ASSESSMENT OF BLUE, GREEN AND GREY WATER FOOTPRINT AT RIVER BASIN LEVEL: A CASE STUDY OF THE KOSHI RIVER BASIN, NEPAL

A DISSERTATION

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By

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CANDIDATE’S DECLARATION

I hereby certify that the work presented in this dissertation entitled ***“*Assessment of Blue, Green and Grey Water Footprint at River Basin Level: a Case Study of the Koshi River Basin, Nepal*”*** in partial fulfillment of the requirements for the award of the degree of **Master of Technology in Irrigation Water Management** submitted in the Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, Roorkee, is an authentic record of my own work carried out during the period from July 2017 to May 2018 under the supervision of **Dr. Ashish Pandey**, Associate Professor, Department of Water Resources Development and Management, Indian Institute of Technology Roorkee, Roorkee, **Er. R.D. Singh**, Adjunct Professor, Department of Water Resources Development and Management, Indian Institute of Technology Roorkee and **Prof. G.S. Murthy**, Professor, Oregon State University, Corvallis OR.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

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SYNOPSIS

Nepal is an agrarian country and almost one-third of Gross Domestic Product (GDP) is dependent on agricultural sector. Koshi river basin is the largest basin in the country and serves large share on agricultural production. Like another country, Nepalese agriculture holds largest water use in agriculture. In this context, it is necessary to reduce water use pressure. In this study monsoon rainfall variability in the Koshi basin have been analyzed in different scale seasonal, monthly, decadal and daily for the period of 1980-2015, and water footprint of different crop (rice, maize, wheat, millet, sugarcane, potato and barley) have been estimated for the year 2005 -2014 to get the average water footprint of crop production during study period. A sample calculation of water footprint has been shown on the appendix.

The current study of water footprint estimation is based on CROPWAT model developed by Food and Agriculture Organization (FAO 2010b) that requires climatic data, soil properties, and crop characteristics as input. This method calculates evapotranspiration from a field, which is the water consumption in field level. Medium soil and 70 % irrigation efficiency is considered in irrigation schedule option, and ET of the crop is calculated considering daily moisture balance for both rainfed and irrigated scenario in the model. It doesn't include conveyance losses during irrigation process. So, water footprint production of any crop (Mm^3/year) doesn't represent the irrigation diversion requirement but represents the crop water use at the field for producing that crop during the study period.

Both the green and blue water footprint estimation is based on ET (the output of CROPWAT model) and yield (derived from statistical data). Blue and green water footprint are calculated for different districts (16 districts within KRB) / for KRB in different years (10 years from 2005 to 2014) and crops (considered 7 local crops). The water footprint of crops production at any district or basin represents the averaged of WF production of seven crops in the respective district or basin. Then trend analysis of each crop is also carried out for basin level. This study gives a picture of green and blue water use in crop production in the field and gives the idea of reducing the water footprint of crop production by selecting suitable crop at a suitable place. Water footprint of sugarcane has been significantly decreased after the introduction of higher yielding or diseases resistant variety of in the year 2010. In the year 2009, most of the crop must tolerate water stress. In this year rainfall is less than other years and recognized as a drought year. To meet crop water requirement irrigation water has been supplied more in that year. So, the blue water use is significantly increased. Crop that has lower water footprint can be intensified in that location and the crop having higher water

footprint can be discontinued for production or measure for water saving technique needs to be implemented to reduce evapotranspiration. The water footprint of agriculture crop production can be reduced by increasing the yield of the crops. Some measures like use of an improved variety of seed, fertilizer, mechanized farming and soil moisture conservation technology can be used to increase yield.

The crop harvested area in this study includes both rainfed as well as irrigated land. Agricultural land occupies 22% of the study area, of which 94% contributes rainfed and 6% contