and for the rest of India. These opportunity costs are found by comparing the water productivity of the competitive crops in the states involved. In this case, soybean oil and milled rice are seen as competitive because they are both grown in the wet season and wheat and raw sugar are seen as competitive because they are both grown in the dry season.

Table 6.7: Opportunity costs of soybean oil, milled rice, wheat and raw sugar in Madhya Pradesh and whole India during the period 1997-2001

Crops	Opportunity costs	
	Madhya Pradesh	India
Unit	-	
1.00 ton of soybean oil	0.88 ton of milled rice	1.64 ton of milled rice
1.00 ton of milled rice	1.13 ton of soybean oil	0.61 ton of soybean oil
1.00 ton of wheat	0.49 ton of raw sugar	0.63 ton of raw sugar
1.00 ton of raw sugar	2.04 ton of wheat	1.58 ton of wheat

Table 6.7 shows that the opportunity cost of soybean oil and wheat is higher in Madhya Pradesh than in the rest of India and that the opportunity cost of milled rice and raw sugar is higher in the rest of India than in Madhya Pradesh.

Table 6.8 now shows the change in production with the elimination of the virtual water flows from Madhya Pradesh when the total water use in the importing and exporting states remains equal. In Table 6.8, the assumption is made that the rest of India will produce the previously imported amount of soybean oil and wheat itself and will reduce the production and export of milled rice and raw sugar to keep the water use equal. Madhya Pradesh will consequently produce the amount of milled rice and raw sugar that is no longer imported and will reduce the production of soybean oil and wheat to keep the water use equal.

Table 6.8: The change in crop production with the elimination of the interstate export of soybean oil and wheat from Madhya Pradesh in the period 1997-2001 when the total water use in the states remains equal

	Madhya Pradesh	India	Total
Unit		Million ton/yr	
Soybean oil	- 0.22	+ 0.12	**- 0.10**
Milled rice	+ 0.20	- 0.20	**0**
Wheat	- 0.52	+ 0.40	**- 0.12**
Raw sugar	+ 0.25	- 0.25	**0**

Table 6.8 shows that the elimination of the export of soybean oil and wheat from Madhya Pradesh to the rest of India, leads to a decrease in crop production, while the water use remains equal. This means that although this export of soybean oil and wheat leads to global water loss, the water loss would be even larger when these export flows are eliminated.

7. Food security: River interlinking versus increasing water productivity

7.1 *Strategies for Indian water management*

The Indian population will be approximately 1.6 billion people in the year 2050 (United Nations, 2006). Furthermore, the average wealth in India is also growing rapidly. This will lead to an absolute increase in the food demand.

From the perspective of water resources management, in which food production equals water use, there are in general three alternative strategies to meet the increasing food demand:

- Water self sufficiency on state level
- Water self sufficiency on national level
- National virtual water import

Here, water self sufficiency means that a state or nation only uses its current internal and external water resources for food self sufficiency.

The first alternative is a situation where all Indian states are water self sufficient. This would mean that the consumption pattern should be shifted to those crops that yield the most with the water resources in the particular state.

The second alternative is the situation where India is nationally water self sufficient and thus food self sufficient. This is more or less the current situation in which states are importing virtual water from other states.

The third alternative is a situation in which water self sufficiency is no longer obtained and virtual water is imported from other countries. Falkenmark (1997, 2005) claims that, in the case of India, virtual water import will be necessary in the near future and that food self sufficiency as a goal will have to be given up. However, this alternative is currently not considered as an option by the Indian government.

If India wants to remain food self sufficient with its rapidly growing population, given that there is a minimum of water use needed to produce the daily diet of the Indian people, water scarcity must be reduced.

At the moment, the Indian government is considering the project of the Interlinking of Rivers (ILR). ILR aims to reduce the water scarcity in water deficit regions by increasing the local water resources with the import of water through the newly constructed connections of rivers.

7.2 *River interlinking project*

The idea of inter basin water transfer have been introduced by Rao (1973), who proposed a link between Ganges river basin and Cauvery river basin. Currently, the project is on the verge of being implemented. This shows that water scarcity is considered as a serious issue by the Indian government at the moment.

The ILR project is divided in a Himalayan and a peninsular component. In total, 174 billion m^3 of water is aimed to be transported through the proposed links; 33 billion m^3 for the redistribution of water in the Himalayan component and 141 billion m^3 for the redistribution of water in the peninsular component (Gupta & Deshpande, 2004). The reason for the relatively low water transport in the Himalayan component is the fact that the Brahmaputra and Brahmani-Baitani river basins, which have a large water surplus, flow at a lower elevation than the Ganges river basin. In this study only the Himalayan component of the ILR project is considered. The reason for this is the fact that the outcome of the interstate and interregional virtual water flows in Chapter 5 offers a better base for comparing the aimed water transport to the virtual water flows.

In Figure 7.1, the proposed links for the Himalayan component of the ILR are presented. It can be seen that all links are meant to transport water from East India to North India. At state level, the links divert water flows to increase the water resources in Haryana, Rajasthan and Uttar Pradesh at the cost of the water resources in Bihar, Jharkhand and West Bengal. In total, 33 billion m^3/yr of water is meant to be transported through the entire Himalayan component. The aimed water transport by link is however still unclear.

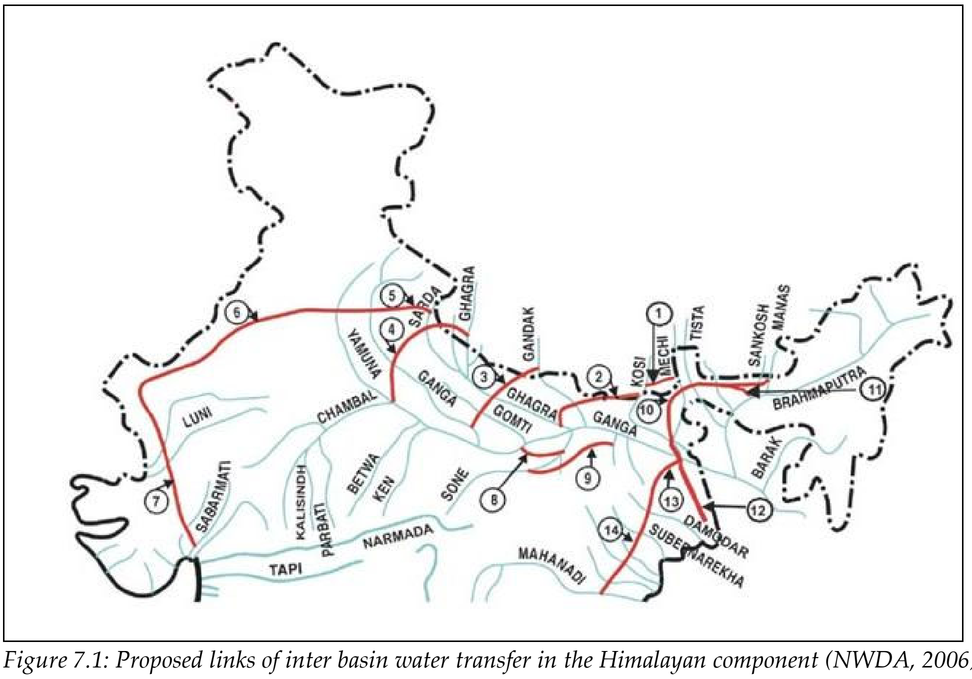

Figure 7.1: Proposed links of inter basin water transfer in the Himalayan component (NWDA, 2006)

The absence of detailed data on the proposed links contributes to the uncertainty in the project. Since many negative side effects can be expected, many scientists are sceptic about the ILR project.

What is striking is the fact that the total water transport through the proposed links in Figure 7.1 has a direction which closely matches the opposite of the direction of the largest interregional virtual water flow, which is from North India to East India (Chapter 5.3).

Since the real and virtual flows are opposite to each other, the question rises if it is possible to eliminate both flows. This is done by taking away the dependency of food import of East India. Since water is not the limiting factor to the crop production in East India, an increase in water productivity in that region can lead to an increase in crop production. The question is whether this increase in water productivity in East India is possible.

7.3 *Increasing water productivity*

7.3.1 Potential yield

An increase of the water productivity of a crop starts with the increase of the yield of a crop. This is possible when a significant gap exists between the current and potential yield of crop.

Potential yield is defined here as the maximum yield that can be generated for a certain crop in a certain state when all needs for an optimal crop growth are supplied. The current yield of a crop depends on many factors; climate (the occurrence of drought or flooding and the amount of sun hours), irrigated or rain fed area, amount of fertilizer use, use of high yielding varieties, water salinity, access to energy (diesel pumps or electricity), tribal or non tribal area (Phansalkar & Verma, 2005) and soil type. We assume that the potential crop yield only depends on the climate.

To demonstrate the result of a possible increase in yield, the example of milled rice in Bihar, Punjab and Uttar Pradesh is used here. This example is used because Bihar is largest importer of virtual water in East India, Punjab and Uttar Pradesh are the largest exporters of virtual water in North India, and milled rice is the crop with the largest contribution to the virtual water flow from North to East India. In this example only milled rice grown during kharif is taken into account, because this offers a better comparison between the states.

During the study period, the yield of milled rice in Bihar during kharif is 1476 kg/ha. This results in an annual production of 5.1 million ton of milled rice. This is not enough to meet the annual consumption in Bihar of 7.1 million ton of milled rice. The deficit is mainly imported from the northern states Uttar Pradesh and Punjab. The yield of milled rice in Punjab in the study period is 3403 kg/ha and in Uttar Pradesh 2031 kg/ha.

The difference in yield between the three states is mainly caused by the fraction irrigated area. In Punjab this fraction is 0.992, while in Uttar Pradesh this is 0.657 and in Bihar 0.393. In the irrigated areas, a rice variety is grown that requires relatively more fertilizer and a reliable supply of water (through irrigation), but has a considerable higher yield than the rice variety grown in the rain fed areas. This rice variety was introduced during the green revolution, which started in Asia in the late sixties of the previous century.

Based on climatic factors, Uttar Pradesh and Bihar have a slightly lower potential yield than Punjab. Uttar Pradesh can potentially reach 95% of the maximum rice yield in Punjab and Bihar 92% (Aggarwal et al., 2000).

Since we are only looking at the relative difference in crop yield, the assumption is made here that Punjab has already reached its potential yield, which is in this case 3403 kg/ha. This would mean that the potential yield in Uttar Pradesh is 3241 kg/ha and in Bihar 3144 kg/ha.

7.3.2 Potential global water saving

An increase in yield to the potential level leads to an increase in water productivity and thus in a decrease in virtual water content. The components of the crop water use of milled rice under the current growth conditions are calculated as presented in Table 7.1 (Appendix VI).

Table 7.1: Calculation of the components of the crop water use of milled rice grown in the wet season under current growth conditions in Bihar, Punjab and Uttar Pradesh

	CWR	CWU_{green}	*IWR*	*iaf*	CWU_{blue}	*N use*	CWU_{gray}	*Yield*	*VWC*
unit	m³/ha	m³/ha	m³/ha	-	m³/ha	kg/ha	m³/ha	kg/ha	m³/ton
year					1997-2001				
Bihar	7620	5878	1742	0.39	685	75	750	1476	4954
Punjab	8922	4234	4688	0.99	4651	103	1030	3403	2914
Uttar Pradesh	8207	5392	2816	0.66	1849	87	873	2031	3995

Assuming that it takes the same irrigated area fraction and nitrate use as in Punjab to achieve the potential yields in Bihar and Uttar Pradesh, the components of the crop water use of milled rice under optimal growth conditions are calculated as presented in Table 7.2.

Table 7.2: Calculation of the components of the crop water use of milled rice grown in the wet season under optimal growth conditions in Bihar, Punjab and Uttar Pradesh

	CWR	CWU_{green}	*IWR*	*iaf*	CWU_{blue}	*N use*	CWU_{gray}	*Yield*	*VWC*
unit	m³/ha	m³/ha	m³/ha	-	m³/ha	kg/ha	m³/ha	kg/ha	m³/ton
year					1997-2001				
Bihar	7620	5878	1742	0.99	1725	103	1030	3144	2747
Punjab	8922	4234	4688	0.99	4641	103	1030	3403	2914
Uttar Pradesh	8207	5392	2816	0.99	2788	103	1030	3241	2842

Table 7.1 and Table 7.2 show that the green crop water use (CWU_{green}) remains the same, the blue crop water use (CWU_{blue}) increases with the irrigated area fraction (*iaf*) and the gray crop water use (CWU_{gray}) increases with the use of nitrate (*N use*).

In Table 7.3, the blue, green, gray and total virtual water content of milled rice grown in the wet season in Punjab, Uttar Pradesh and Bihar is given for the current yields and for the potential yields.

Table 7.3: Current and potential virtual water contents of milled rice grown in the wet season in Bihar, Punjab and Uttar Pradesh

	Bihar		Punjab		Uttar Pradesh	
VWC	Current	Potential	Current	Potential	Current	Potential
unit			m³/ton			
year			1997-2001			
Blue	464	549	1367	1367	910	860
Green	3982	1870	1244	1244	2654	1664
Gray	508	328	303	303	430	318
Total	4954	2747	2914	2914	3995	2842

In the current situation Bihar imports 1.2 million ton of milled rice from Uttar Pradesh and 0.8 million ton from Punjab. Actually Bihar also imports a little from Haryana, but this is neglected here.

In Table 7.4, the reduction of the total water use as a result of the current interstate trade is presented for the current water productivities. Although the situation of food self sufficiency in Bihar is not possible given the current yield and land availability, this is still assumed in the calculation to show the reduction of the total water use as a result of interstate trade in the current situation. In this calculation, the total production and consumption is kept constant.

Table 7.4: Reduction of total water use as a result of current interstate trade with the current water productivity of milled rice grown in the wet season in Bihar, Punjab and Uttar Pradesh while keeping the production and consumption constant

States	No interstate trade with current water productivities						Current interstate trade with current water productivities						reduction total water use
	P[1]	C[2]	Water use				P[1]	C[2]	Water use				
			blue	green	gray	total			blue	green	gray	total	
unit	10^6 ton/yr		10^9 m^3/yr				10^6 ton/yr		10^9 m^3/yr				%
year	1997-2001												
Bihar	7.1	7.1	3.3	28.3	3.6	35.2	5.1	7.1	2.4	20.3	2.6	25.3	+28.1
Punjab	7.7	2.3	10.5	9.6	2.3	22.4	8.5	2.3	11.6	10.6	2.6	24.8	-10.7
UP[3]	10.7	7.4	9.7	28.4	4.6	42.7	11.9	7.4	10.8	31.6	5.1	47.5	-11.2
Total	25.5	16.8	23.5	66.3	10.5	100.3	25.5	16.8	24.8	62.5	10.3	97.6	+2.7

[1] P = production, [2] C = consumption, [3] UP = Uttar Pradesh

Table 7.4 shows that with the current water productivities of milled rice in states involved, the current interstate trade pattern results in a reduction of the total water use of 2.7%.

In Table 7.5, the reduction of the total water use as a result of the current interstate trade with the potential water productivities is presented. In this situation, food self sufficiency in Bihar is realistic given the potential yield and land availability. In this calculation the total production and consumption is again kept constant.

Table 7.5: Reduction of total water use as a result of current interstate trade with the potential water productivity of milled rice grown in the wet season in Bihar, Punjab and Uttar Pradesh while keeping the production and consumption constant

States	No interstate trade with potential water productivities						Current interstate trade with potential water productivities						reduction total water use
	P[1]	C[2]	Water use				P[1]	C[2]	Water use				
			blue	green	gray	total			blue	green	gray	total	
unit	10^6 ton/yr		10^9 m^3/yr				10^6 ton/yr		10^9 m^3/yr				%
year	1997-2001												
Bihar	7.1	7.1	3.9	13.3	2.3	19.5	5.1	7.1	2.8	9.5	1.7	14.0	+28.2
Punjab	7.7	2.3	10.5	9.6	2.3	22.4	8.5	2.3	11.6	10.6	2.6	24.8	-10.7
UP[3]	10.7	7.4	9.2	17.8	3.4	30.4	11.9	7.4	10.2	19.8	3.8	33.8	-11.2
Total	25.5	16.8	23.6	40.7	8.0	72.3	25.5	16.8	24.6	39.9	8.1	72.6	-0.4

[1] P = production, [2] C = consumption, [3] UP = Uttar Pradesh

Table 7.5 shows that with the potential water productivities of milled rice in states involved, the current interstate trade results in no reduction of the total water use.

Table 7.6 presents the reduction of the blue, green and gray water use as a result of the increase in water productivity, in the case of no interstate trade and the current interstate trade, and as a result of the current interstate trade, for the current and potential water productivities.

Table 7.6: Reduction of the blue, green, gray and total water use as a result of current interstate trade with the current and potential water productivity of milled rice grown in the wet season in Bihar, Punjab and Uttar Pradesh while keeping the production and consumption constant

	Reduction of water use with the increase in water productivity (%)		Reduction of water use with current interstate trade of milled rice (%)	
	No interstate trade	Current interstate trade	Current water productivity	Potential water productivity
Blue water use	-0.4	+0.8	-5.5	-4.2
Green water use	+38.6	+36.2	+5.7	+2.0
Gray water use	+23.8	+21.4	+1.9	+1.3
Total water use	+27.9	+25.6	+2.7	-0.4

Table 7.6 shows that with the increase in water productivity of milled rice grown during the wet season in Bihar and Uttar Pradesh, a large volume of green and gray water is saved. Furthermore Table 7.6 shows that the current interstate trade in milled rice from Punjab and Uttar Pradesh to Bihar results in a green and gray water saving at the cost of a blue water loss.

Table 7.4 and Table 7.5 show that by increasing the water productivities and eliminating the interstate trade of milled rice between the states involved, a water volume of 25.3 billion m^3 is globally saved. Of this total, 21.8 billion m^3 consists of green water saving. The remaining water saving consists of 1.2 billion m^3/yr of blue water and 2.3 billion m^3/yr of gray water.

Green water saving may seem useless, as non used green water is lost though evaporation anyway and therefore has a low opportunity cost. In this example, the area used for milled rice growth in Bihar is reduced with the new yield and production volume. If the area, which is not used for milled rice growth anymore, remains unused, the green water saving is useless. If this area is used for more milled rice production, Rockström (2003) and Rockström & Gordon (2001, 2002) show that with an increase in yield and a fixed crop area, the total water productivity remains equal, but the productive part of the water productivity increases. In this example, this means that a relatively larger fraction of the green water, that is lost through evapotranspiration, contributes to the biomass of the crop. And by making better use of green water resources, the crop production can be reduced in places where relatively more blue water resources are needed for crop growth. In that case relative green water saving leads to absolute blue water saving.

Apart from resulting in global water saving, the increase in water productivity in combination with the elimination of the current interstate trade also results in a change in water scarcity in the states of Bihar, Punjab and Uttar Pradesh. This change in water scarcity from production and consumption perspective in the states involved is presented in Table 7.7.

Table 7.7: Change in blue, green and total water scarcity from consumption and production perspective in Bihar, Punjab and Uttar Pradesh with the increase in water productivity combined with the omission of the current interstate trade in milled rice between the states involved

States	Water scarcity from production perspective[1]						Water scarcity from consumption perspective[1]					
	Current situation[2]			Potential situation[3]			Current situation[2]			Potential situation[3]		
	B	G	T	B	G	T	B	G	T	B	G	T
Bihar	0.03	0.38	0.07	0.03	0.27	0.06	0.05	0.47	0.10	0.04	0.29	0.07
Punjab	0.45	0.65	0.51	0.43	0.61	0.48	0.24	0.32	0.26	0.24	0.32	0.26
UP	0.20	0.43	0.27	0.19	0.34	0.23	0.18	0.34	0.23	0.17	0.29	0.21

[1] *B = blue water scarcity, G = green water scarcity, T = total water scarcity,* [2] *Source: Table 6.3,* [3] *Source: Appendix XX.*

Table 7.7 shows that increase in water productivity in combination with the omission of the current interstate trade in milled rice from Punjab and Uttar Pradesh to Bihar results in a reduction of the total water scarcity from production perspective in all three states. Furthermore, the water scarcity from consumption perspective is reduced in Bihar and Uttar Pradesh, because the internal water footprint in these two states in reduced through the increase in water productivity (see Appendix XX).

The large decrease in the green water scarcity from both perspectives in Bihar seems strange, because the green crop water use can not be changed. The reason for this decrease is simply because the potential yield and the potential production of milled rice of 7.1 million ton/yr combined need a smaller crop area. In other words; with the potential yield and the current area cropped with milled rice, a production larger than 7.1 can be realised. Since our examples assume less agricultural area, less green water is used for evapotranspiration.

Large increases in water productivity are also possible in the eastern states Chhattisgarh, Jharkhand, and Orissa, because the water productivity is generally low in these states.

7.4 *River interlinking versus increasing water productivity*

7.4.1 <u>Potential reduction of water scarcity</u>

In Figure 7.2, water scarcity from production perspective in the present situation is compared to the current net import of virtual water for the northern and eastern states. Furthermore, the water scarcity is given for a situation without virtual water flows, in which the assumption is made that all consumed goods are produced within the state of consumption. For the importing states this means that the additional products in these states are produced at the same water efficiency level as the currently imported products and that the required agricultural area for this additional production of goods is available. In Figure 7.2, the national water scarcity is shown as a reference for relative water scarcity or water abundance.

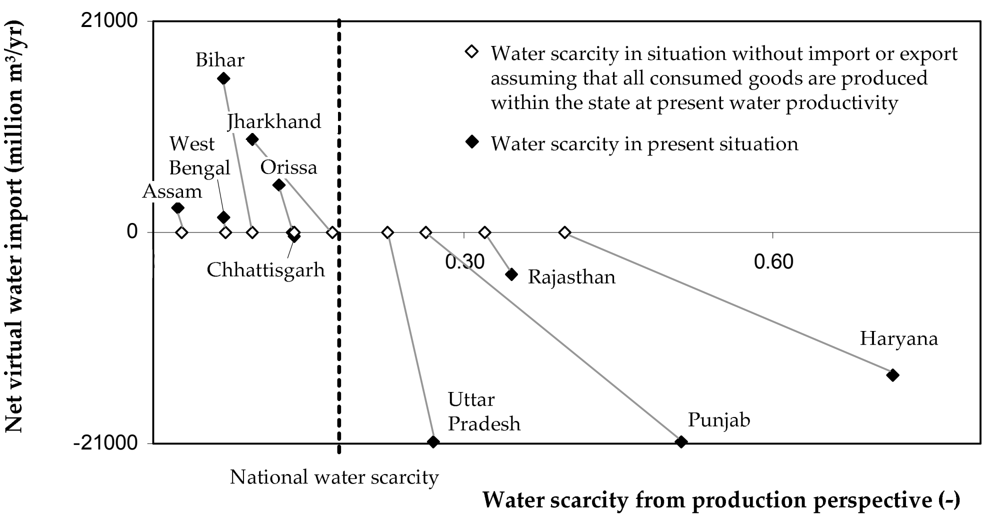

Figure 7.2: Water scarcity from production perspective versus net import virtual water import in the eastern and northern states of India.

The gray lines in Figure 7.2 show the development of the water scarcity from production perspective if the exporting states stop exporting and the importing states start producing all previously imported goods themselves at the same efficiency as in the current exporting states. These lines show that the northern states remain relatively water scarce when they stop exporting virtual water and that the eastern states remain relatively water abundant when they become food self sufficient, which is line with our findings in Figure 6.4.

Whether real water is transported from east to the north or less virtual water is transported from the north to the east, both options result in a reduction of water scarcity in the water scarce northern states at the expense of the water abundant eastern states.

With the execution of the river interlinking project, the national average water scarcity is not directly changed. This is because the total national water use and total national water resources are not directly changed. The national water scarcity will only drop if the production in the areas with high water productivity increases at the cost of the production in the areas with low water productivity. This can only be realised in case the northern states can significantly increase their agricultural area. Since it is unclear how much water the northern states will actually receive through the ILR project, the reduction of the local water scarcity is hard to estimate. Based on the magnitude of the total water use compared to the magnitude of the total aimed real water transport, it seems impossible to bring the water scarcity from consumption perspective in the northern states below the national water scarcity with the ILR project.

With the increase in water productivity in the water abundant states in combination with the elimination of the virtual water flows between the north and the east, the national average water scarcity can be reduced significantly. This is because the increase in water productivity reduces the total water footprint and therefore reduces the national water scarcity.

In Figure 7.3, the four possible combinations of water scarcity from production perspective and net import of virtual water in a state are given. Here, a state is water abundant when the water scarcity in that state is below the national water scarcity and a state is water scarce when the water scarcity in that state is above the national water scarcity. Figure 7.3 also shows the consequences of the following strategies; the interlinking of rivers to transport water from water abundant areas to water scarce areas (A), the reduction of the food export in the water scarce states and of food import in the water abundant states (B), and the increase in water productivity (C).

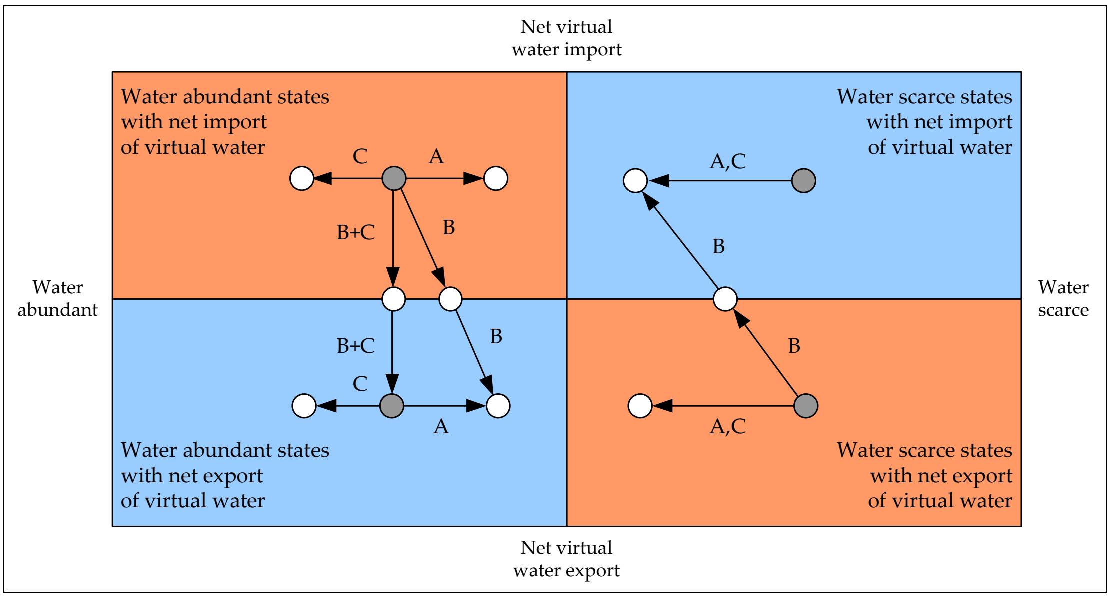

Figure 7.3: The four combinations of water scarcity and net import of virtual water and the consequences of the following strategies; the interlinking of rivers to transport water from water abundant areas to water scarce areas (A), the reduction of the food export in the water scarce states and of food import in the water abundant states (B), and the increase in water productivity (C).

Figure 7.3 shows that strategy A (ILR project) reduces the water scarcity in the water scarce states at the cost of the water abundant states. However, this is not enough to shift these states from water scarce to water abundant. Furthermore, Figure 7.3 shows that a combination of strategy B and strategy C reduces the water scarcity in the water scarce states and keeps the water scarcity in the water abundant states more or less constant, which means that the national water scarcity is reduced.

As can be seen in Figure 7.3, the ILR project does not change the illogical situation from a water management perspective. Since the volume of water that can be transported is limited, the northern states can not become water abundant states. In order to change the illogical situation in which a large part of the water abundance in the eastern states is unutilized, the eastern states have to change from importing virtual water to exporting virtual water. If the agricultural area cannot be expanded, the only way to achieve this is to increase the water productivity.

So all in all, the ILR project reduces local water scarcity, but will not significantly reduce the national water scarcity. Furthermore, in the case of milled rice, a trade flow is currently maintained that causes a global saving of green and gray water, but a global loss of blue water.

From the perspective of logical water management, the transport of (blue) water only seems useful when a virtual water flow is maintained that results in global blue water saving.

Yang (2003) indicates that there is a water resources threshold with respect to the import of cereals. Below this threshold, cereal import demand will increase exponentially with the decrease of the water availability per capita. This would mean that the northern states eventually are bound to reduce their export of virtual water and maybe even start importing virtual water.

7.5 *Water saving by changing crop patterns*

Finally, after presenting the option of reducing or increasing crop production and changing the direction of trade, the option of changing crop patterns in order to achieve global water saving is briefly discussed here.

The theory of comparative advantage is used here to evaluate changes in crop patterns in the Indian states. The three important parameters in this evaluation are the potential yield, the water requirement and the water productivity of a crop.

In Figure 7.4, the possible relation between the total water availability and the crop yield of two crops is shown. Here, the potential yield is found when the water availability equals the crop water requirement. The steepness of the curve represents the water productivity.

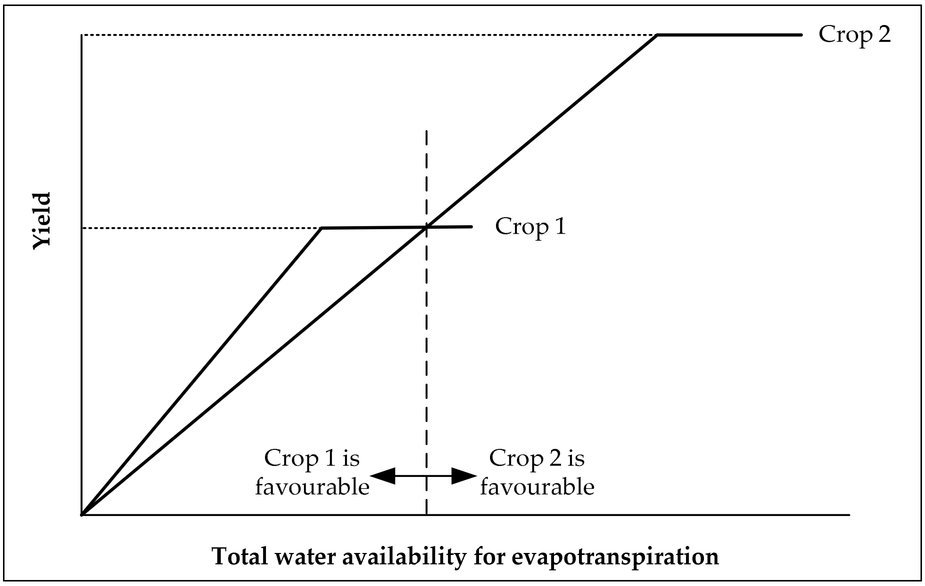

Figure 7.4: The possible relation between the total water availability for evapotranspiration and the crop yield for two crops in a state

Figure 7.4 shows a situation in which crop 1 generates a higher yield in states with a relatively low water availability and crop 2 generates a higher yield in states with a relatively high water availability.

When two crops are compared to each other, the boundary condition is that the crops are competitive. In the case of green water use, crops are only competitive if they are grown in the same season under comparable conditions. In the case of blue water use, crops can also be competitive if they are not grown in the same season, because blue water, especially in the form of groundwater, is available over a longer time period.

In this study we have seen that in the current situation a large amount of milled rice as well as wheat is annually exported from Punjab and Uttar Pradesh to Bihar. Based on the theory of comparative advantage, Bihar must have a relative advantage in water productivity for one of these two crops. Because milled rice and wheat are not grown in during the same season, we only compare blue and gray water use.

The opportunity costs of milled rice and wheat in the states Bihar, Punjab and Uttar Pradesh are presented in Table 7.8.

Table 7.8: Opportunity costs of milled rice and wheat in the states Bihar, Punjab and Uttar Pradesh with the exclusion of green water productivity in the present situation during the period 1997-2001

Crops	Opportunity costs		
	Bihar	Punjab	Uttar Pradesh
Unit		-	
1.00 ton of milled rice	0.72 ton of wheat	3.00 ton of wheat	1.09 ton of wheat
1.00 ton of wheat	1.39 ton of milled rice	0.33 ton of milled rice	0.92 ton of milled rice

From Table 7.8, the conclusion can be carefully made that Bihar currently has a relative advantage in blue and gray water productivity of milled rice when compared to Punjab and Uttar Pradesh. This means that the current trade flows of milled rice from Punjab and Uttar Pradesh to Bihar do not save water according to the theory of comparative advantage. It is worth noticing that the relative advantage in water productivity of a crop may change when the calculation is made for potential crop yields instead of actual crop yields. In this case this is not likely to happen, as Bihar receives significantly more green water than Punjab and Uttar Pradesh in the wet season, and therefore requires relatively less blue water for rice growth, and receives less green water than Punjab and Uttar Pradesh in the dry season, and therefore requires relatively more blue water for wheat growth.

Of course it is still too early to make such a conclusion. We just want to indicate that a state like Bihar currently has no significant crop export, while there must be a crop in which Bihar has the highest relative advantage in water productivity.

When looking at the current trade patterns and the theory of comparative advantage in the present situation, it might be useful to include the yield response factor of a crop in the analysis. The yield response factor is a constant that determines the sensitivity of the crop yield to water deficit (Doorenbos & Kassam, 1979).

The comparison of relative advantages in water productivities of crops might not be sufficient to determine the optimal policies for maximizing the social benefits from limited water resources (Wichelns, 2001). This means that the availability of labour, capital and land in a state should also be taken into account in the calculation of relative advantages in water productivity of crops. This is because water is not always the limiting factor for the increase in crop production. In Bihar for example, there is enough water and labour, but the production is limited by the availability of land and capital.

8. Conclusion and discussion

8.1 *Conclusion*

In the period 1997-2001, the total virtual water flow as a result of interstate trade in agricultural commodities in India was 106 billion m^3/yr, which was equal to 13% of the total water use in Indian agriculture. In the same period, the net international export from India was 15 billion m^3/yr. A comparable study for China showed a total virtual water flow between Chinese sub-regions of billion 128 m^3/yr in the year 1999, which was equal to 10% of the total agricultural water use in China (Ma et al., 2006). In the period 1997-2001, the global sum of international virtual water flows related to the trade of agricultural commodities was 987 billion m^3/yr (Chapagain and Hoekstra, 2004). Of the total virtual water flow within India, 35% is due to the interstate trade of milled rice, 17% due the interstate trade of raw sugar and 14% due to the interstate trade of edible oils. The largest interregional net virtual water flow is 22 billion m^3/yr and flows from the North India to the East India. As a result of international and interstate virtual water flows, the states Haryana, Madhya Pradesh, Punjab and Uttar Pradesh relatively have the largest negative virtual water balance and Bihar, Jharkhand and Kerala relatively have the largest positive virtual water balance.

During our study period, the average water footprint of the consumption of agricultural commodities in India was 777 $m^3/cap/yr$. In the same period, the average global water footprint of the consumption of agricultural commodities was 1066 $m^3/cap/yr$, which did not include gray water use. The internal component is responsible for 658 $m^3/cap/yr$ and the external component for 119 $m^3/cap/yr$. Furthermore, the blue component came to 227 $m^3/cap/yr$, the green component to 459 $m^3/cap/yr$ and the gray component to 92 $m^3/cap/yr$. A significant relation is visible between high water footprints and poor agricultural practice in the Indian states. The states Chhattisgarh and Orissa have the highest water footprint, which is mainly because of the low water productivity in the local rice production.

For India as a whole, the water use from consumption perspective (777 billion m^3/yr) was very close to the water use from production perspective (792 billion m^3/yr). However, for individual states, like Bihar and Punjab, the consumption perspective often provides a very new picture if compared to the traditional production perspective.

From the perspective of consumption, the water scarcity is the highest in the Rajasthan, Punjab, Uttar Pradesh, Tamil Nadu and Haryana. This means that the water resources of these states are closest to be exhausted in case of food self sufficiency. Because most of these states are also net exporters of virtual water, the water scarcity from a production perspective is even higher in these states.

The total net global water saving as a result of the interstate trade in agricultural commodities in India was 41 billion m^3/yr. This means the total water use in Indian agriculture was 5%

lower than it would have been without interstate trade. The interstate trade in wheat alone already caused a global water saving of 23 billion m^3/yr.

It must be noted that the above mentioned numbers are somewhat uncertain, as this study is based on approximately 77% of the total crop production, 61% of the total production value and 84% of the total agricultural land use in India.

Currently, India is considering implementing the concept of river interlinking. This concept means that water abundant regions will provide water to water scarce regions through the connection of rivers. Looking at the interlinking project from the perspective of the virtual water flows as calculated in this study, it can be seen that the proposed water transfer from East to North India has a direction exactly opposite to the direction of the virtual water flow as a result of interstate trade. In this study, it is demonstrated that an increase in water productivity in the water abundant states has a better chance of reducing the national water scarcity than the proposed water transfer. The river interlinking project mainly reduces local water scarcity, while water scarcity needs to be reduced significantly at a national level in order to remain food self sufficient as a nation. The only long term option for reducing the national water scarcity and remaining food self sufficient is to increase the water productivity in India. The largest opportunity for this increase lies in East India, where there is an abundance of water and a large increase in water productivity seems possible.

8.2 Discussion

The methodology used in this study is largely based on earlier studies, which already calculated international virtual water flows and water footprints of nations (Hoekstra & Chapagain, 2007), virtual water flows and water footprints within a nation (Ma et al., 2006), the water footprint of a product (Chapagain et al., 2006) and global water saving as a result of international trade (Chapagain & Hoekstra, 2006). In this study, these previous methodologies are integrated and upgraded where possible. The main upgrades are the incorporation and assessment of green and blue water resources and the demonstration of how a consumption perspective on water management can quantitatively dispute water management strategies that are determined with a production perspective.

The data that is used and generated in this study are rough and in some cases not complete. The roughness is due to the large scale of the study areas. Since one set of climatic parameters per state is used and only one set of crop parameters for whole India per season, the calculated virtual water content of crops do catch the main regional patterns but seem quite unreliable in the case of rain fed crops grown during the dry season. An incompleteness of this study is due the exclusion of crops. Important crops like coconuts, mango and pimento still represent a significant part of the total water use.

Furthermore, the livestock products are excluded from this study. During the study period livestock products contributed a small part to the total water use in Indian agriculture. But the production and interstate of especially milk is increasing quickly. For example, Gujarat has an enormous milk production and where Gujarat in this study is assessed as an importer of virtual water, the inclusion of milk might well turn Gujarat into a net exporter of virtual water.

The external water resources are very roughly estimated. The influence of large hill ranges like the Western Ghats are not taken into account. And in the assessment of the current water scarcity, the determination of the utilizable fraction of the total water resources will improve the reliability of the water scarcity at state level.

This study covers the period 1997-2001 and since patterns of crop production and crop trade change in time as a result of the average increase in welfare, the data that is used and generated might become less suitable to describe the present and future situations.

By only looking at virtual water, the social benefits from limited water resources will not be maximized. So the fact that we are only looking at water resources is a limitation to this study. The availability of labour, capital and land should therefore be included in the relative advantage of the water productivity of crops. This might also change the importance of certain crops, which might not require much water, but may require much labour, land or capital. However, since the food self sufficiency is projected to become critical in the future, the present point of view is important for the future of India.

It could be argued that the importance of water is small compared to the importance of land, labour, energy and capital. For example, irrigation in Bihar is currently executed with diesel pumps while in Punjab electricity is available, which is much cheaper. Water is a relatively costless resource, while products with virtual water embodied in it are seen as relatively costly. In other words; the import of real water feeds the perception of self sufficiency, whereas the import of virtual water feeds the perception of dependency.

This study also misses a more detailed case study, which would have given a better insight in the practical implementation possibilities of both the river interlinking project and the increase in water productivity.

Still we feel that this study gives a good indication of the virtual water flows in India, because it is indisputable that the direction of the largest virtual water flow is opposite to the direction of the aimed real water transport and that the water productivity in East India still has a large gap with the potential water productivity. In general, we can also dispute whether the exclusion of the alternative of national virtual water import to meet the increasing food demand is a smart move, because whatever internal solution will be chosen to meet the food demand in the future in India, the average water availability per capita in India will keep dropping with the increase in population.

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Appendices

Appendix I. Symbols

Symbol	Unit	Description
CWR	m^3/ha	Crop water requirement of crop c per crop period
$ET_{c,opt}$	mm/day	Crop evapotranspiration with an abundance of water
K_c	-	Crop coefficient
ET_0	mm/day	Reference evapotranspiration
CWU_{green}	m^3/ha	Green crop water use
$ET_{c,rw}$	mm/day	Crop evapotranspiration under rain fed conditions
P_{eff}	mm/day	Effective rainfall
P_{tot}	mm/day	Total rainfall
CWU_{blue}	m^3/ha	Blue crop water use
$ET_{c,iw}$	mm/day	Crop evapotranspiration of irrigation water
IWR	mm/day	Irrigation water requirement
iaf	-	Irrigated area fraction
$ET_{c,act}$	mm/day	Total actual crop evapotranspiration
CWU_{tot}	m^3/ha	Total actual crop water use
WD	-	Water deficit during crop growth
DWR	m^3/ha	Dilution water requirement
$N_{leached}$	ton/ha	Amount of nitrate that leaches to groundwater
df	m^3/ton	Dilution factor
N_{used}	ton/ha	Amount of nitrate supplied to the field
lf	-	Leaching factor
rl	mg/l	Recommended level of nitrogen
VWC_{tot}	m^3/ton	Total virtual water content of a crop
VWC_{blue}	m^3/ton	Blue virtual water content of a crop
VWC_{green}	m^3/ton	Green virtual water content of a crop
VWC_{gray}	m^3/ton	Gray virtual water content of a crop
Y_c	ton/ha	Yield of a crop
pf	-	Product fraction of a processed product
vf	-	Value fraction of a processed product
VWC_{pc}	m^3/ton	Virtual water content of a processed product
WP	ton/m^3	Water productivity of a crop
AWU	m^3/yr	Total agricultural water use
P	ton/yr	Production volume
AWU_{blue}	m^3/yr	Blue agricultural water use
AWU_{green}	m^3/yr	Green agricultural water use
AWU_{gray}	m^3/yr	Gray agricultural water use
S_t	ton/yr	Total supply volume of a crop
U_t	ton/yr	Total utilization volume of a crop
P_t	ton/yr	Total production volume of a crop
$I_{t,in}$	ton/yr	Total international import volume of a crop
SI_t	ton/yr	Total stock increase volume of a crop
SD_t	ton/yr	Total stock decrease volume of a crop
$E_{t,in}$	ton/yr	Total international export volume of a crop
Fd_t	ton/yr	Total animal feed volume of a crop
Sd_t	ton/yr	Total seed volume of a crop
M_t	ton/yr	Total manufacture volume of a crop
W_t	ton/yr	Total waste volume of a crop
Ou_t	ton/yr	Total other use volume of a crop
C_t	ton/yr	Total consumption volume of a crop
S_s	ton/yr	State supply volume of a crop
U_s	ton/yr	State utilization volume of a crop
P_s	ton/yr	State production volume of a crop
$I_{s,in}$	ton/yr	State international import volume of a crop
$I_{s,is}$	ton/yr	State interstate import volume of a crop

SI_s	ton/yr	State stock increase volume of a crop
SD_s	ton/yr	State stock decrease volume of a crop
$E_{s,in}$	ton/yr	State international export volume of a crop
$E_{s,is}$	ton/yr	State interstate export volume of a crop
Fd_s	ton/yr	State animal feed volume of a crop
Sd_s	ton/yr	State seed volume of a crop
M_s	ton/yr	State manufacture volume of a crop
W_s	ton/yr	State waste volume of a crop
Ou_s	ton/yr	State other use volume of a crop
C_s	ton/yr	State consumption volume of a crop
$T_{t,is}$	ton/yr	Total interstate trade of a crop
Sp_s	ton/yr	State surplus of a crop
RU_t	ton/yr	Total remaining utilizations of a crop
VWF_s	m^3/yr	Virtual water flow as a result of crop trade between two states
$VWF_{s,tot}$	m^3/yr	Total virtual water flow as a result of interstate trade of a crop
VWI_{net}	m^3/yr	Net virtual water balance of a state
WFP_{tot}	m^3/yr	Total water footprint
WFP_i	m^3/yr	Internal water footprint
WFP_e	m^3/yr	External water footprint
VWE_{gross}	m^3/yr	Gross export of virtual water
VWI_{gross}	m^3/yr	Gross import of virtual water
WFP_{cap}	m^3/cap/yr	Total water footprint per capita
Pop	capita	Population
Q_{in}	m^3/yr	Total volume of water flowing into a state
Q_{out}	m^3/yr	Total volume of water flowing out of a state
ET_{tot}	m^3/yr	Total volume of evapotranspiration within a state
Q_e	m^3/yr	Total outflow of external water from a state
Q_i	m^3/yr	Total inflow of external water in a state
$NAWU_{green}$	m^3/yr	Total use of rain water in non agricultural areas
WR_{green}	m^3/yr	Total green water resources
$A_{non,agric}$	ha/yr	Total non agricultural area
$WR_{blue,i}$	m^3/yr	Internal blue water resources
$A_{s,rb}$	ha	Area of state in a river basin
A_{rb}	ha	Area of river basin
A_s	ha	Area of state
$Q_{i,rb}$	m^3/yr	Contribution of internal water resources to river basin discharge
$Q_{out,rb}$	m^3/yr	Total outflow of water from a state
$Q_{in,rb}$	m^3/yr	Total inflow of external water into a state in a river basin
$WR_{blue,e}$	m^3/yr	External blue water resources
$WR_{blue,tot}$	m^3/yr	Total blue water resources
WR_{tot}	m^3/yr	Total water resources
Q_{rb}	m^3/yr	Total discharge volume of state s
WS_{prod}	-	Total water scarcity from a production perspective
$WS_{prod,green}$	-	Green water scarcity from a production perspective
$WS_{prod,blue}$	-	Blue water scarcity from a production perspective
WS_{cons}	-	Total water scarcity from a consumption perspective
$WS_{cons,green}$	-	Green water scarcity from a consumption perspective
$WS_{cons,blue}$	-	Blue water scarcity from a consumption perspective
ΔS_s	m^3/yr	State water saving as a result of import of a crop
ΔS_g	m^3/yr	Global water saving as result of interstate trade of a crop
WP_{ET}	mm	Total water productivity
WP_T	mm	Productive part of water productivity

Appendix II. Area and population of the Indian states

Area, population and population density of the Indian states and union territories						
State/ Union Territory[1]	Abbrev.[2]	Area[3]	Population[4]			Population density[5]
			rural	urban	total	
unit		km²		1000 capita		cap/km2
year				1997-2001		
Andaman & Nicobar	ANI	8,249	234	111	346	42
Andhra Pradesh	AP	275,068	54,127	19,963	74,083	269
Arunachal Pradesh	ARP	83,743	850	219	1,067	13
Assam	AS	78,483	22,682	3,299	25,911	330
Bihar	BH	94,164	72,608	8,329	80,682	857
Chandigarh	CDG	144	90	776	875	6,080
Chhattisgarh	CG	135,194	16,265	4,015	20,252	150
Dadra & Nagar Haveli	DNH	491	166	48	214	437
Daman & Diu	DMD	122	99	55	154	1,261
Delhi	DL	1,483	923	12,381	13,464	9,079
Goa	GOA	3,702	662	643	1,310	354
Gujarat	GJ	196,024	31,011	18,160	49,257	251
Haryana	HR	44,212	14,684	5,867	20,554	465
Himachal Pradesh	HP	55,673	5,356	571	5,908	106
Jammu & Kashmir	JK	222,236	7,452	2,414	9,861	44
Jharkhand	JH	79,700	20,470	5,750	26,194	329
Karnataka	KT	191,791	34,087	17,231	51,375	268
Kerala	KL	38,863	23,032	7,931	30,953	796
Lakshadweep	LSW	32	33	26	59	1,842
Madhya Pradesh	MP	308,144	43,360	15,318	58,663	190
Maharashtra	MH	307,713	54,495	39,429	94,174	306
Manipur	MNP	22,327	1,554	553	2,106	94
Meghalaya	MGL	22,429	1,822	436	2,254	100
Mizoram	MIZ	21,081	437	423	864	41
Nagaland	NGL	16,579	1,609	329	1,934	117
Orissa	OR	155,707	30,568	5,293	35,777	230
Pondicherry	PDC	492	318	622	947	1,925
Punjab	PJ	50,362	15,726	7,926	23,679	470
Rajasthan	RJ	342,236	42,297	12,677	54,930	161
Sikkim	SIK	7,096	470	57	526	74
Tamil Nadu	TN	130,058	34,119	26,366	60,664	466
Tripura	TRP	10,492	2,592	524	3,110	296
Uttar Pradesh	UP	238,566	128,630	33,135	161,558	677
Uttaranchal	UA	53,566	6,165	2,090	8,252	154
West Bengal	WB	88,752	56,421	21,515	77,938	878
All India		3,284,974	725,415	274,482	999,896	304
Total included in study		3,087,995	714,478	269,660	984,129	319
		94%	98%	98%	98%	

[1] The shaded states and union territories are excluded from this study, 2 Abbrev. = the abbreviations of the states and union territories used in this study, [3] Source: en.wikipedia.org, [4] Source: Census of India (2006), FAO (2006), [5] Population density = total population divided by state area.

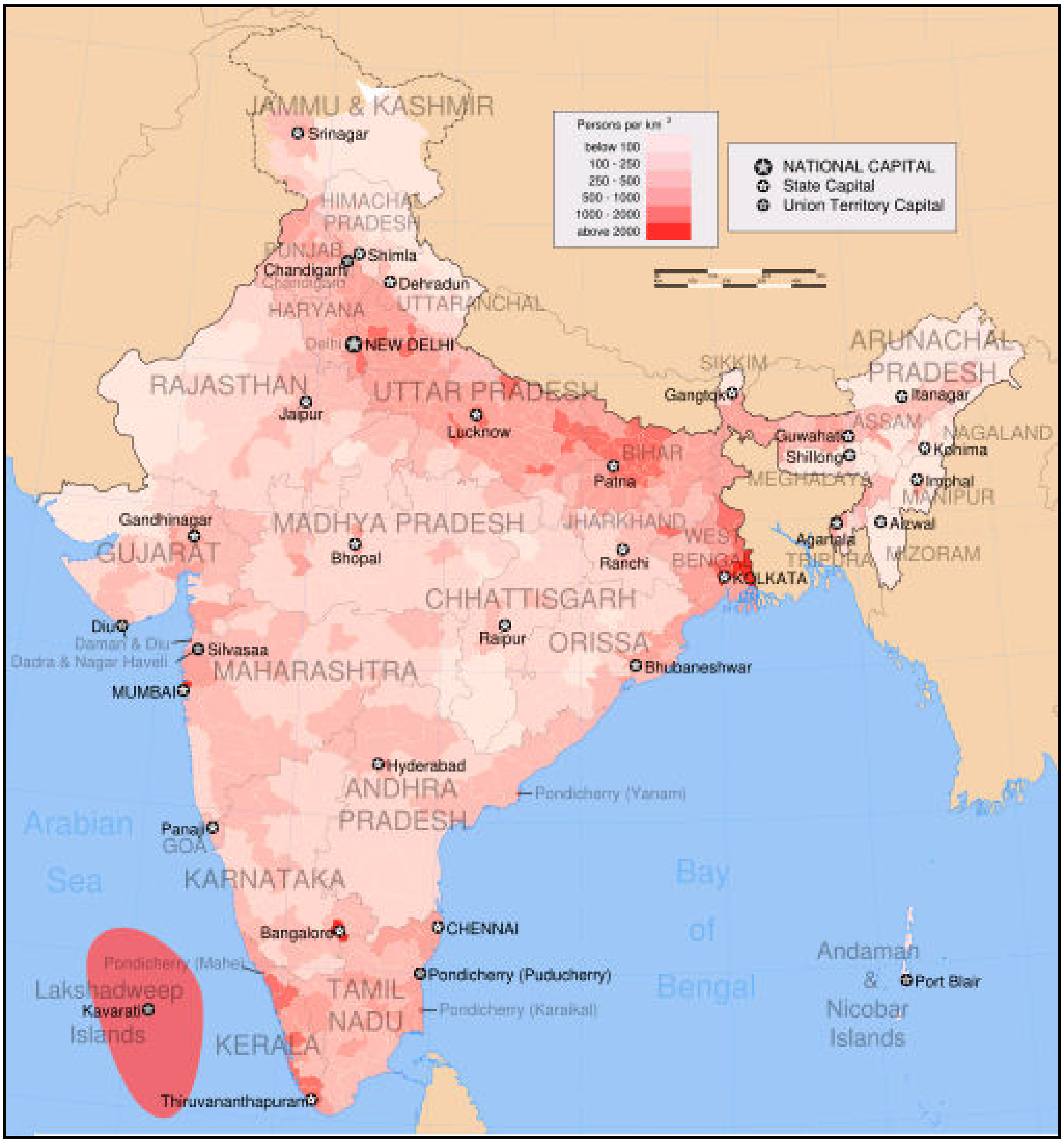


Figure A.1: Population density map of India (Source: en.wikipedia.org)

Appendix III. Crop production India

Primary crops	CC[1]	P[2]	VWC[3]	WU[4]		PP[5]	VP[6]		LU[7]	
unit		10^3 ton/yr	m^3/ton	Gm^3/yr	%	US$/ton	10^9 US$/yr	%	10^6 ha/yr	%
year						1997-2001				
Rice, Paddy	C	130903	2850	373.1	39.3	126	16.5	21.4	44.6	25.0
Wheat	C	70606	1654	116.8	12.3	148	10.4	13.5	26.7	15.0
Seed Cotton	OC	5716	8264	47.2	5.0	509	2.9	3.8	8.9	5.0
Sugar Cane	SC	286042	159	45.6	4.8	18	5.1	6.7	4.1	2.3
Millet	C	10162	3269	33.2	3.5	101	1.0	1.3	12.6	7.0
Sorghum	C	7990	4053	32.4	3.4	118	0.9	1.2	10.1	5.7
Soybeans	OC	6364	4124	26.2	2.8	232	1.5	1.9	6.3	3.5
Groundnuts in Shell	OC	6991	3420	23.9	2.5	327	2.3	3.0	6.8	3.8
Maize	C	11764	1937	22.8	2.4	115	1.3	1.7	6.4	3.6
Beans, Dry	P	2609	8335	21.7	2.3	292	0.8	1.0	6.7	3.8
Coconuts	OC	9345	2255	21.1	2.2	87	0.8	1.1	1.8	1.0
Mangoes	F	10582	1525	16.1	1.7	359	3.8	4.9	1.4	0.8
Chick-Peas	P	5494	2712	14.9	1.6	352	1.9	2.5	6.8	3.8
Rapeseed	OC	5400	2618	14.1	1.5	313	1.7	2.2	6.1	3.4
Pimento, Allspice	SP	953	11126	10.6	1.1	850	0.8	1.1	0.9	0.5
Pigeon Peas	P	2433	4066	9.9	1.0	380	0.9	1.2	3.5	1.9
Castor Beans	OC	794	9807	7.8	0.8	277	0.2	0.3	0.8	0.4
Fruit Fresh nes[8]	F	6424	1066	6.9	0.7	214	1.4	1.8	0.7	0.4
Cashew Nuts	TN	444	15340	6.8	0.7	728	0.3	0.4	0.7	0.4
Bananas	F	15574	415	6.5	0.7	140	2.2	2.8	0.5	0.3
Lentils	P	940	6652	6.3	0.7	311	0.3	0.4	1.4	0.8
Tea nes[8]	ST	832	7002	5.8	0.6	186	0.2	0.2	0.5	0.3
Vegetables Fresh nes[8]	V	25772	207	5.3	0.6	158	4.1	5.3	2.1	1.2
Jute	VF	1729	2823	4.9	0.5	200	0.3	0.4	0.8	0.4
Sesame Seed	OC	579	8415	4.9	0.5	441	0.3	0.3	1.6	0.9
Potatoes	SR	22535	213	4.8	0.5	107	2.4	3.1	1.3	0.7
Natural Rubber	R	583	7626	4.4	0.5	701	0.4	0.5	0.4	0.2
Sunflower Seed	OC	780	4304	3.4	0.4	372	0.3	0.4	1.4	0.8
Spices nes[8]	SP	799	4054	3.2	0.3	488	0.4	0.5	1.0	0.6
Areca Nuts (Betel)	TN	322	9985	3.2	0.3	1279	0.4	0.5	0.3	0.2
Pulses nes[8]	P	1043	3078	3.2	0.3	500	0.5	0.7	1.8	1.0
Coffee, Green	ST	258	12180	3.1	0.3	1553	0.4	0.5	0.3	0.2
Fruit Trop. Fresh nes[7]	F	2810	1104	3.1	0.3	214	0.6	0.8	0.3	0.2
Barley	C	1511	1966	3.0	0.3	124	0.2	0.2	0.8	0.4
Linseed	OC	264	11080	2.9	0.3	343	0.1	0.1	0.7	0.4
Onions, Dry	V	4931	538	2.7	0.3	115	0.6	0.7	0.5	0.3
Apples	F	1256	1812	2.3	0.2	498	0.6	0.8	0.2	0.1
Tomatoes	V	7232	302	2.2	0.2	149	1.1	1.4	0.4	0.2
Peas, Dry	P	707	3040	2.1	0.2	234	0.2	0.2	0.6	0.4
Cassava	SR	6549	283	1.9	0.2	67	0.4	0.6	0.2	0.1
Safflower Seed	OC	251	6864	1.7	0.2	295	0.1	0.1	0.4	0.2
Tobacco Leaves	T	602	2627	1.6	0.2	508	0.3	0.4	0.4	0.2
Oilseeds nes[8]	OC	147	8023	1.2	0.1	327	0.0	0.1	0.5	0.3
Nutmeg, Cardamoms	SP	13	90511	1.1	0.1	1762	0.0	0.0	0.1	0.1
Eggplants	V	7728	146	1.1	0.1	-	-	0.0	0.5	0.3
Jute-Like Fibres	VF	199	5295	1.1	0.1	200	0.0	0.1	0.1	0.0
Oranges	F	2842	364	1.0	0.1	360	1.0	1.3	0.1	0.1
Cabbages	V	5428	180	1.0	0.1	121	0.7	0.8	0.2	0.1
Pumpkins, Gourds	V	3400	238	0.8	0.1	-	-	0.0	0.4	0.2
Lemons, Limes	F	1298	611	0.8	0.1	262	0.3	0.4	0.1	0.1

Primary crops	CC[1]	P[2]	VWC[3]	WU[4]		PP[5]	VP[6]		LU[7]	
unit		10^3 ton/yr	m^3/ton	Gm^3/ yr	%	US$/ ton	10^9 US$/yr	%	10^6 ha/yr	%
year						1997-2001				
Anise, Badian, Fennel	SP	110	7063	0.8	0.1	513	0.1	0.1	0.3	0.2
Garlic	V	514	1268	0.7	0.1	486	0.2	0.3	0.1	0.1
Papayas	F	652	922	0.6	0.1	182	0.1	0.2	0.1	0.0
Okra	V	3442	168	0.6	0.1	-	-	0.0	0.3	0.2
Pepper White/Black	SP	61	8333	0.5	0.1	2982	0.2	0.2	0.2	0.1
Peas, Green	V	2766	178	0.5	0.1	273	0.8	1.0	0.3	0.2
Cauliflower	V	4736	100	0.5	0.0	244	1.2	1.5	0.3	0.1
Ginger	SP	263	1556	0.4	0.0	356	0.1	0.1	0.1	0.0
Walnuts	TN	28	11721	0.3	0.0	1077	0.0	0.0	0.0	0.0
Pineapples	F	1063	305	0.3	0.0	190	0.2	0.3	0.1	0.0
Sweet Potatoes	SR	1076	277	0.3	0.0	108	0.1	0.2	0.1	0.1
Grapes	F	1039	238	0.2	0.0	341	0.4	0.5	0.0	0.0
Pears	F	175	1287	0.2	0.0	199	0.0	0.0	0.0	0.0
Lettuce	V	778	258	0.2	0.0	-	-	0.0	0.1	0.1
Beans, Green	V	412	487	0.2	0.0	158	0.1	0.1	0.1	0.1
Peaches, Nectarines	F	117	1564	0.2	0.0	174	0.0	0.0	0.0	0.0
Plums	F	73	1907	0.1	0.0	174	0.0	0.0	0.0	0.0
Watermelons	F	252	362	0.1	0.0	87	0.0	0.0	0.0	0.0
Cocoa Beans	ST	6	13775	0.1	0.0	-	-	0.0	0.0	0.0
Cantaloupes, Melons	F	642	115	0.1	0.0	525	0.3	0.4	0.0	0.0
Carrots	V	344	192	0.1	0.0	319	0.1	0.1	0.0	0.0
Citrus Fruit nes[8]	F	116	528	0.1	0.0	235	0.0	0.0	0.0	0.0
Grapefruit, Pomelos	F	120	411	0.0	0.0	174	0.0	0.0	0.0	0.0
Cucumbers, Gherkins	V	118	357	0.0	0.0	-	-	0.0	0.0	0.0
Apricots	F	9	2424	0.0	0.0	174	0.0	0.0	0.0	0.0
Figs	F	10	2147	0.0	0.0	174	0.0	0.0	0.0	0.0
Cherries	F	7	2532	0.0	0.0	631	0.0	0.0	0.0	0.0
Chillies/Peppers, Green	V	49	285	0.0	0.0	850	0.0	0.1	0.0	0.0
Stone Fruit nes, Fresh[8]	F	1	1434	0.0	0.0	-	-	0.0	0.0	0.0
Berries nes[8]	F	1	897	0.0	0.0	-	-	0.0	0.0	0.0
All crops		718914		949.0	100		77.1	100	178.3	100

[1] CC= crop categories; C = cereals, OC = oil crops, SC = sugar crops, P = pulses, F = fruits, SP = spices, TN = tree nuts, ST = stimulants, V = vegetables, VF = vegetable fibres, SR = starchy roots, R = rubber and T = tobacco. [2] P = National crop production, source: FAOSTAT (FAO, 2006), [3] VWC = Virtual water content of crop, source: Chapagain and Hoekstra (2004) [4] WU = Water use, which is the production times virtual water content, [5] PP = producer price (US$ 1997-2001), source: FAOSTAT (FAO, 2006), for a few crops this value is not given, [6] VP = Value of production, which is the production times producer price, [7] LU = Land use, source: FAOSTAT (FAO, 2006), [8] Nes = not elsewhere specified.

Appendix IV. List of weather stations

MEASUREMENT STATION	DISTRICT	STATE / UNION TERRITORY	ALTITUDE (m)	LATITUDE (o,/)	LONGITUDE (o,/)
AGRA	AGRA	UTTAR PRADESH	169	27.1	78.02
AHMADABAD	AHMADABAD	GUJARAT	55	23.04	72.38
AHMADNAGAR	AHMADNAGAR	MAHARASHTRA	657	19.05	74.48
AJMER	AJMER	RAJASTHAN	486	26.27	74.37
AKOLA	AKOLA	MAHARASHTRA	282	20.42	77.02
ALIBAG	RAIGARH	MAHARASHTRA	7	18.38	72.52
ALIGARH	ALIGARH	UTTAR PRADESH	187	27.53	78.04
ALLABABAD	ALLAHABAD	UTTAR PRADESH	98	25.27	81.44
AMBALA	AMBALA	HARYANA	272	30.23	76.46
AMINI	(N/A)	LAKSHADWEEP	4	11.07	72.44
AMRAOTI	AMRAVATI	MAHARASHTRA	370	20.56	77.47
AMRITSAR	AMRITSAR	PUNJAB	234	31.38	74.52
ANGUL	DHENKANAL	ORISSA	139	20.5	85.06
ASANSOL	BARDDHAMAN	WEST BENGAL	126	23.41	86.58
AURANGABAD	AURANGABAD	MAHARASHTRA	581	19.53	75.2
BAHRAICH	BAHRAICH	UTTAR PRADESH	124	27.34	81.36
BALASORE	BALESHWAR	ORISSA	20	21.31	86.56
BALEHONNUR	CHIKMAGALUR	KARNATAKA	889	13.22	75.27
BANGALORE	BANGLORE	KARNATAKA	921	12.58	77.35
BAREILLY	BAREILLY	UTTAR PRADESH	173	28.22	79.24
BARMER	BARMER	RAJASTHAN	194	25.45	71.23
BARODA	VADODARA	GUJARAT	34	22.18	73.15
BELGAUM	BELGAUM	KARNATAKA	753	15.51	74.32
BELLARY	BELLARY	KARNATAKA	449	15.09	76.51
BERHAMPORE	MURSHIDABAD	WEST BENGAL	19	24.08	88.16
BHAVNAGAR (AERO)	BHAVNAGAR	GUJARAT	11	21.45	72.11
BHOPAL (BAIRAGARH)	SEHORE	MADHYA PRADESH	523	23.17	77.21
BHUJ (RUDRAMATA)	KACHCHH	GUJARAT	80	23.15	69.4
BIDAR	BIDAR	KARNATAKA	664	17.55	77.32
BIJAPUR	BIJAPUR	KARNATAKA	594	16.49	75.43
BIKANER	BIKANER	RAJASTHAN	224	28	73.18
BOMBAY	GREATER BOMBAY	MAHARASHTRA	11	18.54	72.49
BURDWAN	BARDDHAMAN	WEST BENGAL	32	23.14	87.51
CALCUTTA (DUM DUM)	24 PARGANAS	WEST BENGAL	6	22.39	88.26
CHAIBASA	SINGHBHUM	JHARKHAND	226	22.33	85.49
CHANDBALI	BALESHWAR	ORISSA	6	20.47	86.44
CHANDRAPUR	CHANDRAPUR	MAHARASHTRA	193	19.58	79.18
CHERRAPUNJI	(N/A)	MEGHALAYA	1313	25.15	91.44
CHITRADURGA	CHITRADURGA	KARNATAKA	733	14.14	76.26
COCHIN	ERNAKULAM	KERALA	3	9.58	76.14
COIMBATORE	COIMBATORE	TAMIL NADU	409	11	78.58
COONOOR	NILGIRI	TAMIL NADU	1747	11.21	76.48
CUDDALORE	SOUTH ARCOT	TAMIL NADU	12	11.46	79.46
CUDDAPAH	CUDDAPAH	ANDHRA PRADESH	130	14.29	78.5
CUTTACK	CUTTACK	ORISSA	27	20.28	85.56
DALTONGANJ	PALAMU	JHARKHAND	221	24.03	84.04
DARBHANGA	DARBHANGA	BIHAR	49	26.1	85.54
DARJEELING	DARJEELING	WEST BENGAL	2127	27.03	88.16
DEHRA DUN	DEHRADUN	UTTARANCHAL	682	30.19	78.02
DHAMBAD	DHANBAD	JHARKHAND	257	23.47	86.26
DHUBRI	(N/A)	ASSAM	35	26.01	89.58
DIBRUGARH	(N/A)	ASSAM	110	27.29	95.01
DOHAD	DAHOD	GUJARAT	333	22.5	74.16
DUMKA	DUMKA	JHARKHAND	149	24.16	87.15

MEASUREMENT STATION	DISTRICT	STATE / UNION TERRITORY	ALTITUDE (m)	LATITUDE (o,/)	LONGITUDE (o,/)
DWARKA	JAMNAGAR	GUJARAT	11	22.22	69.05
FATEHPOR	FATEHPUR	UTTAR PRADESH	114	25.56	80.5
GADAG	DHARWAD	KARNATAKA	650	15.25	75.38
GANGANAGAR	GANGANAGAR	RAJASTHAN	177	29.55	73.53
GAUHATI	(N/A)	ASSAM	54	26.06	91.35
GAYA	GAYA	BIHAR	116	24.45	84.57
GONDA	GONDA	UTTAR PRADESH	110	27.08	81.58
GOPALPUR	GANJAM	ORISSA	17	19.16	84.53
GORAKHPUR	GORAKHPUR	UTTAR PRADESH	77	26.45	83.22
GULBARGA	GULBARGA	KARNATAKA	458	17.21	76.51
GUNA	GUNA	MADHYA PRADESH	478	24.39	77.19
GWALIOR	GWALIOR	MADHYA PRADESH	207	26.14	78.15
HANAMKONDA	ADILABAD	ANDHRA PRADESH	269	19.01	79.34
HASSAN	HASSAN	KARNATAKA	960	13	76.09
HAZARIBAGH	HAZARIBAG	JHARKHAND	611	23.59	85.22
HISSAR	HISSAR	HARYANA	221	29.1	75.44
HONAVAR	UTTAR KANNAD	KARNATAKA	29	14.17	74.27
HOSHANGABAD	SEHORE	MADHYA PRADESH	302	22.46	77.46
HYDERABAD	HYDERABAD	ANDHRA PRADESH	545	17.27	78.28
INDORE	INDORE	MADHYA PRADESH	567	22.43	75.48
JABALPUR	JABALPUR	MADHYA PRADESH	393	23.12	79.57
JAGDALPUR	BASTAR	CHHATTISGARH	553	19.05	82.02
JAIPUR (SANGANER)	JAIPUR	RAJASTHAN	390	26.49	75.48
JALGAON	JALGAON	MAHARASHTRA	201	21.03	75.34
JALPAIGURI	JALPAIGURI	WEST BENGAL	83	26.32	88.43
JAMMU	(N/A)	JAMMU & KASHMIR	366	32.4	74.5
JAMNAGAR (AERO)	JAMNAGAR	GUJARAT	20	22.27	70.02
JAMSHEDPUR	SINGHBHUM	JHARKHAND	129	22.49	86.11
JHALAWAR	JHALAWAR	RAJASTHAN	321	24.32	76.1
JHANSI	JHANSI	UTTAR PRADESH	251	25.27	78.35
JODHPUR	JODHPUR	RAJASTHAN	224	26.18	73.01
KAKINADA	EAST GODAVARI	ANDHRA PRADESH	8	16.57	82.14
KALIMPONG	DARJEELING	WEST BENGAL	1209	27.04	88.28
KALINGAPATAM	SRIKAKULAM	ANDHRA PRADESH	6	18.2	84.08
KANKER	BASTAR	CHHATTISGARH	402	20.16	81.29
KANPUR AIR FLD	KANPUR	UTTAR PRADESH	126	26.26	80.22
KHANDWA	EAST NIMAR	MADHYA PRADESH	318	21.5	76.22
KODAIKANAL	MADURAI	TAMIL NADU	2343	10.14	77.28
KOTA	KOTA	RAJASTHAN	257	25.11	75.51
KOZHIKODE (CALICUT)	(N/A)	KERALA	5	11.15	75.47
KRISHNANAGAR	NADIA	WEST BENGAL	15	23.24	88.31
KURNOOL	KURNOOL	ANDHRA PRADESH	281	15.5	78.04
LEH	(N/A)	JAMMU & KASHMIR	3514	34.09	77.34
LUCKNOW	LUCKNOW	UTTAR PRADESH	111	26.52	80.56
LUDHIANA	LUDHIANA	PUNJAB	247	30.56	75.52
LUMDING	(N/A)	ASSAM	149	25.45	93.11
MACHILIPATAM	KRISHNA	ANDHRA PRADESH	3	16.12	81.09
MADRAS	CHENGALPATTU	TAMIL NADU	16	13	80.11
MADURAI	MADURAI	TAMIL NADU	133	9.55	78.07
MAHABALESHWAR	SATARA	MAHARASHTRA	1382	17.56	73.4
MAINPURI	MAINPURI	UTTAR PRADESH	157	27.14	79.03
MALDA	MALDAH	WEST BENGAL	31	25.02	88.08
MALEGAON	NASHIK	MAHARASHTRA	437	20.33	74.32
MANGALORE	DAKSHIN KANNAD	KARNATAKA	22	12.52	74.51
MARMUGAO	NORTH GOA	GOA	62	15.25	73.47
MERCARA	KODAGU	KARNATAKA	1152	12.25	75.44
MIDNAPORE	MEDINIPUR	WEST BENGAL	45	22.25	87.19
MINICOY	(N/A)	LAKSHADWEEP	2	8.18	73
MIRAJ (SANGLI)	SANGLI	MAHARASHTRA	554	16.49	74.41
MOTIHARI	CHAMPARAN	BIHAR	66	26.4	84.55
MOUNT ABU	SIROHI	RAJASTHAN	1195	24.36	72.43
MOWGONG	HAMIRPUR	UTTAR PRADESH	229	25.04	79.27

MEASUREMENT STATION	DISTRICT	STATE / UNION TERRITORY	ALTITUDE (m)	LATITUDE (o,/)	LONGITUDE (o,/)
MUKTESWAR (KUMAON)	ALMORA	UTTARANCHAL	2311	29.28	79.39
MUSSOORIE	TEHRI GARWAHAL	UTTARANCHAL	2042	30.27	78.05
MYSORE	MANDYA	KARNATAKA	767	12.18	76.42
NAGAPPATTINAM	THANJAVUR	TAMIL NADU	9	10.46	79.51
NELLORE	NELLORE	ANDHRA PRADESH	20	14.27	79.59
NEW DELHI-SAFDARJANG	(N/A)	DELHI	216	28.35	77.12
NIMACH	MANDSAUR	MADHYA PRADESH	496	24.28	74.54
NIZAMABAD	NIZAMABAD	ANDHRA PRADESH	381	18.4	78.06
PACHMARHI	HOSHANGABAD	MADHYA PRADESH	1075	22.28	78.26
PAMBAN	(N/A)	TAMIL NADU	11	9.16	79.18
PATNA	PATNA	BIHAR	53	25.37	85.1
PENDRA	BILASPUR	CHHATTISGARH	625	22.46	81.54
PHALODI	JODHPUR	RAJASTHAN	234	27.08	72.22
POONA	PUNE	MAHARASHTRA	559	18.32	73.51
PURI	PURI	ORISSA	6	19.48	85.49
PURNEA	BHAGALPUR	BIHAR	38	25.16	87.28
RAICHOR	RAICHOR	KARNATAKA	400	16.12	77.21
RAIPUR	RAIPUR	CHHATTISGARH	298	21.14	81.39
RAJKOT	RAJKOT	GUJARAT	138	22.18	70.47
RANCHI	RANCHI	JHARKHAND	655	23.26	85.24
RENTACHINTALA	GUNTUR	ANDHRA PRADESH	106	16.33	79.33
ROORKEE	SAHARANPUR	UTTARANCHAL	274	29.51	77.53
SABAUR	BHAGALPUR	BIHAR	37	25.14	87.04
SAGAR	SAGAR	MADHYA PRADESH	551	23.51	78.45
SAGAR ISLAND	(N/A)	WEST BENGAL	3	21.39	88.03
SALEM	SALEM	TAMIL NADU	278	11.39	78.1
SAMBALPUR	SAMBALPUR	ORISSA	148	21.28	83.58
SATNA	SATNA	MADHYA PRADESH	317	24.34	80.5
SEONI	SEONI	MADHYA PRADESH	619	22.05	79.33
SHILLONG	(N/A)	MEGHALAYA	1598	25.34	91.53
SHOLAPUR	SOLAPUR	MAHARASHTRA	479	17.4	75.54
SIBSAGAR	(N/A)	ASSAM	97	26.59	94.38
SILCHAR	(N/A)	ASSAM	29	24.49	92.48
SHIMLA	(N/A)	HIMACHAL PRADESH	2202	31.06	77.1
SRINAGAR	(N/A)	JAMMU & KASHMIR	1586	34.05	74.5
SURAT	SURAT	GUJARAT	12	21.12	72.5
TEZPUR	(N/A)	ASSAM	79	26.37	92.47
TIRUCHCHIRAPALLI	TIRUCHCHIRAPPALLI	TAMIL NADU	88	10.46	78.43
TRIVANDRUM	THIRUVANENTHAPURAM	KERALA	64	8.29	76.57
UMARIA	SHAHDOL	MADHYA PRADESH	459	23.32	80.53
VARANASI (BABATPUR)	VARANASI	UTTAR PRADESH	85	25.27	82.52
VELLORE	VELLORE	TAMIL NADU	214	12.55	79.09
VERAVAL	JUNAGARH	GUJARAT	8	20.54	70.22
VISHAKHAPATNAM	VISAKHAPATNAM	ANDHRA PRADESH	3	17.43	83.14

Source: CLIMWAT (FAO, 2006), shaded weather stations are excluded from the calculation of the ET_0, because they are either situated in non agricultural area like deserts and mountains or very clearly cause an uneven distribution of the weather stations over the state area.

Appendix V. Crop parameters

Crop	Season	Length of crop development stages[1]				Total duration	Sowing date	Harvest date	Crop coefficients[2]		
		I	CD	MS	LS				I	MS	LS
Unit		days					date		-		
Rice	kharif	30	30	80	40	180	1-Jun	1-Dec	1.05	1.10	0.75
	rabi	30	30	60	30	150	1-Dec	1-May	1.05	1.25	0.75
Wheat	rabi	15	25	50	30	120	15-Nov	15-Mar	0.70	1.15	0.30
Millet	kharif	15	25	40	25	105	15-Jun	1-Oct	0.30	1.00	0.30
Sorghum	kharif	20	35	45	30	130	1-Jun	10-Oct	0.30	1.05	0.55
	rabi	20	35	45	30	130	10-Oct	20-Feb	0.30	1.05	0.55
Maize	kharif	20	35	40	30	125	1-Jun	5-Oct	0.30	1.20	0.50
	rabi	20	35	40	30	125	1-Oct	5-Feb	0.30	1.20	0.50
Sugar cane	perennial	30	50	180	60	320	1-Mar	20-Jan	0.40	1.25	0.75
Chick peas	rabi	20	30	50	30	130	10-Nov	20-Mar	0.40	1.00	0.35
Pigeon Peas	kharif	20	30	60	30	140	1-Jul	20-Nov	0.40	1.15	0.30
Dry beans	kharif	15	25	30	20	90	1-Jul	1-Oct	0.40	1.15	0.35
	rabi	15	25	30	20	90	1-Nov	1-Feb	0.40	1.15	0.35
Soybean	kharif	20	30	60	25	135	1-Jul	15-Nov	0.40	1.15	0.50
Groundnut	kharif	35	45	35	25	140	1-Jun	20-Oct	0.40	1.15	0.60
	rabi	25	35	45	25	130	1-Dec	10-Apr	0.40	1.15	0.60
Rapeseed	rabi	30	30	60	30	150	1-Nov	1-Apr	0.35	1.15	0.35
Seed cotton	kharif	30	50	60	55	195	1-Jun	15-Dec	0.35	1.20	0.60

[1,2] I = initial stage, CD = crop development state, MS = mid-season stage and LS = late season stage. [1] sources: Allen et al. (1998) and Directorate of Pulses Development (Government of India, 2006), [2] sources: Allen et al. (1998).

Appendix VI. Product and value fractions

Product and value fractions of the processed crops in India

Primary crop	Processed product	Product fraction[1]	Value fraction[2]
Year		1997-2001	
Paddy rice	Milled rice[3]	0.66	1.00
Wheat[4]	-	1.00	1.00
Maize[4]	-	1.00	1.00
Millet[4]	-	1.00	1.00
Sorghum[4]	-	1.00	1.00
Sugar cane	Raw sugar[5]	0.105	1.00
Chickpeas[6]	-	1.00	1.00
Pigeon peas[6]	-	1.00	1.00
Dry beans[6]	-	1.00	1.00
Soybean	Soybean oil[7]	0.18	0.34
Soybean	Soybean cake	0.79	0.66
Groundnut in shell	Groundnut shelled	0.705	1.00
Groundnut shelled	Groundnut oil[7]	0.415	1.00
Rapeseed	Rapeseed oil[7]	0.344	1.00
Coconut	Coconut oil[7]	0.12	-
Sunflower seed	Sunflower seed oil[7]	0.368	-
Seed cotton	Cottonseed	0.67	0.21
Seed cotton	Cotton lint	0.33	0.79
Cottonseed	Cottonseed oil[7]	0.14	1.00

[1] *Source: FAO (2006).*

[2] *Source: Chapagain and Hoekstra (2004).*

[3] *Because of annual changes between the volumes of processed rice products, the product fraction of the milled rice equivalent might change in time. The product fraction that is used for the milled rice equivalent in India is 0.66.*

[4] *Wheat, maize, millet and sorghum are generally consumed in the form of flour, which has a product fraction lower than 1 (0.98 for whole grain wheat flour, 0.80 for maize flour, 0.93 for millet flour and 0.95 for sorghum flour). But in this study the consumption is given in the primary equivalent, which means the product fraction of these grains are 1.00.*

[5] *The average global fraction of sugar cane that ends up in the form of raw sugar is 0.10. For India this product fraction of the raw sugar equivalent is the same.*

[6] *In general, pulses are consumed as a whole, which means a product fraction of 1.00. Only in the case of chickpeas, approximately 50% is consumed in the form of flour known as besan (Price et al., 2003). This flour has a product fraction of 0.80. In this study, this fact is not taken into account, which means all pulses are assumed to have a product fraction of 1.00.*

[7] *The product fractions of the edible oils are directly taken from the crop balances. These are found by dividing the volume of oil produced by the volume of the primary crop that is manufactured.*

Appendix VII. National crop balances

Products[1]	Domestic supply[2]					Domestic utilization[3]						Per capita
	P	I	ΔS	E	DS	Fd	Sd	M	W	Ou	C	C
Unit	1000 ton/yr											kg/yr
Year	1997-2001											
Rice, milled equivalent	87317	25	-3858	2606	80878	349	4694	4	872	30	74929	74.9
Wheat	70607	943	-4632	850	66067	847	4816	5	2995	0	57404	57.4
Maize	11735	75	0	40	11770	4780	707	3	1278	46	4956	5.0
Millet	10123	0	0	12	10110	162	361	0	497	0	9091	9.1
Sorghum	7943	0	0	0	7943	95	293	0	543	0	7011	7.0
Sugar cane	288202	0	0	0	288202	2957	19021	253254	0	0	12969	13.0
Sugar, non centrifugal[4]	9008			0	9008	450					8558	8.6
Sugar, raw equivalent[4]	17469	524	-1244	422	16327			4			16324	16.3
Pulses[5]	13349	931	0	175	14105	1202	719	0	457	0	11727	11.7
Soybean[6]	6385	7	-580	40	5772	0	376	4810	294	0	292	0.3
Soybean oil	867	607	-22	6	1447	0	0	0	0	0	1447	1.4
Groundnut shelled	4941	0	-8	154	4779	20	323	3902	148	0	385	0.4
Groundnut oil	1621	0	-40	0	1581	0	0	0	0	0	1581	1.6
Sunflower seed oil[7]	281	312	-2	1	589	0	0	0	0	32	557	0.6
Rape and mustard seed	5400	2	0	3	5399	0	41	4819	162	0	377	0.4
Rape and mustard oil	1656	122	-3	2	1772	0	0	0	0	8	1764	1.8
Cottonseed	3696	0	0	0	3696	609	174	2728	185	0	0	0.0
Cottonseed oil	382	27	-7	0	402	0	0	0	0	0	402	0.4
Coconut oil[7]	422	19	-4	3	433	0	0	0	0	13	420	0.4
Palm oil[7]	0	2608	-98	25	2485	0	0	0	0	438	2048	2.0

[1] *The national crop balances are taken from food balance sheets of FAO (2006), since cotton lint is not considered as food, this crop is excluded.*

[2] *P = domestic crop production, I = crop import , ΔS = crop withdrawn from domestic stocks, E = crop export, DS = domestic supply (=P+I+ΔS-E).*

[3] *Fd = feed (amount of crop for livestock and poultry feeding), Sd = seed use (amount of crop set aside for reproduction purposes), M = crop manufacture (amount of crop which is further processed), W = crop waste, Ou = other crop use, C = human crop consumption.*

[4] *FAO divides sugar from sugar cane in centrifugal sugar (raw equivalent) and non-centrifugal (raw) sugar. Centrifugal sugar is created when raw sugar is divided in sugar crystals and molasses by the use of a centrifuge. In India two types of centrifugal sugar are consumed; plantation white sugar and khandsari. Plantation white sugar is the result of the first refining process in the sugar mills. In developed countries white sugar undergoes one more refining process to obtain an even purer form of sugar. Khandsari, mainly produced in Uttar Pradesh, is very similar to plantation white sugar. The difference is that khandsari is produced by small scale country mills. Non-centrifugal sugar (known as gur) is sugar which still includes the molasses and is mostly consumed in rural areas as a food item instead of a sweetener. In this study raw sugar refers to the sum of non centrifugal sugar and centrifugal sugar in the raw equivalent.*

[5] *The export of pulses consists mainly of lentils, that are excluded from this study, therefore this export is also excluded.*

[6] *Soybean cake is not mentioned in the food balance sheets of FAO (2006), and while the import and export is known (FAO, 2006), the various domestic utilizations are unknown.*

[7] *The shaded crops are only taken into account in the state crop balances of "remaining edible oils".*

Appendix VIII. Virtual water contents of crops

Here, an example of the calculation of the crop water requirement of a crop.

Calculation of the crop water requirement for milled rice in Andhra Pradesh during kharif

Column	1	2	3	4	5	6	7
Parameter	ET_0	P_{tot}	P_{eff}	K_c	$ET_{c,opt}$	$ET_{c,rw}$	IWR
Unit		mm/10days		-		mm/10days	
Source		CROPWAT		App.IV	col.1*col.4	Min (col.3,5)	col.5-col.6
Period*			crop growing season: 1 june - 30 november (App.IV)				
1-Jan	37.95	1.36	1.35				
10-Jan	37.95	1.36	1.35				
20-Jan	37.95	1.36	1.35				
1-Feb	47.36	3.30	3.24				
10-Feb	47.36	3.30	3.24				
20-Feb	47.36	3.30	3.24				
1-Mar	58.84	3.27	3.22				
10-Mar	58.84	3.27	3.22				
20-Mar	58.84	3.27	3.22				
1-Apr	65.11	6.55	6.34				
10-Apr	65.11	6.55	6.34				
20-Apr	65.11	6.55	6.34				
1-May	69.75	13.67	12.72				
10-May	69.75	13.67	12.72				
20-May	69.75	13.67	12.72				
1-Jun	62.55	34.55	28.39	1.05	65.67	28.39	37.28
10-Jun	62.55	34.55	28.39	1.05	65.67	28.39	37.28
20-Jun	62.55	34.55	28.39	1.05	65.67	28.39	37.28
1-Jul	49.00	55.33	38.32	1.06	51.94	38.32	13.62
10-Jul	49.00	55.33	38.32	1.08	52.92	38.32	14.60
20-Jul	49.00	55.33	38.32	1.1	53.90	38.32	15.58
1-Aug	47.74	49.06	36.43	1.1	52.51	36.43	16.08
10-Aug	47.74	49.06	36.43	1.1	52.51	36.43	16.08
20-Aug	47.74	49.06	36.43	1.1	52.51	36.43	16.08
1-Sep	44.88	53.79	39.53	1.1	49.37	39.53	9.84
10-Sep	44.88	53.79	39.53	1.1	49.37	39.53	9.84
20-Sep	44.88	53.79	39.53	1.1	49.37	39.53	9.84
1-Oct	41.93	54.52	36.53	1.1	46.12	36.53	9.59
10-Oct	41.93	54.52	36.53	1.1	46.12	36.53	9.59
20-Oct	41.93	54.52	36.53	1.05	44.02	36.53	7.50
1-Nov	36.59	27.00	20.34	0.96	35.13	20.34	14.78
10-Nov	36.59	27.00	20.34	0.87	31.83	20.34	11.49
20-Nov	36.59	27.00	20.34	0.8	29.27	20.34	8.93
1-Dec	33.87	5.82	5.35				
10-Dec	33.87	5.82	5.35				
20-Dec	33.87	5.82	5.35				
Total					**893.92**	**598.64**	**295.28**

**Shaded area is time outside the growth period of the crop.*

Milled rice in kharif season

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	VWC blue	VWC green	VWC gray	VWC total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	m³/ton			
AP	8939	5986	2953	0.93	2757	2695	6803	2516	1096	2380	397	3873
AS	6503	6110	394	0.00	0	2278	3121	1370	0	4461	413	4874
BH	7620	5878	1742	0.39	685	3463	5112	1476	464	3982	508	4954
CG	7247	5823	1424	0.25	349	3740	3849	1030	339	5653	661	6653
DL	9627	4497	5130	1.00	5120	7	9	1312	3902	3427	807	8137
GJ	9119	4519	4600	0.63	2884	642	911	1406	2051	3213	606	5869
HR	9573	4185	5388	1.00	5377	1032	2597	2526	2128	1656	411	4195
HP	5422	4422	1000	0.63	625	82	124	1514	413	2921	568	3901
JK	7291	3702	3589	0.90	3227	258	473	1824	1769	2029	538	4336
JH	7118	5785	1333	0.40	528	1494	1733	1160	455	4988	648	6091
KT	8198	5824	2374	0.64	1508	1083	2561	2363	638	2465	365	3468
KL	6882	6882	0	0.52	0	297	606	2048	0	3361	397	3757
MP	7759	5327	2433	0.20	482	1725	1368	794	606	6705	831	8142
MH	8375	5803	2571	0.27	681	1468	2334	1590	429	3650	434	4512
OR	7446	6765	681	0.35	241	4223	5131	1215	198	5570	602	6371
PJ	8922	4234	4688	0.99	4651	2500	8506	3403	1367	1244	303	2914
RJ	10066	3525	6541	0.61	3990	169	197	1166	3421	3023	729	7173
TN	9661	5017	4644	0.92	4288	1923	6437	3347	1281	1499	298	3078
UA	6510	4969	1541	0.66	1013	294	601	2047	495	2427	427	3349
UP	8207	5392	2816	0.66	1849	5862	11901	2031	910	2654	430	3995
WB	7087	6470	617	0.23	145	4494	9216	2047	71	3160	330	3561
Total	8638	5714	2925	0.49	1436	39728	73590	1852	775	3086	430	4290

Milled rice in rabi season

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	VWC blue	VWC green	VWC gray	VWC total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	m³/ton			
AP	8312	585	7727	1.00	7727	1285	4172	3233	2390	181	318	2890
AS	4997	2524	2473	0.69	1711	270	550	2015	849	1253	437	2538
BH	6282	627	5655	1.00	5655	125	244	1944	2909	323	532	3764
CG	6997	887	6110	1.00	6110	0	0	0	0	0	0	0
DL	6884	681	6203	1.00	6203	0	0	0	0	0	0	0
GJ	8431	88	8343	1.00	8343	0	0	0	0	0	0	0
HR	5845	1002	4843	1.00	4843	0	0	0	0	0	0	0
HP	3662	2306	1356	1.00	1356	0	0	0	0	0	0	0
JK	3621	2485	1136	1.00	1136	0	0	0	0	0	0	0
JH	6486	883	5602	1.00	5602	0	0	0	0	0	0	0
KT	8663	554	8109	1.00	8109	343	972	2828	2867	196	365	3428
KL	8072	2078	5994	1.00	5994	55	137	2482	2415	837	417	3669
MP	6999	560	6439	1.00	6439	0	0	0	0	0	0	0
MH	8358	304	8055	1.00	8055	33	66	2037	3954	149	510	4613
OR	7263	902	6361	1.00	6361	273	578	2092	3040	431	488	3959
PJ	5051	1094	3957	1.00	3957	0	0	0	0	0	0	0
RJ	6728	279	6449	1.00	6449	0	0	0	0	0	0	0
TN	8328	1737	6591	1.00	6591	245	867	3537	1864	491	292	2647
UA	4795	1879	2916	1.00	2916	0	0	0	0	0	0	0
UP	6157	576	5581	1.00	5581	5	11	2492	2240	231	409	2880
WB	6386	1055	5331	1.00	5331	1446	4654	3218	1656	328	321	2306
Total	7252	987	6265	1.00	6265	4080	12251	2990	2093	330	344	2767

Milled rice total

State	A	P	Y	N use	VWC			
					blue	green	gray	total
Unit	10^3 ha	10^3 ton	kg/ha	kg/ha	m^3/ton			
AP	3980	10975	2758	101	1588	1544	367	3499
AS	2548	3670	1441	60	127	3980	417	4524
BH	3588	5356	1493	76	575	3815	509	4899
CG	3740	3849	1029	68	339	5653	661	6653
DL	7	9	1280	103	3902	3427	807	8137
GJ	642	911	1419	86	2051	3213	606	5869
HR	1032	2597	2516	103	2128	1656	411	4195
HP	82	124	1512	86	413	2921	568	3901
JK	258	473	1834	99	1769	2029	538	4336
JH	1494	1733	1160	75	455	4988	648	6091
KT	1426	3533	2477	90	1252	1841	365	3457
KL	352	743	2113	85	446	2895	400	3741
MP	1725	1368	793	66	606	6705	831	8142
MH	1501	2400	1599	70	526	3553	436	4515
OR	4496	5709	1270	75	486	5049	591	6126
PJ	2500	8506	3402	103	1367	1244	303	2914
RJ	169	197	1168	85	3421	3023	729	7173
TN	2168	7304	3369	100	1350	1379	297	3027
UA	294	601	2046	87	495	2427	427	3349
UP	5866	11913	2031	87	912	2652	430	3993
WB	5941	13870	2335	76	603	2210	327	3139
Total	43808	85841	1959	82	963	2692	417	4073

Wheat total (rabi season only)

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	N use	VWC			
										blue	green	gray	total
Unit	m^3/ha	m^3/ha	m^3/ha	-	m^3/ha	10^3 ha	10^3 ton	kg/ha	kg/ha	m^3/ton			
AP	4625	652	3973	0.77	3063	13	8	601	94	5100	1085	1561	7747
AS	2622	1058	1564	0.00	0	82	100	1230	56	0	860	454	1314
BH	3004	436	2569	0.90	2307	2051	4508	2194	101	1051	198	457	1707
CG	3635	575	3059	0.59	1814	72	72	1004	85	1806	573	849	3228
DL	3363	559	2805	1.00	2805	30	42	1439	106	1950	388	755	3093
GJ	4630	90	4540	0.86	3900	549	1271	2297	99	1698	39	426	2163
HR	2765	840	1925	0.99	1905	2188	8653	3945	105	483	213	266	962
HP	1737	1510	227	0.19	42	369	530	1431	65	29	1055	452	1537
JK	1727	1524	202	0.26	52	252	352	1421	68	36	1072	490	1599
JH	3271	657	2614	0.90	2347	61	101	1657	101	1417	397	606	2420
KT	5044	386	4657	0.43	2003	259	198	761	77	2632	508	1010	4149
KL	5026	1345	3681	0.00	0	0	0	0	56	0	0	0	0
MP	3559	520	3040	0.71	2170	4256	7326	1707	91	1271	304	531	2106
MH	4603	302	4301	0.84	3591	873	1106	1255	97	2862	241	768	3871
OR	3969	747	3222	1.00	3222	6	8	1320	106	2441	566	785	3792
PJ	2267	858	1409	0.98	1374	3333	14462	4336	104	317	198	240	755
RJ	3296	233	3063	0.98	3011	2576	6528	2534	105	1188	92	413	1694
TN	4903	1600	3303	0.00	0	0	0	0	56	0	0	0	0
UA	2313	1478	835	0.92	770	380	703	1851	102	416	799	550	1764
UP	2922	485	2437	0.92	2246	8921	23739	2655	102	846	183	382	1411
WB	3240	602	2639	0.79	2085	375	867	2307	95	904	261	411	1576
Total	3040	566	2475	0.88	2170	26645	70573	2648	99	822	214	376	1412

Maize in kharif season

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	VWC blue	VWC green	VWC gray	VWC total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	m³/ton			
AP	5153	4090	1063	0.15	156	359	1032	2892	54	1414	139	1607
AS	3921	3921	0	0.04	0	20	14	697	0	5626	537	6163
BH	4422	4405	17	0.06	1	271	468	1729	1	2547	220	2768
CG	4022	4022	0	0.00	0	91	97	1063	0	3783	345	4129
DL	5599	4252	1347	0.00	0	0	0	0	0	0	0	0
GJ	4939	3956	982	0.11	103	405	581	1416	73	2793	272	3138
HR	5826	3940	1886	0.15	277	18	42	2270	122	1736	177	2034
HP	3126	3103	23	0.08	2	300	688	2293	1	1353	168	1522
JK	4514	3314	1200	0.10	116	320	507	1585	73	2091	245	2410
JH	4026	4026	0	0.00	0	102	133	1283	0	3137	281	3418
KT	4608	3899	709	0.43	304	518	1521	2937	104	1327	158	1589
KL	3851	3824	27	0.00	0	0	0	0	0	0	0	0
MP	4227	4174	52	0.01	1	814	1312	1607	0	2598	229	2827
MH	4562	4183	380	0.00	0	230	343	1512	0	2766	246	3011
OR	4173	4173	0	0.10	0	52	65	1228	0	3398	316	3714
PJ	5464	3963	1501	0.55	820	161	412	2555	321	1551	192	2064
RJ	5927	3405	2522	0.08	199	964	1102	1138	175	2993	336	3504
TN	5811	2837	2974	1.00	2973	23	37	1578	1884	1798	371	4053
UA	3689	3680	8	0.29	2	35	49	1398	2	2633	308	2943
UP	4752	4597	154	0.29	44	927	1297	1403	31	3277	308	3617
WB	4103	4103	0	0.07	0	35	90	2524	0	1625	151	1776
Total	4804	3950	854	0.15	130	5648	9790	1724	75	2281	231	2587

Maize in rabi season

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	VWC blue	VWC green	VWC gray	VWC total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	m³/ton			
AP	3912	1260	2652	1.00	2652	90	414	4574	580	275	130	985
AS	2336	939	1397	0.00	0	0	0	0	0	0	0	0
BH	2623	662	1961	1.00	1961	347	969	2794	702	237	213	1152
CG	3059	742	2317	0.00	0	0	0	0	0	0	0	0
DL	2950	527	2423	0.00	0	0	0	0	0	0	0	0
GJ	4132	321	3811	0.00	0	0	0	0	0	0	0	0
HR	2433	709	1725	0.00	0	0	0	0	0	0	0	0
HP	1599	1032	567	0.00	0	0	0	0	0	0	0	0
JK	1699	1104	594	0.00	0	0	0	0	0	0	0	0
JH	2826	777	2049	0.00	0	0	0	0	0	0	0	0
KT	4310	942	3368	1.00	3368	71	163	2287	1473	412	261	2145
KL	4323	2024	2299	0.00	0	0	0	0	0	0	0	0
MP	3035	807	2228	0.00	0	0	0	0	0	0	0	0
MH	3963	809	3154	0.78	2455	72	107	1485	1653	545	367	2565
OR	3439	1039	2400	0.00	0	0	0	0	0	0	0	0
PJ	2015	710	1306	0.00	0	0	0	0	0	0	0	0
RJ	2891	277	2613	0.00	0	0	0	0	0	0	0	0
TN	4190	2508	1682	0.26	436	58	93	1612	270	1556	266	2092
UA	2108	1100	1008	0.00	0	0	0	0	0	0	0	0
UP	2517	693	1823	0.00	0	0	0	0	0	0	0	0
WB	2813	784	2029	0.00	0	0	0	0	0	0	0	0
Total	3315	962	2353	0.91	2133	639	1746	2735	780	351	210	1342

Maize total

State	A	P	Y	N use	VWC			
					blue	green	gray	total
Unit	10^3 ha	10^3 ton	kg/ha	kg/ha	m^3/ton			
AP	450	1446	3215	44	204	1088	137	1429
AS	20	14	697	37	0	5626	537	6163
BH	618	1437	2325	50	473	990	216	1679
CG	91	97	1063	37	0	3783	345	4129
DL	0	0	0	0	0	0	0	0
GJ	405	581	1436	39	73	2793	272	3138
HR	18	42	2262	40	122	1736	177	2034
HP	300	688	2294	38	1	1353	168	1522
JK	320	507	1585	39	73	2091	245	2410
JH	102	133	1302	37	0	3137	281	3418
KT	589	1684	2858	48	236	1239	168	1643
KL	0	0	0	0	0	0	0	0
MP	814	1312	1611	37	0	2598	229	2827
MH	302	450	1488	41	394	2236	275	2905
OR	52	65	1231	39	0	3398	316	3714
PJ	161	412	2560	49	321	1551	192	2064
RJ	964	1102	1142	38	175	2993	336	3504
TN	81	130	1603	47	731	1625	296	2652
UA	35	49	1400	43	2	2633	308	2943
UP	927	1297	1400	43	31	3277	308	3617
WB	35	90	2535	38	0	1625	151	1776
Total	6287	11536	1835	42	182	1989	228	2399

Millet total (kharif season only)

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	N use	VWC			
										blue	green	gray	total
Unit	m^3/ha	m^3/ha	m^3/ha	-	m^3/ha	10^3 ha	10^3 ton	kg/ha	kg/ha	m^3/ton			
AP	3709	3242	467	0.20	92	282	261	924	27	99	3508	292	3899
AS	2856	2856	0	0.00	0	10	5	483	18	0	5911	382	6293
BH	3172	3172	0	0.00	0	32	32	972	19	0	3264	189	3453
CG	2859	2859	0	0.09	0	320	70	219	22	0	13066	1018	14084
DL	3989	3608	382	1.00	382	3	2	910	62	419	3967	696	5082
GJ	3502	3217	285	0.21	59	1013	1098	1082	27	55	2972	253	3281
HR	4185	3413	772	0.22	169	600	684	1140	28	148	2994	246	3388
HP	2223	2223	0	0.05	0	15	10	658	21	0	3380	316	3695
JK	3265	2834	431	0.00	2	20	9	467	19	4	6070	398	6472
JH	2878	2878	0	0.00	0	71	42	583	19	0	4937	318	5255
KT	3321	3088	233	0.10	23	1436	1888	1314	23	17	2350	172	2539
KL	2797	2797	0	0.00	0	2	1	767	18	0	3645	239	3884
MP	2972	2972	0	0.00	0	645	307	477	18	0	6235	387	6622
MH	3245	3239	6	0.05	0	1970	1401	710	20	0	4564	287	4851
OR	2996	2996	0	0.00	0	129	69	539	18	0	5558	342	5900
PJ	3923	3393	529	0.79	419	5	5	962	53	435	3529	550	4515
RJ	4224	3047	1177	0.05	58	4516	2273	492	21	117	6198	408	6723
TN	4223	2434	1789	0.13	236	331	495	1492	24	158	1631	162	1952
UA	2616	2616	0	0.05	0	217	268	1238	21	0	2113	168	2281
UP	3380	3380	0	0.05	0	889	1148	1289	21	0	2622	161	2783
WB	2957	2957	0	0.00	0	18	18	1019	18	0	2902	181	3083
Total	3653	3106	547	0.08	45	12524	10086	805	22	56	3892	273	4222

Sorghum in kharif season

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	VWC blue	VWC green	VWC gray	VWC total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	m³/ton			
AP	4880	4209	672	0.00	0	335	274	823	0	5111	329	5440
AS	3706	3706	0	0.00	0	0	0	0	0	0	0	0
BH	4196	4158	38	0.00	0	5	4	724	0	5747	385	6132
CG	3835	3835	0	0.00	0	0	0	0	0	0	0	0
DL	5299	4243	1056	1.00	1056	9	4	445	2374	9542	1318	13235
GJ	4722	3884	838	0.00	0	150	142	938	0	4141	285	4426
HR	5488	3932	1556	0.61	951	115	23	198	4813	19903	2349	27065
HP	2972	2923	49	0.00	0	0	0	0	0	0	0	0
JK	4251	3330	920	0.00	0	0	0	0	0	0	0	0
JH	3829	3829	0	0.00	0	0	0	0	0	0	0	0
KT	4382	3990	392	0.00	0	391	528	1347	0	2963	199	3162
KL	3675	3675	0	0.00	0	2	1	473	0	7764	549	8313
MP	4040	3931	109	0.00	0	690	568	821	0	4787	327	5114
MH	4355	4203	152	0.00	0	1924	2417	1256	0	3346	214	3560
OR	3972	3972	0	0.00	0	14	8	557	0	7127	484	7611
PJ	5144	3955	1189	0.00	0	0	0	0	0	0	0	0
RJ	5610	3422	2188	0.01	13	606	177	295	44	11598	926	12568
TN	5481	2972	2509	0.00	0	289	216	740	0	4014	361	4375
UA	3507	3488	19	0.00	0	0	0	0	0	0	0	0
UP	4507	4400	107	0.01	1	352	299	852	1	5164	320	5485
WB	3893	3893	0	0.00	0	1	1	474	0	8210	566	8777
Total	3990	3975	15	0.00	26	4884	4660	955	27	4163	282	4473

Sorghum in rabi season

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	VWC blue	VWC green	VWC gray	VWC total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	m³/ton			
AP	3835	1074	2761	0.07	193	379	298	795	242	1351	370	1964
AS	2224	963	1261	0.00	0	0	0	0	0	0	0	0
BH	2503	583	1921	0.00	0	0	0	0	0	0	0	0
CG	2990	688	2302	0.00	0	0	0	0	0	0	0	0
DL	2816	560	2256	0.00	0	0	0	0	0	0	0	0
GJ	3955	258	3698	0.18	677	53	40	734	923	351	434	1708
HR	2313	797	1516	0.00	0	0	0	0	0	0	0	0
HP	1494	1147	347	0.00	0	0	0	0	0	0	0	0
JK	1546	1224	322	0.00	0	0	0	0	0	0	0	0
JH	2721	753	1969	0.00	0	0	0	0	0	0	0	0
KT	4222	781	3441	0.11	364	1503	1039	692	527	1129	438	2094
KL	4245	1648	2597	0.00	0	0	0	0	0	0	0	0
MP	2946	735	2211	0.00	2	7	5	798	3	921	329	1252
MH	3855	644	3211	0.15	477	3214	1795	560	852	1150	566	2568
OR	3329	991	2338	0.00	0	0	0	0	0	0	0	0
PJ	1904	781	1123	0.00	0	0	0	0	0	0	0	0
RJ	2766	272	2495	0.00	0	0	0	0	0	0	0	0
TN	4109	2048	2062	0.69	1418	57	104	1910	742	1072	269	2083
UA	1981	1268	712	0.00	0	0	0	0	0	0	0	0
UP	2415	625	1790	0.00	0	0	0	0	0	0	0	0
WB	2703	737	1967	0.00	0	0	0	0	0	0	0	0
Total	3915	727	3188	0.14	436	5213	3282	630	690	1149	496	2335

Sorghum total

State	A	P	Y	N use	VWC			
					blue	green	gray	total
Unit	10^3 ha	10^3 ton	kg/ha	kg/ha	m³/ton			
AP	714	572	801	28	126	3154	351	3630
AS	0	0	0	0	0	0	0	0
BH	5	4	699	27	0	5747	385	6132
CG	0	0	0	0	0	0	0	0
DL	9	4	444	0	2374	9542	0	11916
GJ	204	182	895	28	204	3304	318	3826
HR	115	23	197	46	4813	19903	2349	27065
HP	0	0	0	27	0	0	0	0
JK	0	0	0	27	0	0	0	0
JH	0	0	0	27	0	0	0	0
KT	1894	1567	827	30	349	1747	357	2454
KL	2	1	490	0	0	7764	0	7764
MP	696	573	823	27	0	4751	327	5078
MH	5138	4212	820	30	363	2410	364	3137
OR	14	8	555	27	0	7127	484	7611
PJ	0	0	0	27	0	0	0	0
RJ	606	177	293	27	44	11598	926	12568
TN	347	319	921	31	241	3058	331	3631
UA	0	0	0	27	0	0	0	0
UP	352	299	849	27	1	5164	320	5485
WB	1	1	475	27	0	8210	566	8777
Total	10097	7941	786	29	301	2918	370	3589

Sugar cane total (rabi season only)

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	N use	VWC			
										blue	green	gray	total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10^3 ha	10^3 ton	kg/ha	kg/ha	m³/ton			
AP	17124	6856	10269	0.94	9663	211	16337	77394	125	125	89	16	230
AS	11589	9961	1628	0.00	0	31	1229	39768	106	0	250	27	277
BH	14507	7313	7194	0.34	2410	107	4716	44008	113	55	166	26	247
CG	14469	7311	7158	0.00	0	0	0	0	0	0	0	0	0
DL	17677	5121	12556	0.00	0	0	0	0	0	0	0	0	0
GJ	17825	4666	13159	1.00	13159	181	12713	70189	126	187	66	18	272
HR	16655	5003	11653	0.98	11420	142	7852	55357	126	206	90	23	319
HP	9790	6810	2980	0.00	0	0	0	0	0	0	0	0	0
JK	12095	5527	6568	0.00	0	0	0	0	0	0	0	0	0
JH	13875	7402	6473	0.00	0	0	0	0	0	0	0	0	0
KT	16325	7062	9263	1.00	9263	344	33394	96100	126	96	73	13	183
KL	13866	11078	2788	1.00	2788	5	475	88367	126	32	125	14	171
MP	15342	6325	9018	0.99	8900	50	1733	36602	126	243	173	36	452
MH	16801	6282	10519	1.00	10519	538	45972	85277	126	123	74	15	212
OR	14618	8568	6051	1.00	6051	20	1198	58615	126	103	146	22	271
PJ	15452	5197	10255	0.96	9855	126	7772	61395	126	161	85	20	266
RJ	18094	3852	14243	0.95	13573	21	975	45315	125	300	85	27	412
TN	17731	7548	10184	1.00	10184	296	31468	106108	126	96	71	12	179
UA	12188	7086	5102	0.90	4567	120	7350	61250	124	75	116	20	211
UP	15217	6169	9048	0.90	8098	1884	112637	59798	124	135	103	21	259
WB	13553	8891	4662	0.36	1664	25	1773	72013	113	23	123	16	162
Total	15179	6014	9164	0.91	8310	4101	287595	70138	124	126	91	18	234

Chickpeas total (rabi season only)

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	N use	VWC			
										blue	green	gray	total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	kg/ha	m³/ton			
AP	4182	655	3527	0.01	32	153	121	773	20	41	848	250	1139
AS	2385	1198	1187	0.00	0	3	1	500	20	0	2397	392	2789
BH	2760	463	2298	0.03	78	106	102	972	20	80	476	210	766
CG	3313	634	2680	0.03	80	148	74	503	20	160	1260	400	1820
DL	3079	583	2496	0.00	0	0	0	0	20	0	0	0	0
GJ	4172	103	4069	0.38	1554	100	74	683	26	2277	151	355	2784
HR	2544	888	1657	0.38	625	256	204	744	26	840	1193	329	2361
HP	1590	1494	96	0.04	4	2	2	1181	20	3	1265	173	1441
JK	1573	1488	86	0.00	0	0	0	0	20	0	0	0	0
JH	2987	714	2273	0.00	0	0	0	0	20	0	0	0	0
KT	4529	466	4063	0.10	418	346	185	533	21	785	874	399	2058
KL	4477	1308	3169	0.00	0	0	0	0	20	0	0	0	0
MP	3248	564	2684	0.38	1012	2462	2211	894	26	1132	631	291	2054
MH	4156	353	3802	0.35	1327	795	460	571	26	2323	618	443	3384
OR	3588	845	2744	0.00	0	30	16	548	20	0	1542	355	1897
PJ	2096	909	1187	0.35	417	11	10	890	26	468	1022	293	1783
RJ	3019	249	2770	0.42	1166	1639	1229	719	27	1622	346	359	2326
TN	4400	1463	2937	0.11	308	7	5	653	21	472	2240	329	3041
UA	2110	1538	572	0.00	0	0	0	0	20	0	0	0	0
UP	2690	510	2180	0.15	323	868	771	888	22	363	574	250	1187
WB	2956	677	2279	0.06	130	32	27	818	21	159	828	246	1233
Total	3435	451	2985	0.30	895	6959	5492	787	25	1159	598	314	2071

Pigeon pea total (kharif season only)

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	N use	VWC			
										blue	green	gray	total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	kg/ha	m³/ton			
AP	5429	4391	1038	0.01	8	416	158	369	20	23	11913	520	12456
AS	4149	4013	136	0.00	0	7	5	711	20	0	5645	276	5920
BH	4629	3717	911	0.00	2	43	59	1389	20	1	2677	141	2819
CG	4352	3633	719	0.00	0	49	20	419	20	0	8673	473	9146
DL	5533	3177	2356	0.00	0	0	0	0	20	0	0	0	0
GJ	5501	2853	2649	0.12	326	353	245	682	22	477	4180	313	4970
HR	5544	3210	2334	0.78	1830	24	25	945	33	1936	3397	321	5655
HP	3195	2555	640	0.00	0	0	0	0	20	0	0	0	0
JK	4382	2748	1634	0.00	0	0	0	0	20	0	0	0	0
JH	4319	3653	666	0.00	1	22	24	1083	20	1	3372	180	3552
KT	5146	4054	1092	0.02	17	494	204	405	20	43	9999	481	10523
KL	4582	4526	56	0.00	0	0	0	0	20	0	0	0	0
MP	4502	3385	1117	0.01	10	311	255	820	20	12	4130	241	4383
MH	5063	3707	1355	0.02	24	1034	693	670	20	36	5536	297	5869
OR	4619	4459	160	0.01	1	139	81	581	20	2	7677	341	8020
PJ	5138	3046	2092	0.86	1805	9	7	801	35	2254	3804	432	6491
RJ	5811	2731	3080	0.06	191	29	22	735	21	260	3716	278	4254
TN	5996	4031	1966	0.03	63	72	46	642	20	98	6276	313	6686
UA	3789	3074	715	0.00	0	0	0	0	20	0	0	0	0
UP	4768	3550	1218	0.13	156	422	498	1184	22	132	2998	185	3315
WB	4414	4112	302	0.00	0	4	3	703	20	0	5848	281	6129
Total	5154	3195	1959	0.04	84	3428	2345	684	20	127	5497	297	5922

Dry beans in kharif season

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	VWC			
									blue	green	gray	total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	m³/ton			
AP	3518	2884	634	0.00	0	431	170	398	0	7252	497	7749
AS	2755	2755	0	0.00	0	0	0	0	0	0	0	0
BH	3000	3000	0	0.00	0	41	24	596	0	5036	329	5365
CG	2700	2700	0	0.01	0	116	43	374	0	7210	535	7745
DL	3704	3112	592	0.00	0	0	0	0	0	0	0	0
GJ	3299	2698	601	0.11	67	291	124	414	161	6515	507	7182
HR	3899	3044	855	0.42	356	14	4	282	1260	10781	924	12965
HP	2078	2078	0	0.18	0	11	4	372	0	5580	601	6182
JK	3079	2480	600	0.15	90	18	8	459	196	5406	481	6083
JH	2723	2723	0	0.02	0	33	24	740	0	3680	271	3951
KT	3195	2748	447	0.00	0	458	139	292	0	9424	648	10072
KL	2768	2749	19	0.00	0	0	0	0	0	0	0	0
MP	2760	2760	0	0.21	0	504	161	319	0	8657	727	9384
MH	3068	2880	188	0.16	31	1304	566	435	71	6625	517	7213
OR	2869	2869	0	0.00	0	261	58	220	0	13013	880	13893
PJ	3645	2947	698	0.76	527	41	24	574	917	5130	558	6606
RJ	3914	2679	1234	0.16	193	1721	344	186	1033	14374	1117	16524
TN	4049	2278	1771	0.00	0	114	55	489	0	4659	402	5061
UA	2434	2434	0	0.00	0	0	0	0	0	0	0	0
UP	3146	3091	55	0.00	0	335	127	377	0	8208	518	8727
WB	2825	2825	0	0.00	0	59	33	563	0	5019	348	5367
Total	3102	2567	534	0.14	73	5750	1907	332	233	8597	662	9492

Dry beans in rabi season

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	VWC			
									blue	green	gray	total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	m³/ton			
AP	2686	711	1975	0.02	38	561	320	569	68	1251	349	1668
AS	1525	564	962	0.00	0	48	25	527	0	1071	373	1444
BH	1697	256	1441	0.03	39	176	99	560	70	456	358	884
CG	2055	331	1724	0.00	0	0	0	0	0	0	0	0
DL	1902	321	1581	0.00	0	0	0	0	0	0	0	0
GJ	2790	103	2687	0.00	0	0	0	0	0	0	0	0
HR	1532	455	1077	0.00	0	0	0	0	0	0	0	0
HP	1003	691	312	0.00	0	0	0	0	0	0	0	0
JK	1028	747	281	0.00	0	0	0	0	0	0	0	0
JH	1873	369	1504	0.00	0	0	0	0	0	0	0	0
KT	3017	506	2511	0.68	1712	25	8	309	5539	1637	1024	8200
KL	3090	1172	1918	0.00	0	0	0	0	0	0	0	0
MP	2012	416	1596	1.00	1596	20	5	274	5834	1521	1448	8802
MH	2703	355	2348	1.00	2348	23	10	448	5235	792	825	6852
OR	2337	605	1732	0.24	419	79	19	243	1724	2486	995	5204
PJ	1231	467	764	0.00	0	0	0	0	0	0	0	0
RJ	1852	168	1684	0.00	0	0	0	0	0	0	0	0
TN	2928	1592	1335	0.12	155	271	122	453	343	3513	481	4337
UA	1351	681	670	0.00	0	0	0	0	0	0	0	0
UP	1612	301	1310	0.81	1062	132	65	493	2153	611	682	3446
WB	1866	383	1483	0.00	0	30	19	630	0	608	314	922
Total	1966	463	1503	0.17	257	1364	691	507	533	1484	445	2463

Dry beans total

State	A	P	Y	N use	VWC			
					blue	green	gray	total
Unit	10³ ha	10³ ton	kg/ha	kg/ha	m³/ton			
AP	992	490	494	20	44	3333	401	3778
AS	48	25	525	20	0	1071	373	1444
BH	217	123	567	20	56	1357	353	1766
CG	116	43	370	20	0	7210	535	7745
DL	0	0	0	0	0	0	0	0
GJ	291	124	425	22	161	6515	507	7182
HR	14	4	290	27	1260	10781	924	12965
HP	11	4	377	23	0	5580	601	6182
JK	18	8	462	22	196	5406	481	6083
JH	33	24	738	20	0	3680	271	3951
KT	483	146	303	20	288	9019	668	9974
KL	0	0	0	0	0	0	0	0
MP	524	166	316	24	183	8433	749	9365
MH	1327	576	434	23	162	6522	523	7207
OR	340	77	227	21	421	10443	908	11771
PJ	41	24	585	33	917	5130	558	6606
RJ	1721	344	200	22	1033	14374	1117	16524
TN	384	177	460	21	236	3871	456	4563
UA	0	0	0	0	0	0	0	0
UP	467	192	411	24	730	5631	574	6935
WB	88	52	584	20	0	3429	336	3765
Total	7115	2598	365	22	313	6706	604	7623

Soybean total (kharif season only)

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	N use	VWC			
										blue	green	gray	total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	kg/ha	m³/ton			
AP	5387	4332	1055	0.00	0	16	16	1001	20	0	4327	196	4523
AS	4121	3975	146	0.00	0	0	0	0	20	0	0	0	0
BH	4598	3707	891	0.00	0	0	0	0	20	0	0	0	0
CG	4318	3610	708	0.00	1	11	8	752	20	2	4801	264	5067
DL	5497	3174	2324	0.00	0	0	0	0	20	0	0	0	0
GJ	5454	2841	2613	0.02	42	6	5	825	20	51	3443	241	3735
HR	5516	3199	2317	0.00	0	0	0	0	20	0	0	0	0
HP	3175	2538	637	0.17	106	1	1	1409	22	75	1801	160	2036
JK	4361	2729	1631	0.00	0	0	0	0	20	0	0	0	0
JH	4286	3630	657	0.00	0	0	0	0	20	0	0	0	0
KT	5100	3988	1112	0.34	381	60	57	946	26	403	4214	269	4886
KL	4538	4482	56	0.00	0	0	0	0	20	0	0	0	0
MP	4469	3359	1110	0.01	11	4430	4144	936	20	12	3589	211	3812
MH	5018	3665	1353	0.01	16	1103	1442	1309	20	12	2800	152	2964
OR	4579	4392	188	0.00	0	1	0	215	20	0	20456	918	21375
PJ	5115	3040	2075	0.00	0	0	0	0	20	0	0	0	0
RJ	5779	2725	3054	0.03	86	614	668	1094	20	78	2490	185	2753
TN	5953	3987	1966	0.00	0	0	0	0	20	0	0	0	0
UA	3763	3064	699	0.02	11	6	5	839	20	13	3653	230	3896
UP	4739	3543	1197	0.02	19	22	11	602	20	32	5885	380	6298
WB	4382	4076	307	0.00	0	1	0	608	20	0	6706	322	7029
Total	4874	3349	1525	0.02	23	6270	6358	1016	20	23	3308	196	3526

Groundnut in kharif season

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	VWC			
									blue	green	gray	total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	m³/ton			
AP	5306	4535	771	0.01	8	1565	1206	763	11	5945	286	6242
AS	4007	4007	0	0.00	0	0	0	0	0	0	0	0
BH	4578	4362	216	0.00	1	3	3	1242	1	3511	181	3692
CG	4247	4143	104	0.09	9	34	38	1119	8	3701	206	3915
DL	5727	3974	1753	0.00	0	0	0	0	0	0	0	0
GJ	5252	3682	1570	0.05	86	1805	1550	849	102	4337	264	4703
HR	5848	3801	2047	0.65	1324	1	1	875	1513	4342	357	6212
HP	3246	3052	193	0.00	0	0	0	0	0	0	0	0
JK	4530	3233	1297	0.00	0	0	0	0	0	0	0	0
JH	4205	4122	84	0.00	0	0	0	0	0	0	0	0
KT	4824	4220	605	0.05	30	894	709	784	38	5380	284	5702
KL	4099	4054	45	0.00	0	6	4	736	0	5507	300	5807
MP	4487	4122	365	0.08	28	213	226	1059	26	3892	216	4134
MH	4833	4271	562	0.08	45	397	409	1031	44	4143	223	4410
OR	4381	4381	0	0.00	0	36	29	802	0	5465	273	5737
PJ	5477	3715	1762	0.46	816	5	5	969	842	3835	293	4970
RJ	6051	3313	2737	0.39	1059	264	281	1059	1000	3128	254	4382
TN	5896	3399	2497	0.00	0	427	814	2057	0	1653	115	1767
UA	3838	3684	155	0.00	0	0	0	0	0	0	0	0
UP	4900	4432	468	0.01	4	119	94	797	5	5558	277	5841
WB	4254	4254	0	0.00	0	3	2	772	0	5507	292	5799
Total	4339	2809	1530	0.06	85	5768	5370	932	95	4356	243	4694

Groundnut in rabi season

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	VWC			
									blue	green	gray	total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	m³/ton			
AP	5451	458	4992	1.00	4992	293	475	1622	3078	283	218	3578
AS	3211	1630	1581	0.00	0	0	0	0	0	0	0	0
BH	3924	513	3410	0.00	0	0	0	0	0	0	0	0
CG	4499	705	3794	0.00	0	0	0	0	0	0	0	0
DL	4312	635	3677	0.00	0	0	0	0	0	0	0	0
GJ	5423	69	5355	1.00	5355	63	106	1679	3189	41	211	3441
HR	3641	943	2698	0.00	0	0	0	0	0	0	0	0
HP	2250	1815	434	0.00	0	0	0	0	0	0	0	0
JK	2202	1900	302	0.00	0	0	0	0	0	0	0	0
JH	4114	754	3361	0.00	0	0	0	0	0	0	0	0
KT	5724	338	5387	1.00	5387	185	212	1148	4693	294	307	5294
KL	5431	1439	3992	0.00	0	0	0	0	0	0	0	0
MP	4454	516	3938	0.00	0	0	0	0	0	0	0	0
MH	5418	238	5180	1.00	5180	104	144	1386	3738	172	254	4164
OR	4706	734	3973	0.43	1726	39	38	991	1741	740	283	2764
PJ	3083	1012	2070	0.00	0	0	0	0	0	0	0	0
RJ	4225	255	3969	0.00	0	0	0	0	0	0	0	0
TN	5533	1141	4392	0.79	3448	340	606	2032	1697	562	182	2440
UA	2949	1665	1284	0.00	0	0	0	0	0	0	0	0
UP	3849	536	3313	0.00	0	0	0	0	0	0	0	0
WB	4059	758	3301	0.00	0	35	49	1419	0	534	154	688
Total	3849	505	3344	0.88	2938	1058	1632	1581	2715	381	218	3315

Groundnut total

State	A	P	Y	N use	VWC			
					blue	green	gray	total
Unit	10^3 ha	10^3 ton	kg/ha	kg/ha	m³/ton			
AP	1858	1681	905	24	878	4345	267	5489
AS	0	0	0	0	0	0	0	0
BH	3	3	1215	22	1	3511	181	3692
CG	34	38	1123	23	8	3701	206	3915
DL	0	0	0	0	0	0	0	0
GJ	1868	1656	887	23	300	4062	260	4622
HR	1	1	857	31	1513	4342	357	6212
HP	0	0	0	0	0	0	0	0
JK	0	0	0	0	0	0	0	0
JH	0	0	0	0	0	0	0	0
KT	1078	922	855	25	1111	4208	289	5608
KL	6	4	730	22	0	5507	300	5807
MP	213	226	1061	23	26	3892	216	4134
MH	500	552	1104	26	1005	3110	231	4346
OR	75	67	894	25	995	2765	279	4038
PJ	5	5	960	28	842	3835	293	4970
RJ	264	281	1065	27	1000	3128	254	4382
TN	767	1420	1852	27	724	1187	143	2055
UA	0	0	0	0	0	0	0	0
UP	119	94	794	22	5	5558	277	5841
WB	38	52	1370	22	0	751	160	911
Total	6827	7002	1026	24	705	3430	237	4372

Rapeseed total (rabi season only)

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	N use	VWC			
										blue	green	gray	total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10^3 ha	10^3 ton	kg/ha	kg/ha	m³/ton			
AP	5414	779	4635	0.04	176	4	1	291	47	606	2680	1660	4945
AS	3126	1512	1613	0.01	10	308	142	464	46	21	3261	1002	4285
BH	3664	518	3146	0.35	1085	110	92	841	58	1290	615	696	2602
CG	4334	751	3583	0.03	104	59	31	523	47	199	1434	892	2525
DL	4068	632	3436	0.00	0	4	1	171	46	0	3689	2768	6456
GJ	5403	131	5272	0.95	4992	301	344	1152	80	4333	114	698	5145
HR	3382	983	2399	0.83	1984	483	607	1267	76	1566	775	601	2942
HP	2107	1874	233	0.11	26	12	6	553	50	46	3389	908	4343
JK	2082	1909	173	0.79	137	72	42	591	74	232	3232	1271	4735
JH	3929	828	3101	0.00	0	0	0	0	0	0	0	0	0
KT	5814	625	5189	0.03	150	8	2	263	47	573	2379	1802	4754
KL	5686	1515	4170	0.00	0	0	0	0	0	0	0	0	0
MP	4258	653	3606	0.35	1269	617	514	835	59	1521	782	702	3005
MH	5377	456	4921	0.14	709	11	2	225	51	3151	2030	2302	7483
OR	4659	1007	3653	0.07	259	17	2	142	48	1831	7109	3443	12383
PJ	2800	1012	1788	0.88	1572	66	68	1057	77	1487	957	743	3187
RJ	3979	279	3700	0.76	2812	2485	2147	873	73	3220	320	846	4385
TN	5639	1596	4043	0.00	0	1	0	212	46	0	7544	2150	9694
UA	2784	1716	1068	0.71	754	16	11	734	71	1028	2339	977	4344
UP	3573	560	3013	0.71	2127	1098	1002	921	71	2310	608	780	3698
WB	3887	829	3058	0.75	2284	413	335	811	73	2816	1022	895	4733
Total	3988	485	3503	0.65	2265	6082	5350	887	69	2553	635	785	3972

Seed cotton total (kharif season only)

State	CWR	CWU green	IWR	iaf	CWU blue	A	P	Y	N use	VWC blue	VWC green	VWC gray	VWC total
Unit	m³/ha	m³/ha	m³/ha	-	m³/ha	10³ ha	10³ ton	kg/ha	kg/ha	m³/ton			
AP	7687	5619	2068	0.19	383	1071	918	856	83	447	6564	970	7981
AS	5632	4965	667	0.00	0	0	0	0	0	0	0	0	0
BH	6403	4720	1683	0.00	0	0	0	0	0	0	0	0	0
CG	6176	4630	1546	0.00	0	0	0	0	0	0	0	0	0
DL	7783	4174	3610	0.00	0	0	0	0	0	0	0	0	0
GJ	7874	3871	4003	0.41	1629	1658	876	530	92	3074	7304	1742	12119
HR	7641	4022	3619	1.00	3608	588	607	1044	116	3457	3853	1118	8428
HP	4430	3451	978	0.00	0	0	0	0	0	0	0	0	0
JK	5910	3628	2282	0.00	0	0	0	0	0	0	0	0	0
JH	6066	4609	1457	0.00	0	0	0	0	0	0	0	0	0
KT	7344	5013	2331	0.14	317	574	398	696	81	455	7200	1171	8826
KL	6515	6080	435	0.00	0	0	0	0	0	0	0	0	0
MP	6447	4496	1951	0.35	677	530	195	366	90	1851	12294	2441	16586
MH	7270	4732	2537	0.04	107	3186	1345	421	77	253	11246	1836	13335
OR	6538	5550	988	0.00	0	0	0	0	0	0	0	0	0
PJ	7037	3954	3083	1.00	3074	526	620	1179	116	2608	3355	982	6945
RJ	8083	3440	4643	0.98	4527	541	367	672	115	6739	5121	1692	13551
TN	8384	5462	2922	0.37	1069	182	168	921	90	1161	5931	981	8074
UA	5335	4078	1257	0.00	0	0	0	0	0	0	0	0	0
UP	6664	4658	2005	0.00	0	0	0	0	0	0	0	0	0
WB	6122	5060	1062	0.00	0	0	0	0	0	0	0	0	0
Total	7078	3846	3232	0.35	1125	8857	5494	621	90	1887	7300	1446	10633

Appendix IX. Comparison of calculated gray water use to nitrate use by state

Since this gray water use is based on the average nitrate use for crops in whole India, the calculated gray water use is here compared to the total nitrate consumption per state (ASD, 2003).

States	Gray water use[1]	Nitrate consumption[2]	Gray water use[3]	
% of crops included	85%	100%	100%	85%
Unit	10^9 m^3/yr	10^9 kg N/yr	10^9 m^3/yr	
Year	1997-2001	2000-2001	2000-2001	2000-2001
Andhra Pradesh	6	1.36	14	12
Assam	2	0.07	1	1
Bihar[4]	5	0.75	8	7
Chhattisgarh[4]	3	-	0	0
Delhi	0	-	0	0
Gujarat	5	0.5	5	4
Haryana	5	0.71	7	6
Himachal Pradesh	0	0.02	0	0
Jammu & Kashmir	1	0.05	1	0
Jharkhand[4]	1	-	0	0
Karnataka	4	0.73	7	6
Kerala	0	0.07	1	1
Madhya Pradesh[4]	8	0.53	5	5
Maharashtra	8	0.97	10	8
Orissa	4	0.21	2	2
Punjab	7	1.01	10	9
Rajasthan	8	0.5	5	4
Tamil Nadu	3	0.54	5	5
Uttar Pradesh[4]	18	2.28	23	20
Uttaranchal[4]	1	-	0	0
West Bengal	5	0.56	6	5
Total	95	10.92	109	95

[1] Gray water use as calculated in this study, [2] Total reported consumption of nitrate by state (ASD, 2003), [3] Gray water use based on reported consumption of nitrate by state, [4] Reported consumption considers Bihar and Jharkhand, Madhya Pradesh and Chhattisgarh and Uttar Pradesh and Uttaranchal as undivided states.

This comparison shows that the gray water use in Andhra Pradesh, Karnataka and Punjab is significantly underestimated in this study and that the gray water use is Madhya Pradesh, Chhattisgarh, Orissa and Rajasthan is significantly overestimated.

Appendix X. Sensitivity analysis of virtual water content of kharif milled rice

The divergence in the *VWC* of the kharif milled rice in the Indian states is in our calculations quantitatively created by four parameters (see Figure A.1); the crop water requirement of milled rice in a state, (*CWR*), the fraction of irrigated area of milled rice in a state (*iaf*), the yield of milled rice in a state (Y_c) and the use of nitrate in a state (*N use*). Since the crop parameters are the same for all Indian states, the *CWR* is only determined by the average reference evapotranspiration in a state (ET_0). In Figure A.2 the qualitative parameter *Crop variety* is added, because normally this parameter has a significant influence on *CWR* and Y_c and *N use*.

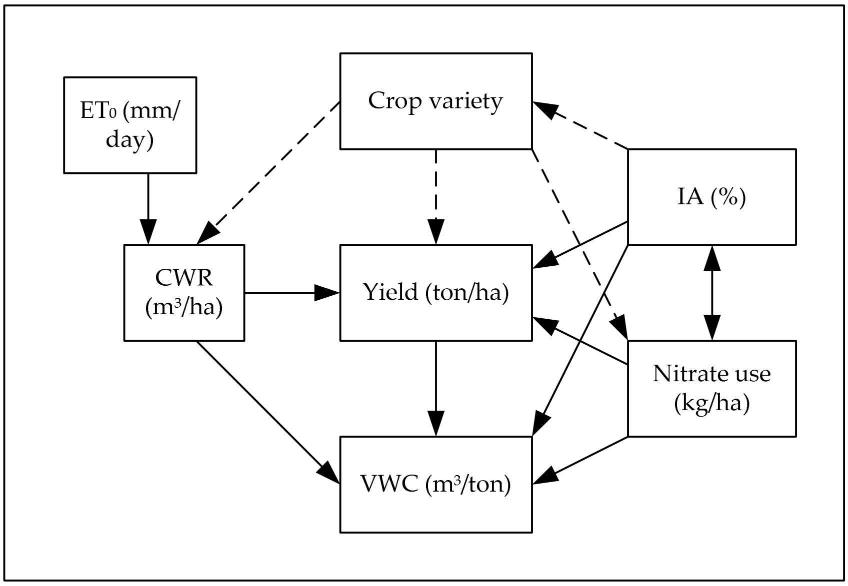


Figure A.2

Table A.1: Sensitivity analysis *VWC* kharif milled rice

Parameters	R^2	Significance
VWC – CWR	0.00175	0.857
VWC – iaf	0.262	0.01757
VWC – Yield*	**0.691**	**0.000003**
VWC – N use	0.262	0.01757
Yield – CWR	0.156	0.07679
Yield – iaf*	**0.543**	**0.000140**
Yield – N use*	**0.543**	**0.000140**

**significant correlation*

In Table A.1, it can be seen that there is a significant correlation between the *VWC* and the *Yield* of kharif milled rice. Furthermore there is also a significant correlation between the *Yield* and *iaf* of kharif milled rice. Since the *N use* is directly based on the *iaf*, the values of these parameters are the same.

Appendix XI. Production, consumption and surplus of crops

ST/UT	Milled rice			Wheat			Maize			Millet		
	P	C	Sp	P	C	Sp	P	C	Sp	P	C	Sp
Unit	1000 ton/yr			1000 ton/yr			1000 ton/yr			1000 ton/yr		
Year	1997-2001											
ANI	29	38	-11	0	7	-7	0	0	0	0	0	0
AP	10935	9818	420	8	330	-324	1446	39	1163	261	312	-73
ARP	129	163	-43	6	15	-10	49	12	29	17	16	-1
AS	3657	3701	-277	100	230	-141	14	0	12	5	0	5
BH	5337	7066	-2070	4508	6396	-2387	1437	758	437	37	0	34
CDG	2	18	-16	0	78	-78	0	1	-1	0	0	0
CG	3835	2891	700	72	271	-207	97	16	64	69	70	-7
DNH	22	17	3	1	5	-5	0	0	0	2	5	-3
DMD	4	13	-9	0	7	-7	0	0	0	0	1	-1
DL	9	295	-287	42	1138	-1100	0	0	0	2	0	2
GOA	155	116	28	0	49	-49	0	0	0	1	0	1
GJ	908	1235	-385	1271	2811	-1680	581	580	-97	1094	1960	-959
HR	2588	194	2229	8653	2523	5173	42	17	18	681	106	517
HP	124	303	-187	530	480	-9	688	265	307	10	10	-1
JK	472	998	-557	352	521	-208	507	224	198	10	8	1
JH	1727	3085	-1469	101	1213	-1124	133	105	5	38	41	-6
KT	3521	3369	-72	198	772	-595	1684	113	1287	1886	1646	80
KL	741	3190	-2497	0	399	-399	0	0	0	3	1	2
LSW	2	7	-5	0	1	-1	0	0	0	0	0	0
MP	1363	1656	-380	7326	5942	573	1312	894	197	312	70	216
MH	2392	3503	-1264	1106	4394	-3411	450	58	315	1391	1483	-210
MNP	372	394	-45	0	4	-4	10	1	8	0	0	0
MGL	167	294	-138	7	7	-1	24	9	11	2	0	2
MIZ	103	124	-27	0	9	-9	15	1	12	0	0	0
NGL	199	315	-129	7	13	-6	46	13	25	8	0	7
OR	5688	5852	-526	8	347	-340	65	7	46	70	190	-126
PDC	58	106	-51	0	7	-7	0	0	0	1	1	0
PJ	8475	235	7700	14462	2694	10168	412	84	259	6	6	-1
RJ	196	174	10	6528	6627	-821	1102	1177	-262	2280	2362	-275
SIK	22	63	-43	12	8	2	53	10	35	5	1	4
TN	7277	6867	-54	0	372	-372	130	3	105	493	379	73
TRP	525	470	22	3	16	-13	2	0	1	0	0	0
UP	11867	7363	3748	23739	17401	3711	1297	545	533	1137	399	641
UA	599	370	191	703	884	-259	49	26	14	270	19	228
WB	13820	10624	2315	867	1433	-662	90	0	75	18	3	13
Total	87317	74929	6823	70609	57404	5393	11735	4956	4793	10123	9091	174

ST/UT	Sorghum			Sugar			Pulses			Groundnut oil		
	P	C	Sp	P	C	Sp	P	C	Sp	P	C	Sp
Unit	1000 ton/yr			1000 ton/yr			1000 ton/yr			1000 ton/yr		
Year	1997-2001											
ANI	0	0	0	0	7	-7	0	5	-5	0	0	0
AP	572	409	103	1708	1049	546	807	776	-40	498	248	203
ARP	0	0	0	0	12	-12	6	7	-1	0	0	0
AS	0	0	0	128	339	-219	66	188	-128	0	0	0
BH	4	0	3	493	1066	-605	674	879	-264	1	0	1
CDG	0	0	0	0	26	-26	0	16	-16	0	1	-1
CG	0	49	-49	0	538	-538	214	248	-53	6	23	-18
DNH	0	4	-4	0	3	-3	4	4	0	0	1	-1
DMD	0	1	-1	0	3	-3	1	2	-1	0	1	-1
DL	4	0	4	0	312	-312	0	207	-207	0	0	0
GOA	0	4	-4	9	38	-30	9	15	-7	1	2	-1
GJ	182	310	-147	1329	1866	-624	501	643	-186	492	364	81
HR	23	0	20	821	992	-226	250	286	-59	0	0	0
HP	0	0	0	0	172	-172	14	109	-96	0	0	0
JK	0	0	0	0	174	-174	16	136	-121	0	0	0
JH	0	0	0	0	351	-351	59	291	-237	0	0	0
KT	1567	2065	-663	3491	1576	1685	754	717	-29	273	194	53
KL	1	0	1	50	636	-589	19	244	-227	1	0	1
LSW	0	0	0	0	3	-3	0	0	0	0	0	0
MP	573	323	190	181	1551	-1382	3180	724	2176	72	70	-5
MH	4212	3742	27	4806	2586	1903	1865	1292	408	164	405	-257
MNP	0	0	0	10	13	-4	1	7	-7	0	0	0
MGL	0	0	0	10	29	-20	3	9	-6	0	0	0
MIZ	0	0	0	10	19	-9	7	9	-3	0	0	0
NGL	1	0	1	10	27	-17	15	19	-6	1	0	1
OR	8	1	6	125	396	-279	248	245	-19	20	4	14
PDC	0	0	0	0	14	-14	4	12	-9	1	1	0
PJ	0	0	0	813	1237	-478	56	353	-302	1	3	-1
RJ	177	34	125	102	1858	-1763	1709	553	1006	83	87	-11
SIK	0	0	0	0	4	-4	6	4	2	0	0	0
TN	319	9	277	3290	938	2135	293	753	-486	420	174	206
TRP	0	0	0	15	41	-27	5	20	-16	0	0	0
UP	299	55	212	11776	5698	5300	2383	2321	-148	28	0	25
UA	0	3	-3	768	286	431	20	118	-99	0	0	0
WB	1	2	-2	185	1030	-857	176	527	-367	15	2	11
Total	7943	7011	95	30132	24889	3255	13364	11741	447	2075	1580	300

ST/UT	Rapeseed oil			Remaining edible oils			Cotton lint		
	P	C	Sp	P	C	Sp	P	C	Sp
Unit	1000 ton/yr			1000 ton/yr			1000 ton/yr		
Year				1997-2001					
ANI	0	1	-1	0	2	-2	0	0	0
AP	0	0	0	256	416	-255	296	66	229
ARP	7	2	5	1	5	-4	0	1	-1
AS	49	78	-31	13	12	-7	0	18	-18
BH	32	242	-212	6	129	-124	0	57	-57
CDG	0	2	-2	0	12	-12	0	1	-1
CG	7	21	-15	1	144	-143	0	15	-15
DNH	0	0	0	0	1	-1	0	0	0
DMD	0	0	0	0	2	-2	0	0	0
DL	0	40	-40	0	140	-140	0	24	-24
GOA	0	0	0	11	14	-10	0	2	-2
GJ	118	11	103	107	293	-214	380	49	331
HR	209	34	167	65	155	-105	185	22	163
HP	2	16	-14	0	51	-50	0	7	-7
JK	15	53	-39	0	22	-22	0	11	-11
JH	0	80	-80	0	46	-46	0	19	-19
KT	1	0	1	283	218	-51	127	54	73
KL	0	0	0	501	385	-204	0	40	-40
LSW	0	0	0	0	1	-1	0	0	0
MP	181	62	113	767	425	224	65	46	18
MH	1	20	-19	471	756	-378	441	102	339
MNP	0	4	-3	0	2	-2	0	2	-2
MGL	2	5	-4	0	4	-4	0	2	-2
MIZ	1	3	-2	0	3	-3	0	1	-1
NGL	5	3	1	4	1	3	0	2	-2
OR	1	56	-55	14	92	-86	0	24	-24
PDC	0	0	0	0	15	-15	0	1	-1
PJ	23	20	2	67	330	-279	187	28	159
RJ	739	104	607	153	166	-40	115	53	62
SIK	1	2	-1	1	0	0	0	1	-1
TN	0	0	0	308	409	-290	54	55	-1
TRP	1	14	-14	0	5	-5	0	3	-3
UP	348	558	-224	10	507	-499	0	134	-134
UA	1	29	-27	1	27	-26	0	11	-11
WB	115	298	-187	30	89	-78	0	75	-75
Total	1858	1760	29	3071	4879	-2870	1848	926	922

Appendix XII. Assessment of interstate and international crop trade

Here, the distribution of the calculated interstate and international crop trade is presented.

The total interstate export $E_{t,is}$ is distributed over the total interstate import $I_{t,is}$. This crop distribution is based on the assumption that crops are traded as much as possible with neighbouring states. The first distribution step is to assess the "obvious" trade flows. These are the flows between adjacent states, when no other states are directly competitive. A second step can be used for assessing the short distance trade flows that remain after the first step. In the last step the remaining crop deficits are filled up by the remaining crop surplus.

The international trade of the Indian states is assessed according the part of the national crop surplus (in the case of international export) or the part of the national crop deficit (in the case of international import).

Milled rice

The first step is to assess the trade flows between states, when no other states are directly competitive:

- West Bengal to the North Eastern States (Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura). Although West Bengal is not adjacent to the most of these states, it is still by far the most nearby rice surplus state. Tripura has a small surplus which goes to Mizoram.
- Uttaranchal to Himachal Pradesh. In this region there are a lot of rice surplus states, so the surplus goes to the only neighbouring deficit state, which is Himachal Pradesh.
- Chhattisgarh to Madhya Pradesh and Orissa. Because Chhattisgarh was part of Madhya Pradesh until November 2000, we assume that these trade systems still more or less exist. The remaining rice surplus of Chhattisgarh goes to Orissa.
- Goa to Karnataka and Rajasthan to Gujarat.

In the second step, the short distance trade flows are assessed that remain after step 1:

- West Bengal to Jharkhand and Orissa. Jharkhand and Orissa receive an equal part of the remaining rice surplus of West Bengal.
- Andhra Pradesh to Orissa, Karnataka and Tamil Nadu. The small surplus that remains after filling up these three adjacent states goes to Maharashtra.
- Uttar Pradesh to Bihar and Jharkhand (the latter one was part of Bihar before November 2000). After the first step Uttar Pradesh is only neighbouring state of Bihar and Jharkhand with a rice surplus. First Jharkhand is filled up, then the remaining surplus goes to Bihar.
- Haryana to Delhi. Because the rice surplus in Uttar Pradesh is all distributed over Bihar and Jharkhand, the deficit of Delhi is entirely filled up by the rice from Haryana.

In the last step the remaining rice deficits are filled up by the remaining rice surplus in Haryana and Punjab. These two states are also well known for their function of food grain supplier to the rest of India. The total of this remaining surplus is 5.72 million ton of rice of which 1.06 million ton originates from Haryana and 4.66 million ton originates from Punjab. So all left over deficits are filled with 19% of rice from Haryana and 81% of rice from Punjab.

Interstate trade of milled rice

ES	IS															Es,is	Es,in
	AS	BH	DL	GJ	HP	JK	JH	KT	KL	MP	MH	MGL	NGL	OR	TN		
Unit	Million ton/yr																
AP								0.1			0.0			0.1	0.1	**0.3**	**0.1**
CG										0.4				0.0		**0.4**	**0.1**
HR		0.2	0.3	0.1	0.0	0.1			0.5		0.2					**1.4**	**0.3**
PJ		0.7		0.3	0.1	0.5			2.0		1.0					**4.7**	**1.2**
RJ				0.0												**0.0**	**0.0**
UP		1.2					1.1									**2.3**	**0.6**
UA					0.1											**0.1**	**0.0**
WB	0.3						0.4					0.1	0.1	0.4		**1.4**	**0.3**
Is,is	**0.3**	**2.1**	**0.3**	**0.4**	**0.2**	**0.6**	**1.5**	**0.1**	**2.5**	**0.4**	**1.3**	**0.1**	**0.1**	**0.5**	**0.1**	**10.5**	**2.6**
Is,in	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	

Wheat

The first step is to assess the trade flows between states, when no other states are directly competitive:

- Madhya Pradesh to Chhattisgarh. Because Chhattisgarh was part of Madhya Pradesh before November 2000, in which we assume that these trade systems still exist. The remaining part of wheat surplus in Madhya Pradesh goes to Maharashtra.
- Uttar Pradesh to Uttaranchal. Because Uttaranchal was part of Uttar Pradesh before November 2000, we again assume that these trade systems still exist.

In the second step the remaining wheat deficits are filled up by the remaining wheat surplus in Haryana, Punjab and Uttar Pradesh. The total of this remaining surplus is 12.65 million ton of rice of which 3.50 million ton originates from Haryana, 6.88 million ton originates from Punjab and 2.27 million ton originates from Uttar Pradesh. This means that all the remaining deficits are filled up with 28% of rice from Haryana, 54% of rice from Punjab and 18% of rice from Uttar Pradesh.

Interstate trade of wheat

ES	IS																Es,is	Es,in
	AP	AS	BH	CG	DL	GJ	JK	JH	KT	KL	MH	OR	RJ	TN	UA	WB		
Unit	Million ton/yr																	
HR	0.1	0.0	0.6		0.3	0.4	0.1	0.3	0.2	0.1	0.8	0.1	0.2	0.1		0.2	**3.5**	**0.2**
MP				0.2							0.2						**0.4**	**0.0**
PJ	0.2	0.1	1.2		0.6	0.9	0.1	0.6	0.3	0.2	1.6	0.2	0.4	0.2		0.3	**6.9**	**0.4**
UP	0.1	0.0	0.4		0.2	0.3	0.0	0.2	0.1	0.1	0.5	0.1	0.1	0.1	0.2	0.1	**2.5**	**0.2**
Is,is	**0.3**	**0.1**	**2.2**	**0.2**	**1.0**	**1.6**	**0.2**	**1.0**	**0.6**	**0.4**	**3.2**	**0.3**	**0.8**	**0.3**	**0.2**	**0.6**	**13.3**	**0.9**
Is,in	**0.0**	**0.0**	**0.2**	**0.0**	**0.1**	**0.1**	**0.0**	**0.1**	**0.0**	**0.0**	**0.2**	**0.0**	**0.1**	**0.0**	**0.0**	**0.0**	**0.9**	

Maize

The maize deficit in Rajasthan and Gujarat is filled up with maize from Andhra Pradesh and Karnataka.

Interstate trade of maize

ES	IS: GJ	IS: RJ	**Es,is**	**Es,in**
Unit	Million ton./yr			
AP		0.1	**0.1**	**0.0**
KT	0.1	0.0	**0.1**	**0.0**
Is,is	**0.1**	**0.2**	**0.3**	**0.1**
Is,in	**0.0**	**0.0**	**0.0**	

Millet

The first step is to assess the trade flows between states, when no other states are directly competitive:

- The millet surplus in Tamil Nadu goes to the only neighbouring deficit state Andhra Pradesh and then the millet surplus of Karnataka goes to the millet deficit Maharashtra.
- The millet deficit in Orissa in filled up by closest millet surplus state Madhya Pradesh. Then the millet deficit of Maharashtra is filled up by the closest surplus state Madhya Pradesh, which is not sufficient to fill up the entire millet deficit in Maharashtra.

In the second step the remaining millet deficits are filled up by the remaining millet surplus in Haryana, Uttar Pradesh and Uttaranchal. The total of this remaining surplus is 1.28 million ton of millet of which 0.48 million ton originates from Haryana and 0.80 million ton originates from Uttar Pradesh and Uttaranchal (these two states are linked together because it not clear whether it comes from Uttar Pradesh or Uttaranchal). This means that all the remaining deficits are filled up with 38% of millet from Haryana and 62% of millet from Uttar Pradesh and Uttaranchal.

Interstate trade of millet

ES	IS: AP	IS: GJ	IS: MH	IS: OR	IS: RJ	**Es,is**
Unit	Million ton/yr					
HR		0.3	0.0		0.1	**0.5**
KT	0.0		0.1			**0.1**
MP			0.1	0.1		**0.2**
TN	0.1					**0.1**
UP		0.4	0.0		0.1	**0.6**
UA		0.2	0.0		0.0	**0.2**
Is,is	**0.1**	**1.0**	**0.2**	**0.1**	**0.3**	**1.7**

Sorghum

The first step is to assess the trade flows between states, when no other states are directly competitive:

- The sorghum surplus of the states Maharashtra, Andhra Pradesh and Tamil Nadu all goes to the main sorghum deficit state Karnataka.

The remaining deficits in Gujarat and Karnataka are filled up by the remaining surplus, which is 0.48 million ton (0.15 from Madhya Pradesh, 0.21 from Uttar Pradesh, 0.12 from Rajasthan).

Interstate trade of sorghum

ES	IS		**Es,is**
	GJ	KT	
Unit	Million ton/yr		
AP		0.1	**0.1**
MP	0.0	0.1	**0.2**
RJ	0.1		**0.1**
TN		0.2	**0.2**
UP		0.2	**0.2**
Is,is	**0.1**	**0.7**	**0.9**

Raw sugar

The first step is to assess the trade flows between states, when no other states are directly competitive:

- Uttar Pradesh and Uttaranchal provide all the Northern states (Punjab, Haryana, Delhi, Himachal Pradesh, Jammu & Kashmir, Bihar, Jharkhand, West Bengal and all the north eastern states. Andhra Pradesh, Karnataka, Maharashtra and Tamil Nadu provide Gujarat, Kerala and Orissa.

The border area in the form of Rajasthan, Madhya Pradesh and Chhattisgarh is filled up with the remaining surplus of sugar in the exporting states. Most of this comes from the southern surplus states.

Interstate trade of raw sugar

ES	IS															**Es,is**	**Es,in**
	AS	BH	CG	DL	GJ	HR	HP	JK	JH	KL	MP	OR	PJ	RJ	WB		
AP			0.1									0.3				**0.4**	**0.0**
KT											0.1			1.1		**1.2**	**0.1**
MH			0.4		0.6						0.3					**1.3**	**0.1**
TN										0.6	0.9					**1.5**	**0.1**
UP	0.2	0.5		0.3		0.2	0.1	0.2	0.3				0.4	0.5	0.7	**3.7**	**0.2**
UA	0.0	0.0		0.0		0.0	0.0	0.0	0.0				0.0	0.0	0.1	**0.3**	**0.0**
Is,is	**0.2**	**0.6**	**0.5**	**0.3**	**0.6**	**0.2**	**0.2**	**0.2**	**0.3**	**0.6**	**1.3**	**0.3**	**0.4**	**1.7**	**0.8**	**8.3**	**0.4**
Is,in	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**	**0.0**	**0.1**	**0.1**	**0.5**	

Pulses

The only three states that have an interstate export of pulses are Madhya Pradesh, Maharashtra and Rajasthan. Based on the reported consumption (NSSO report no. 461) and production of the individual pulses in these three states, the assumption is made that the interstate trade of pulses exists of chickpeas only. In Madhya Pradesh and Rajasthan the annual chickpeas production is higher than the annual total pulse consumption, which makes the export of chickpeas very likely. In Maharashtra the export of pulses is likely to exist of a mix of chickpeas, pigeon peas and dry beans. Since this the export of pulses from this state so little, the assumption of the interstate trade existing of chickpeas only is considered as acceptable. The chickpeas from the exporting states are evenly distributed to the various deficit states according to their part of the total interstate export.

Interstate trade of chickpeas

ES	IS													**Es,is**
	AS	BH	DL	GJ	HP	JK	JH	KL	PJ	TN	UP	UA	WB	
MP	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.1	0.2	0.1	0.0	0.2	**1.3**
MH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.3**
RJ	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.1	**0.6**
Is,is	**0.1**	**0.2**	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**0.2**	**0.2**	**0.3**	**0.1**	**0.1**	**0.3**	**2.2**

Groundnut oil

The first step is to assess the trade flows between states, when no other states are directly competitive:

- All surplus in Orissa to Chhattisgarh
- All surplus in Uttar Pradesh to Rajasthan
- The remaining deficit in Chhattisgarh is filled with groundnut from Andhra Pradesh
- The deficit in Madhya Pradesh is filled with groundnut from Gujarat

The remaining groundnut surplus of Andhra Pradesh, Karnataka, Tamil Nadu and Gujarat goes to Maharashtra.

Interstate trade of groundnut oil

ES	IS				**Es,is**	**Es,in**
	CG	MP	MH	RJ		
AP	0.01		0.09		**0.10**	**0.02**
GJ		0.01	0.03		**0.04**	**0.01**
KT			0.03		**0.03**	**0.01**
OR	0.01				**0.01**	**0.00**
TN			0.11		**0.11**	**0.02**
UP				0.01	**0.01**	**0.00**
Is,is	**0.02**	**0.01**	**0.26**	**0.01**	**0.30**	**0.06**
Is,in	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	

Rapeseed oil

The surplus states are Gujarat, Haryana, Madhya Pradesh and Rajasthan. The rapeseed oil from the exporting states is evenly distributed to the various importing states according to their part of the total interstate export.

Interstate trade of rapeseed oil

ES	IS												Es,is	Es,in
	AS	BH	CG	DL	HP	JK	JH	MH	OR	UP	UA	WB		
GJ	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.00	0.02	**0.09**	**0.00**
HR	0.00	0.03	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.03	0.00	0.03	**0.14**	**0.00**
MP	0.00	0.02	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.00	0.02	**0.10**	**0.00**
RJ	0.02	0.11	0.01	0.02	0.01	0.02	0.04	0.01	0.03	0.12	0.01	0.10	**0.52**	**0.00**
Is,is	**0.03**	**0.19**	**0.01**	**0.03**	**0.01**	**0.03**	**0.07**	**0.02**	**0.05**	**0.20**	**0.02**	**0.16**	**0.85**	**0.00**
Is,in	**0.00**	**0.03**	**0.00**	**0.01**	**0.00**	**0.00**	**0.01**	**0.00**	**0.01**	**0.03**	**0.00**	**0.02**	**0.12**	

Remaining edible oils

In Madhya Pradesh the surplus is in the form of soybean oil. The interstate trade exists therefore only of soybean oil. This surplus is distributed over the deficit states.

Interstate trade of soybean oil

ES	IS										Es,is
	AP	BH	CG	DL	GJ	KL	MH	PJ	TN	UP	
MP	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	**0.12**
Is,is	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.02**	**0.01**	**0.01**	**0.02**	**0.12**

Cotton lint

The cotton lint from the exporting states is evenly distributed to the various importing states According to their part of the total interstate export.

Interstate trade of cotton lint

ES	IS				Es,is	Es,in
	BH	KL	UP	WB		
AP	0.01	0.00	0.01	0.01	**0.05**	**0.18**
GJ	0.01	0.01	0.02	0.01	**0.07**	**0.27**
HR	0.00	0.00	0.01	0.01	**0.03**	**0.13**
KT	0.00	0.00	0.00	0.00	**0.01**	**0.06**
MP	0.00	0.00	0.00	0.00	**0.00**	**0.01**
MH	0.01	0.01	0.02	0.01	**0.07**	**0.27**
PJ	0.00	0.00	0.01	0.01	**0.03**	**0.13**
RJ	0.00	0.00	0.00	0.00	**0.01**	**0.05**
Is,is	**0.03**	**0.02**	**0.08**	**0.05**	**0.27**	**1.10**
Is,in	**0.02**	**0.02**	**0.05**	**0.03**	**0.18**	

Appendix XIII. Interstate virtual water flows by colour

Gross total virtual water flows

States	AP	AS	BH	CG	DL	GJ	HR	HP	JK	JH	KT	KL	MP	MH	OR	PJ	RJ	TN	UP	UA	WB	Export
AP		35	110	481	46	0	0	14	21	36	529	77	0	1814	1051	0	92	190	259	21	144	**4952**
AS	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	**4**
BH	0	0		1	0	78	0	0	0	0	0	0	0	6	0	0	63	0	0	0	0	**149**
CG	0	0	0		0	0	0	0	0	0	0	0	2524	0	296	0	15	0	0	0	0	**2835**
DL	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
GJ	0	120	530	84	155		0	49	99	188	0	168	87	561	178	0	0	5	874	83	572	**3847**
HR	80	101	1647	49	1560	2369		86	549	415	148	2098	0	1877	189	0	542	94	478	50	510	**13006**
HP	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	26	0	0	0	0	**26**
JK	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	26	0	0	0	0	**26**
JH	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	**0**
KT	19	12	39	10	16	97	0	5	7	13		27	95	663	17	0	1900	1	91	7	51	**3130**
KL	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	**0**
MP	112	147	470	739	266	312	83	114	150	297	600	273		999	932	348	43	513	518	122	532	**7671**
MH	11	122	343	873	169	1279	16	60	85	153	85	251	686		121	82	0	137	680	79	455	**5788**
OR	0	0	0	140	0	0	0	0	0	0	0	0	0	0		0	9	0	0	0	0	**149**
PJ	124	75	3123	18	450	1542	0	181	1410	453	228	6109	0	4167	159		344	144	156	13	341	**19351**
RJ	18	289	1620	138	390	1542	27	147	331	674	13	140	0	130	407	138		224	1721	242	1517	**9852**
TN	128	0	0	0	0	0	0	0	0	0	905	944	1541	738	0	0	15		0	0	0	**4293**
UP	76	502	6503	9	930	1591	480	371	424	5450	1190	94	0	851	80	1022	2227	88		341	1995	**24542**
UA	0	31	86	3	44	348	32	411	25	52	0	0	0	27	0	67	182	0	0		121	**1447**
WB	0	868	0	0	0	28	0	0	0	1122	0	0	0	2	1122	0	15	0	0	0		**4447**
Import	**569**	**2304**	**14469**	**2544**	**4026**	**9186**	**638**	**1439**	**3101**	**8853**	**3699**	**10180**	**4933**	**11836**	**4552**	**1658**	**5504**	**1397**	**4777**	**960**	**6238**	**105516**

Gross blue virtual water flows

States	**AP**	**AS**	**BH**	**CG**	**DL**	**GJ**	**HR**	**HP**	**JK**	**JH**	**KT**	**KL**	**MP**	**MH**	**OR**	**PJ**	**RJ**	**TN**	**UP**	**UA**	**WB**	**Export**
AP		2	6	171	3	0	0	1	1	2	99	4	0	313	510	0	13	86	15	1	8	**1236**
AS	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
BH	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0	0	0	**11**
CG	0	0	0		0	0	0	0	0	0	0	0	129	0	15	0	0	0	0	0	0	**144**
DL	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
GJ	0	56	304	33	71		0	24	56	112	0	43	6	57	89	0	0	1	402	43	295	**1626**
HR	40	50	831	19	788	497		43	278	206	74	1058	0	906	94	0	117	47	231	25	253	**5637**
HP	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
JK	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	1	0	0	0	0	**1**
JH	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	**0**
KT	0	1	2	1	1	14	0	0	0	1		1	50	100	1	0	994	0	5	0	3	**1199**
KL	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	**0**
MP	20	76	223	279	119	90	28	53	76	150	14	111		256	35	146	0	235	176	60	262	**2453**
MH	7	25	54	469	41	727	11	19	23	46	14	46	399		6	56	0	90	40	19	75	**2184**
OR	0	0	0	25	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	**25**
PJ	52	31	1414	7	187	692	0	84	656	189	96	2853	0	1894	65		137	60	59	5	139	**8761**
RJ	13	206	1173	97	277	84	19	105	239	487	9	90	0	95	294	97		156	1233	174	1092	**6040**
TN	10	0	0	0	0	0	0	0	0	0	60	506	826	260	0	0	4		0	0	0	**1679**
UP	46	265	2075	0	506	238	251	194	225	1562	85	57	0	454	48	534	810	53		205	1054	**8828**
UA	0	11	30	0	16	0	11	66	9	18	0	0	0	0	0	24	28	0	0		43	**262**
WB	0	167	0	0	0	0	0	0	0	215	0	0	0	0	215	0	0	0	0	0		**845**
Import	**189**	**888**	**6112**	**1101**	**2008**	**2342**	**320**	**588**	**1564**	**2987**	**452**	**4770**	**1410**	**4335**	**1372**	**856**	**2116**	**729**	**2158**	**533**	**3224**	**40931**

Gross green virtual water flows

States	**AP**	**AS**	**BH**	**CG**	**DL**	**GJ**	**HR**	**HP**	**JK**	**JH**	**KT**	**KL**	**MP**	**MH**	**OR**	**PJ**	**RJ**	**TN**	**UP**	**UA**	**WB**	**Export**
AP		29	90	278	38	0	0	11	17	30	377	63	0	1408	450	0	70	85	213	17	119	**3323**
AS	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	**4**
BH	0	0		1	0	74	0	0	0	0	0	0	0	6	0	0	45	0	0	0	0	**126**
CG	0	0	0		0	0	0	0	0	0	0	0	2145	0	251	0	13	0	0	0	0	**2410**
DL	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
GJ	0	48	152	39	62		0	19	29	50	0	102	77	471	64	0	0	3	349	29	196	**1733**
HR	18	30	517	23	564	1601		32	202	107	33	815	0	645	53	0	344	21	164	16	148	**5390**
HP	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	23	0	0	0	0	**23**
JK	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	23	0	0	0	0	**23**
JH	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	**0**
KT	18	10	31	8	13	73	0	4	6	10		22	38	527	13	0	770	1	74	6	41	**1696**
KL	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	**0**
MP	83	48	167	330	110	190	45	45	50	99	545	128		602	832	160	39	213	263	43	181	**4221**
MH	2	80	242	337	106	458	3	34	50	87	61	171	239		99	15	0	29	547	49	319	**2996**
OR	0	0	0	106	0	0	0	0	0	0	0	0	0	0		0	9	0	0	0	0	**114**
PJ	33	24	1186	9	124	552	0	77	590	123	60	2586	0	1577	48		105	38	75	6	108	**7444**
RJ	3	30	143	16	42	1336	4	16	31	62	2	29	0	9	37	21		34	167	24	144	**2167**
TN	107	0	0	0	0	0	0	0	0	0	762	375	612	426	0	0	9		0	0	0	**2301**
UP	10	191	3671	8	300	1176	191	147	155	3278	1006	12	0	187	10	406	1217	11		44	752	**12888**
UA	0	17	47	2	24	322	17	294	14	29	0	0	0	25	0	37	139	0	0		67	**1045**
WB	0	611	0	0	0	26	0	0	0	790	0	0	0	2	790	0	14	0	0	0		**3141**
Import	**273**	**1119**	**6247**	**1158**	**1383**	**5808**	**261**	**679**	**1145**	**4667**	**2847**	**4302**	**3111**	**5886**	**2648**	**639**	**2824**	**434**	**1853**	**235**	**2074**	**51044**

Gross gray virtual water flows

States	AP	AS	BH	CG	DL	GJ	HR	HP	JK	JH	KT	KL	MP	MH	OR	PJ	RJ	TN	UP	UA	WB	Export
AP		4	13	31	6	0	0	2	3	4	53	9	0	92	91	0	9	20	32	3	18	**393**
AS	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
BH	0	0		0	0	4	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	**11**
CG	0	0	0		0	0	0	0	0	0	0	0	251	0	29	0	1	0	0	0	0	**282**
DL	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
GJ	0	17	74	12	22		0	7	14	26	0	24	5	34	25	0	0	1	123	12	80	**488**
HR	22	21	298	7	208	271		11	69	102	41	225	0	326	42	0	81	26	84	9	108	**1980**
HP	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	3	0	0	0	0	**3**
JK	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	3	0	0	0	0	**3**
JH	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	**0**
KT	1	2	5	1	2	10	0	1	1	2		4	7	37	2	0	136	0	12	1	7	**235**
KL	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	**0**
MP	9	23	80	130	37	32	9	16	24	47	40	33		140	65	42	3	65	79	19	88	**998**
MH	1	17	47	67	23	94	2	8	11	21	10	34	48		17	11	0	18	93	11	62	**608**
OR	0	0	0	9	0	0	0	0	0	0	0	0	0	0		0	1	0	0	0	0	**10**
PJ	40	20	523	2	138	299	0	20	164	140	73	670	0	697	46		103	46	22	2	93	**3146**
RJ	3	52	304	25	70	122	4	26	61	125	2	20	0	25	77	21		35	321	44	282	**1645**
TN	11	0	0	0	0	0	0	0	0	0	83	63	102	52	0	0	2		0	0	0	**313**
UP	21	47	757	1	124	177	38	30	43	609	99	26	0	210	22	82	200	24		92	190	**2825**
UA	0	3	8	0	4	26	3	52	2	5	0	0	0	2	0	6	15	0	0		12	**141**
WB	0	90	0	0	0	2	0	0	0	117	0	0	0	0	117	0	1	0	0	0		**461**
Import	**108**	**296**	**2111**	**286**	**635**	**1035**	**57**	**172**	**392**	**1198**	**401**	**1108**	**413**	**1615**	**532**	**163**	**565**	**234**	**766**	**192**	**939**	**13541**

Net total virtual water flows

States	AP	AS	BH	CG	DL	GJ	HR	HP	JK	JH	KT	KL	MP	MH	OR	PJ	RJ	TN	UP	UA	WB	Export
AP		35	110	481	46	0	-80	14	21	36	510	77	-112	1803	1051	-124	73	62	183	21	144	**4383**
AS	-35		0	0	0	-120	-101	0	0	0	-12	0	-147	-122	0	-75	-285	0	-502	-31	-868	**-2300**
BH	-110	0		1	0	-451	-1647	0	0	0	-39	0	-470	-336	0	-3123	-1557	0	-6503	-86	0	**-14321**
CG	-481	0	-1		0	-84	-49	0	0	0	-10	0	1785	-873	156	-18	-123	0	-9	-3	0	**291**
DL	-46	0	0	0		-155	-1560	0	0	0	-16	0	-266	-169	0	-450	-390	0	-930	-44	0	**-4026**
GJ	0	120	451	84	155		-2369	49	99	188	-97	168	-225	-717	178	-1542	-1542	5	-717	-264	544	**-5339**
HR	80	101	1647	49	1560	2369		86	549	415	148	2098	-83	1861	189	0	515	94	-3	19	510	**12368**
HP	-14	0	0	0	0	-49	-86		0	0	-5	0	-114	-60	0	-181	-121	0	-371	-411	0	**-1414**
JK	-21	0	0	0	0	-99	-549	0		0	-7	0	-150	-85	0	-1410	-305	0	-424	-25	0	**-3075**
JH	-36	0	0	0	0	-188	-415	0	0		-13	0	-297	-153	0	-453	-674	0	-5450	-52	-1122	**-8853**
KT	-510	12	39	10	16	97	-148	5	7	13		27	-505	578	17	-228	1887	-904	-1099	7	51	**-569**
KL	-77	0	0	0	0	-168	-2098	0	0	0	-27		-273	-251	0	-6109	-140	-944	-94	0	0	**-10180**
MP	112	147	470	-1785	266	225	83	114	150	297	505	273		313	932	348	43	-1027	518	122	532	**2738**
MH	-1803	122	336	873	169	717	-1861	60	85	153	-578	251	-313		121	-4086	-130	-601	-171	52	453	**-6048**
OR	-1051	0	0	-156	0	-178	-189	0	0	0	-17	0	-932	-121		-159	-398	0	-80	0	-1122	**-4403**
PJ	124	75	3123	18	450	1542	0	181	1410	453	228	6109	-348	4086	159		206	144	-866	-55	341	**17694**
RJ	-73	285	1557	123	390	1542	-515	121	305	674	-1887	140	-43	130	398	-206		209	-506	60	1502	**4348**
TN	-62	0	0	0	0	-5	-94	0	0	0	904	944	1027	601	0	-144	-209		-88	0	0	**2897**
UP	-183	502	6503	9	930	717	3	371	424	5450	1099	94	-518	171	80	866	506	88		341	1995	**19765**
UA	-21	31	86	3	44	264	-19	411	25	52	-7	0	-122	-52	0	55	-60	0	-341		121	**487**
WB	-144	868	0	0	0	-544	-510	0	0	1122	-51	0	-532	-453	1122	-341	-1502	0	-1995	-121		**-1791**
Import	**-4383**	**2300**	**14321**	**-291**	**4026**	**5339**	**-12368**	**1414**	**3075**	**8853**	**569**	**10180**	**-2738**	**6048**	**4403**	**-17694**	**-4348**	**-2897**	**-19765**	**-487**	**1791**	

Appendix XIV. Water footprints by colour

Blue water footprints of the consumption of agricultural commodities

State	Blue state water footprint			Blue water footprint per capita		
	Internal	External	Total	Internal	External	Total
Unit	10^9 m^3/yr			m^3/cap/yr		
Year	1997-2001					
Andhra Pradesh	20	1	21	273	13	286
Assam	0	1	2	18	40	58
Bihar	9	7	16	110	88	198
Chhattisgarh	1	2	3	63	82	144
Delhi	0	3	3	9	200	209
Gujarat	10	3	13	199	66	266
Haryana	8	1	9	390	32	422
Himachal Pradesh	0	1	1	11	135	147
Jammu & Kashmir	1	2	3	91	177	267
Jharkhand	1	3	4	35	130	166
Karnataka	9	1	10	180	13	193
Kerala	0	6	6	11	183	194
Madhya Pradesh	12	2	13	201	27	228
Maharashtra	12	6	17	123	62	184
Orissa	3	2	5	83	50	133
Punjab	9	2	10	362	76	438
Rajasthan	15	3	18	274	47	321
Tamil Nadu	13	2	14	207	28	235
Uttar Pradesh	39	4	43	243	25	269
Uttaranchal	1	1	2	103	84	188
West Bengal	9	4	13	116	52	168
Total	172	55	227	172	55	227

Green water footprints of the consumption of agricultural commodities

State	Green state water footprint			Green water footprint per capita		
	Internal	External	Total	Internal	External	Total
Unit	10^9 m^3/yr			m^3/cap/yr		
Year	1997-2001					
Andhra Pradesh	34	0	34	458	4	462
Assam	16	1	17	601	43	644
Bihar	24	6	30	296	77	374
Chhattisgarh	21	1	22	1020	57	1078
Delhi	0	1	1	7	103	110
Gujarat	22	6	28	453	116	569
Haryana	6	0	6	303	13	316
Himachal Pradesh	2	1	3	320	115	434
Jammu & Kashmir	3	1	4	263	116	379
Jharkhand	9	5	14	360	178	538
Karnataka	27	3	30	519	55	575
Kerala	2	4	7	73	139	212
Madhya Pradesh	30	3	33	516	53	569
Maharashtra	52	6	58	553	62	615
Orissa	31	3	34	869	74	943
Punjab	8	1	9	326	42	368
Rajasthan	29	2	31	528	45	573
Tamil Nadu	15	0	16	255	7	262
Uttar Pradesh	46	2	48	283	11	294
Uttaranchal	2	0	3	297	28	326
West Bengal	28	3	30	358	33	390
Total	407	52	459	407	52	459

Gray water footprints of the consumption of agricultural commodities

State	Gray state water footprint			Gray water footprint per capita		
	Internal	External	Total	Internal	External	Total
Unit	10^9 m^3/yr			m^3/cap/yr		
Year	1997-2001					
Andhra Pradesh	6	0	6	78	1	79
Assam	2	0	2	68	11	80
Bihar	5	2	7	66	26	92
Chhattisgarh	2	0	3	120	14	134
Delhi	0	1	1	3	47	50
Gujarat	4	1	5	74	21	95
Haryana	3	0	3	127	3	130
Himachal Pradesh	0	0	1	73	29	102
Jammu & Kashmir	1	0	1	62	40	101
Jharkhand	1	1	2	47	46	93
Karnataka	4	0	4	74	8	82
Kerala	0	1	1	10	36	46
Madhya Pradesh	7	0	7	116	7	123
Maharashtra	7	2	9	74	17	91
Orissa	4	1	4	99	15	114
Punjab	3	0	3	138	9	146
Rajasthan	6	1	7	111	10	121
Tamil Nadu	3	0	3	48	4	51
Uttar Pradesh	15	1	16	94	5	99
Uttaranchal	1	0	1	85	23	108
West Bengal	5	1	6	60	13	73
Total	78	14	92	78	14	92

Appendix XV. Water footprints compared to consumption volume and climate

The relation between the water footprint (*WFP*) and the consumption volume is quantified by comparing the water footprint to the average income per capita per state during our study period (Figure A.3). No significant relation between the two parameters is found.

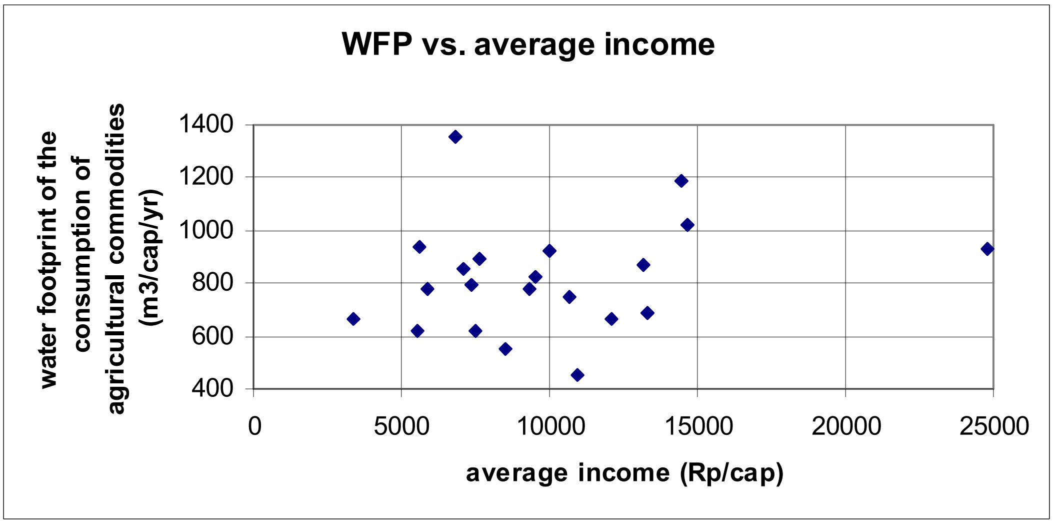


Figure A.3: Relation between the water footprint and the average income of the Indian states in the period 1997-2001

Next, the relation between the water footprint and the climate is quantified by comparing the water footprint to the evaporative demand in a state (Figure A.4). No significant relation between the two parameters is found.

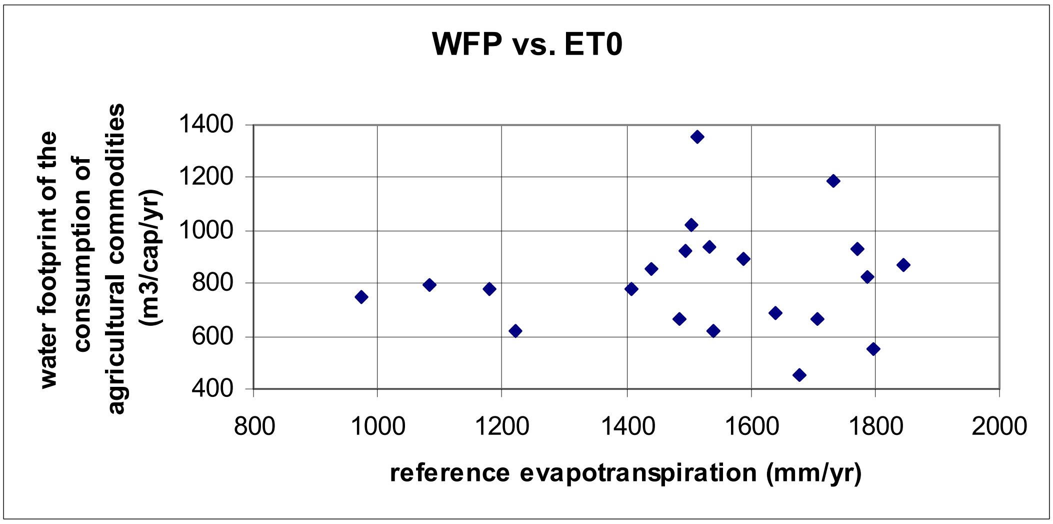


Figure A.4: Relation between the water footprint and the climate of the Indian states in the period 1997-2001

Appendix XVI. Other estimates on the water resources of India

Many studies have been executed to estimate the total water resources of India. The outcome of three important studies is presented here to create a reference for calculations in this study.

FAO (2006e)

A simplified hydrological concept is used in the computation of the total internal renewable water resources. The input is the total precipitation, which results either in evapotranspiration (runoff deficit), infiltration and groundwater recharge (in the aquifers) or direct surface runoff (in the rivers). In this concept an estimate is made for the overlap between aquifers and rivers. This overlap represents that part of the water resources that belongs to rivers as well as aquifers (FAO, 2003). FAO presents the following data on the total water resources of India:

- Precipitation = 1083 mm x 328.726.000 ha = 3559 km^3/year
- Internally produced surface water = 1869 (outflow) – 636 (inflow) = 1233 km^3/year
- Internally produced groundwater = 419 km^3/year
- Overlap of surface and groundwater = 380 km^3/year
- Total internal renewable water resources = 1233 + 419 – 380 = 1272 km^3/year
- Total renewable water resources = 1272 + 636 = 1908 km^3/year
- Runoff deficit (Precipitation - IRWR) = 3559 – 1272 = 2287 km^3/year

Ministry of Water Resources (2006a)

In this assessment of (blue) water resources of the various river basins, the vapour flows are excluded and the inflow of surface water is not separated from internally produced surface water. Therefore the water balance is not complete. The Ministry of Water Resources presents the following data on the total water resources of India:

- Precipitation = 4000 km^3/year
- Internally and externally produced surface water = 1869 km^3/year
- Internally produced groundwater = 432 km^3/year
- Overlap of surface water and groundwater = not estimated

Chaturvedi (1985)

In 1974, the National Commission on Agriculture estimated the national water balance of India for the years 1974, 2000 and 2025 (Chaturvedi, 1985). In this calculation the average annual rainfall is assessed at 3940 km^3 (1194 mm). This is rounded off to 4000 km^3 since snowfall is not yet included. Chaturvedi (1985) presents the following data on the total water resources of India:

- Precipitation (including snowfall) = 4000 km^3/year
- Immediate evapotranspiration from soil = 700 km^3/year
- Infiltration to soil moisture = 1650 km^3/year
- Percolation to groundwater = 500 km^3/year
- Surface runoff to surface water = 1150 km^3/year
- Net flow from groundwater to surface water = 350 km^3/year
- Runoff deficit = soil moisture + evapotranspiration = 2350 km^3/year

Appendix XVII. Average annual precipitation

In Figure A.3 the variation in the average annual precipitation (cm) in India is given. This figure is taken from India Meteorological Department (IMD). Over which time period this average annual precipitation map is calculated is not given by IMD. The Indian Institute of Tropical Meteorology (IITM), that takes the basic weather data for their research from IMD, provides precipitation data from 1871 to 2004. This makes it very likely that Figure A.3 is also based on this time period.

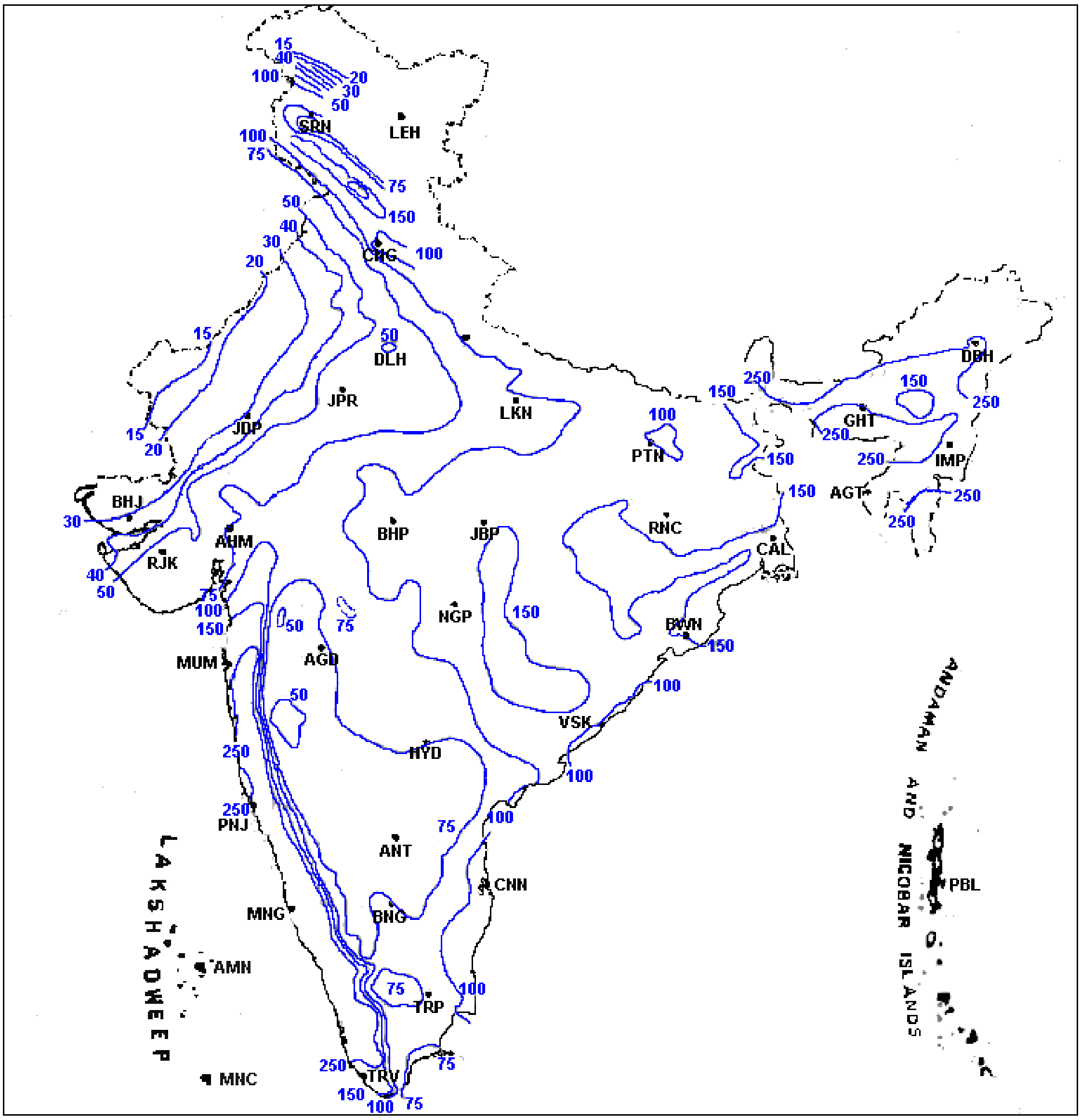


Figure A.5: Average annual precipitation map of India in cm (Source: www.imd.ernet.in/section/climate/annual-rainfall.htm).

Appendix XVIII. Water resources of the Indian states

States	Total water resources				Water resources by capita			
	Green	Blue			Green	Blue		
		Internal	External	Total		Internal	External	Total
unit	billion m^3/yr				m^3/cap/yr			
year	1997-2001							
Andhra Pradesh	188	66	206	272	2537	896	2774	3670
Assam	75	103	567	670	2912	3965	21879	25844
Bihar	64	51	442	493	789	628	5482	6109
Chhattisgarh	91	105	9	114	4496	5174	452	5626
Delhi	1	0	0	0	58	18	0	18
Gujarat	88	47	92	139	1789	961	1860	2821
Haryana	23	8	14	22	1121	391	663	1055
Himachal Pradesh	39	50	11	62	6553	8496	1934	10430
Jammu & Kashmir	104	37	13	49	10577	3712	1291	5004
Jharkhand	55	52	14	65	2082	1970	528	2498
Karnataka	140	113	31	144	2733	2199	612	2811
Kerala	39	65	0	65	1255	2112	0	2112
Madhya Pradesh	170	193	0	193	2898	3289	0	3289
Maharashtra	179	132	19	151	1896	1404	204	1608
Orissa	123	110	78	188	3446	3079	2185	5264
Punjab	26	5	54	58	1102	193	2260	2452
Rajasthan	128	42	4	46	2334	765	71	835
Tamil Nadu	93	34	25	60	1525	568	417	985
Uttar Pradesh	139	93	240	333	863	575	1485	2059
Uttaranchal	36	50	0	50	4347	6045	0	6045
West Bengal	74	76	537	613	945	978	6885	7864
INDIA Total	2048	1705	636	2341	2053	1709	638	2347

Appendix XIX. Blue water flows between the Indian states

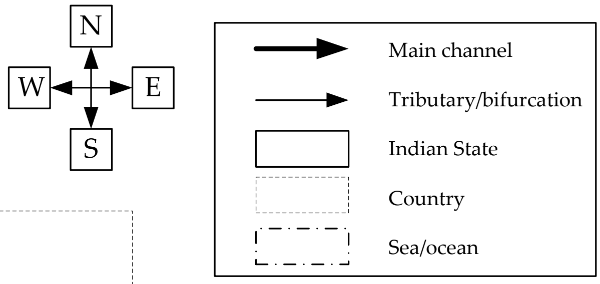
In this Appendix, the annual river discharges (km^3/yr) between the states in the various river basins are given.

From a hydrological point of view India is divided in nineteen major river basins (Figure A.6). All precipitation that falls within the borders of one of these river basins and becomes surface water or groundwater is eventually drained the main river of the particular basin.

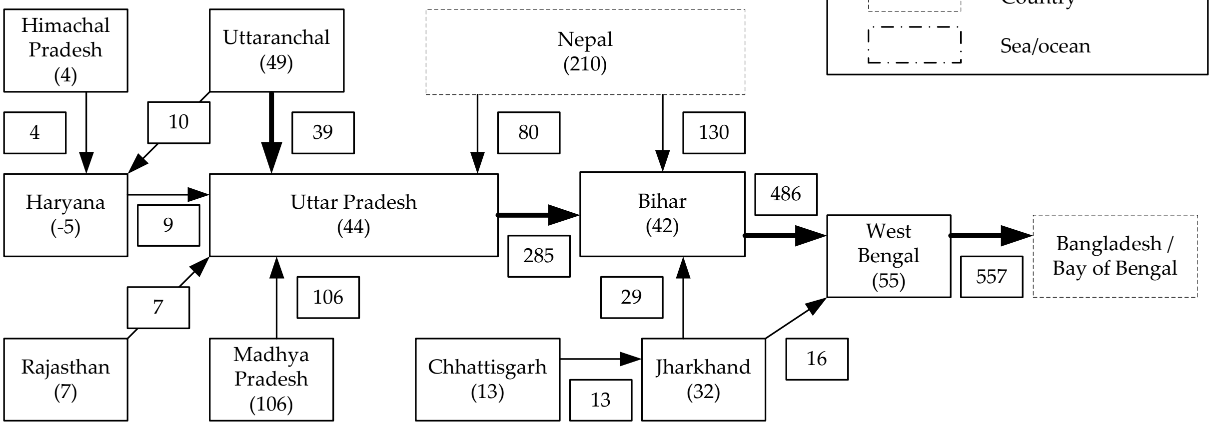
The rivers of India can be divided into the Himalayan river basins and the peninsular river basins. The main rivers that originate in the Himalayan Range are the Ganges, the Indus and the Brahmaputra. These rivers are perennial because they receive water from both rainfall and the melting of ice. The main peninsular rivers are the Narmada, the Tapi, the Godavari, the Krishna, the Cauvery and the Mahanadi. Most of these rivers are seasonal since they receive water from rainfall only.

Figure A.6: River basins of India (source: Central Water Commission India, 2006).

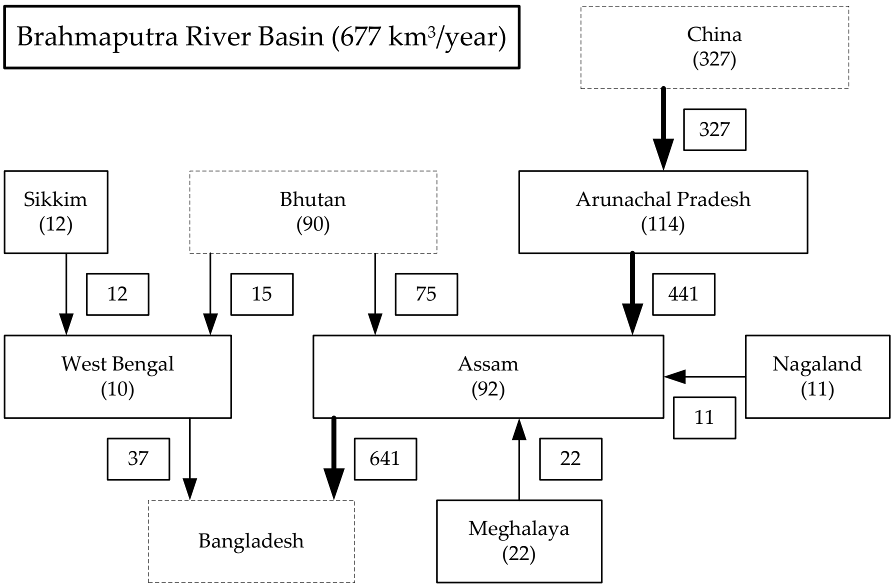
Annual average discharge in km³/ year



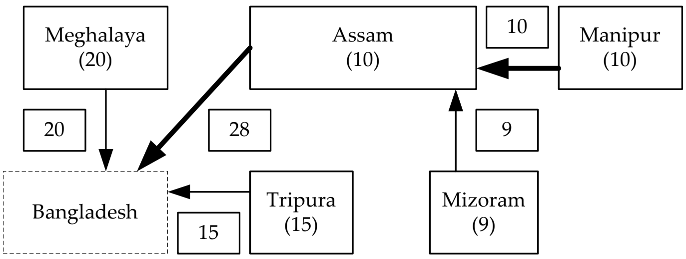
Ganges River Basin (557 km³/year)



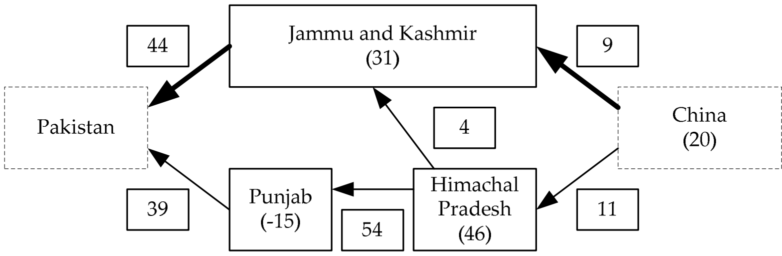
Brahmaputra River Basin (677 km³/year)



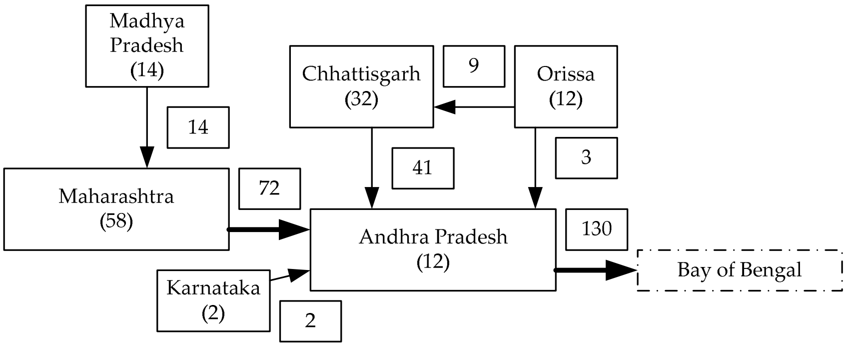
Barak River Basin (63 km³/year)



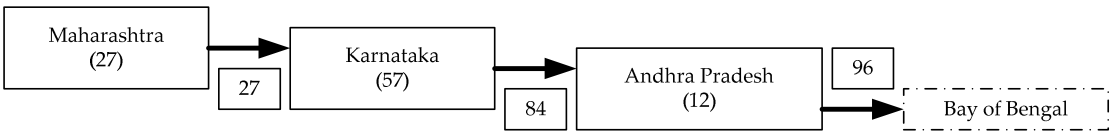
Indus River Basin (84 km³/year)



Godavari River Basin (130 km³/year)

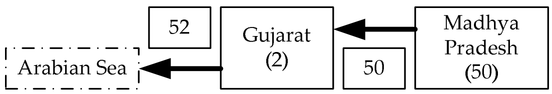


Krishna River Basin (96 km³/year)

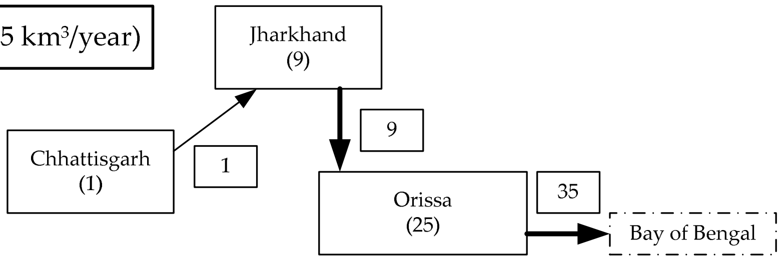


Mahanadi River Basin (103 km³/year)

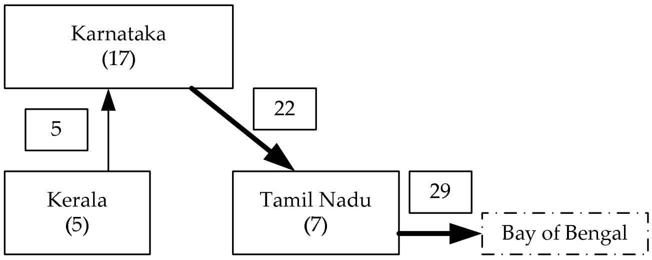
Narmada River Basin (52 km³/year)



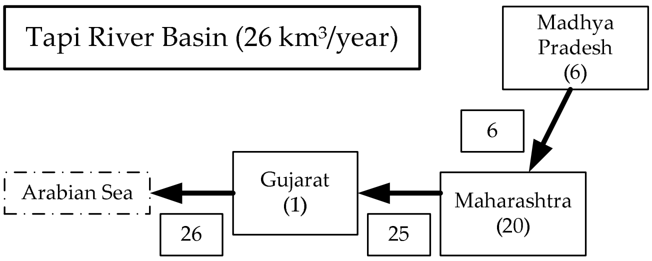
Brahmani-Baitarani River Basin (35 km^3/year)



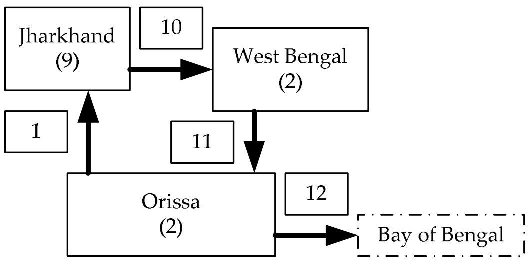
Cauvery River Basin (29 km^3/year)



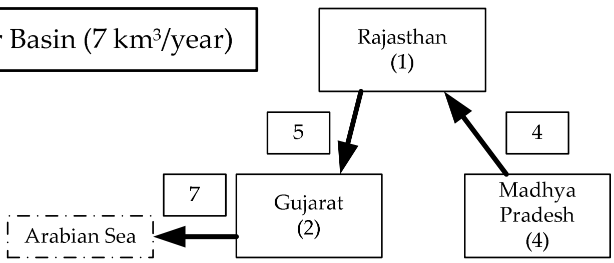
Tapi River Basin (26 km^3/year)



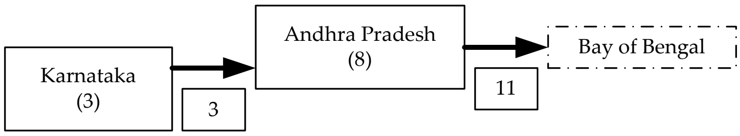
Subernarekha River Basin (13 km^3/year)



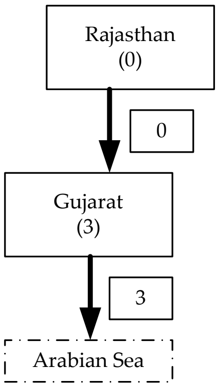
Mahi River Basin (7 km^3/year)



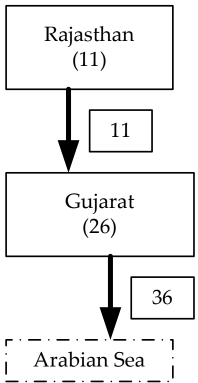
Pennar River Basin (11 km³/year)



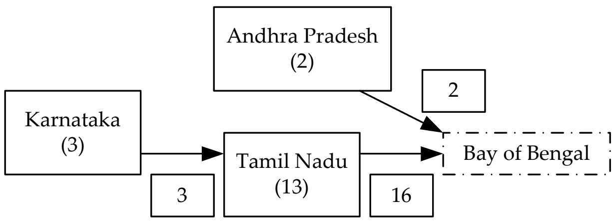
Sabarmati River Basin (3 km³/year)



Luni River Basin and the river basins of Saurashtra (36 km³/year)



East flowing river basins between Pennar River and Kanyakumari (18 km³/year)



River basins which do not cross state borders:

- West flowing river basins between Tapi River and Kanyakumari
- East flowing river basins between Mahanadi River and Pennar River
- North eastern river basins flowing into Myanmar

Areas of states in river basins (km²)	Rivers	Ganges	Brahmaputra	Barak-Meghna	West Tadri-Kanyakumari	Godavari	West Tapi-Tadri	Krishna	Indus	Mahanadi	Narmada	Northeastern rivers	Brahmani-Baitarani	East Mahanadi-Pennar	Cauvery	East Pennar-Kanyakumari	Kutch-Saurashtra	Tapi	Subernarakha	Mahi	Pennar	Sabarmati	Rajasthan inland basin
State	Area	861452	194413	41723	56177	312812	55940	258948	321289	141589	98796	36302	51822	86600	81155	100139	321851	65145	19296	34842	55213	21674	14000
Andhra Pradesh	275068	0	0	0	0	73201	0	76251	0	0	0	0	0	66669	0	10671	0	0	0	0	48276	0	0
Arunachal Pradesh	83743	0	81616	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Assam	78483	0	70800	7683	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bihar	94164	94164	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chhattisgarh	135194	16758	0	0	0	41867	0	0	0	74982	170	0	1316	0	0	0	0	0	0	0	0	0	0
Delhi	1483	1483	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Goa	3702	0	0	0	0	0	3702	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gujarat	196024	0	0	0	0	0	9000	0	0	0	11399	0	0	0	0	0	142544	3837	0	11694	0	17550	0
Haryana	44212	34341	0	0	0	0	0	0	9939	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Himachal Pradesh	55673	4317	0	0	0	0	0	0	51356	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jammu & Kashmir	222236	0	0	0	0	0	0	0	193762	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Jharkhand	79700	49797	0	0	0	0	0	0	0	635	0	0	14508	0	0	0	0	0	14093	0	0	0	0
Karnataka	191791	0	0	0	16600	4405	9790	113272	0	0	0	0	0	0	34273	6514	0	0	0	0	6937	0	0
Kerala	38863	0	0	0	35997	0	0	0	0	0	0	0	0	0	2866	0	0	0	0	0	0	0	0
Madhya Pradesh	308144	182204	0	0	0	23388	0	0	0	154	85689	0	0	0	0	0	0	9804	0	6695	0	0	0
Maharashtra	307713	0	0	0	0	152199	32809	69425	0	238	1538	0	0	0	0	0	0	51504	0	0	0	0	0
Manipur	22327	0	0	7442	0	0	0	0	0	0	0	14885	0	0	0	0	0	0	0	0	0	0	0
Meghalaya	22429	0	11888	10541	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mizoram	21081	0	0	5270	0	0	0	0	0	0	0	15811	0	0	0	0	0	0	0	0	0	0	0
Nagaland	16579	0	10855	0	0	0	0	0	0	0	0	5724	0	0	0	0	0	0	0	0	0	0	0
Orissa	155707	0	0	0	0	17752	0	0	0	65580	0	0	35998	33398	0	0	0	0	2983	0	0	0	0
Punjab	50362	0	0	0	0	0	0	0	50304	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rajasthan	342236	112490	0	0	0	0	0	0	15814	0	0	0	0	0	0	0	179307	0	0	16453	0	4124	14000
Sikkim	7096	0	7096	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tamil Nadu	130058	0	0	0	3580	0	0	0	0	0	0	0	0	0	43868	82610	0	0	0	0	0	0	0
Tripura	10492	0	0	10492	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uttar Pradesh	238566	238566	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Uttaranchal	53566	53566	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
West Bengal	88752	73766	12758	0	0	0	0	0	0		0	0	0	0	0	0	0	0	2220	0	0	0	0

Appendix XX. Assessment of water scarcity in a potential situation

Here the calculation of the water scarcity from production and consumption perspective is presented for the potential situation of increased water productivity combined with the omission of the interstate trade in milled rice from Punjab and Uttar Pradesh to Bihar (see Table 7.7 in Chapter 7.3.2).

Water scarcity in the potential situation from a production perspective

From Table 7.4 and Table 7.5, the water saving as a result of the shift from the current situation to the potential situation can be calculated by colour and by state. The total water use is presented by colour and by state in Table 6.1. In Table A.2, the total agricultural water use is presented for the current and potential situation.

Table A.2: Agricultural water use in the current and potential situation in Bihar, Punjab and Uttar Pradesh in the period 1997-2001

States	Total agricultural water use in current situation			Total agricultural water use in potential situation		
	Blue + Gray	Green	Total	Blue + Gray	Green	Total
Unit	10^9 m^3/yr					
Bihar	14	24	38	15	17	32
Punjab	26	17	43	25	16	41
Uttar Pradesh	67	60	128	64	47	111

The water use in the potential situation are now divided by the water resources in as presented in Appendix XVII to find the water scarcity from a production perspective in the potential situation as presented in Table 7.7 in Chapter 7.3.2.

Water scarcity in the potential situation from a consumption perspective

From Table 7.4 and Table 7.5, the water saving as a result of the shift from the current situation to the potential situation can be calculated by colour and by state. The current water footprints are presented by colour and by state in Table 6.1 and Appendix XIII. In the following table, the water footprints are presented for the current and potential situation.

Table A.3: Water footprint in the current and potential situation in Bihar, Punjab and Uttar Pradesh in the period 1997-2001

States	Total water footprint in current situation			Total water footprint in potential situation		
	Blue + Gray	Green	Total	Blue + Gray	Green	Total
Unit	10^9 m^3/yr					
Bihar	23	30	54	21[1]	19[2]	40
Punjab	13	9	22	13	9	22
Uttar Pradesh	59	48	107	58[3]	41[4]	99

*[1] The internal blue water footprint of Bihar increases with 1.5 billion m^3/yr, the external blue water footprint decreases with 2.2 billion m^3/yr, the internal gray water footprint decreases with 0.3 billion m^3/yr and the external gray water footprint decreases with 0.8 billion m^3/yr; this leads to a total reduction of the blue and gray water footprint of 1.8 billion m^3/yr. [2] The internal green water footprint of Bihar decreases with 7.0 billion m^3/yr and the external green water footprint decreases with 4.2 billion m^3/yr, this leads to a total reduction of the green water footprint of 11.2 billion m^3/yr. [3] The internal blue water footprint of Uttar Pradesh decreases with 0.3 billion m^3/yr. In the case of no interstate trade, the total blue water saving is 0.5 billion m^3/yr and 69% of the production is consumed within the state (7.4 million ton/yr out of 10.7 million ton/yr), so the internal blue water footprint decreases with 0.5 * 69% = 0.3 billion m^3/yr, The internal gray water footprint decreases with 0.8 billion m^3/yr. In*

*the case of no interstate trade, the total gray water saving is 1.2 billion m^3/yr and 69% of the production is consumed within the state, so the internal gray water footprint decreases with 1.2 * 69% = 0.8 billion m^3/yr. So in total, the blue and gray water footprint of Uttar Pradesh decreases with 1.1 billion m^3/yr.* [4] *The internal green water footprint of Uttar Pradesh decreases with 7.3 billion m^3/yr. In the case of no interstate trade, the total green water saving is 10.6 billion m^3/yr and 69% of the production is consumed within the state, so the internal green water footprint decreases with 10.6 * 69% = 7.3 billion m^3/yr.*

The water footprints in the potential situation are now divided by the water resources (Appendix XVII) to find the water scarcity from a consumption perspective in the potential situation as presented in Table 7.7 in Chapter 7.3.2.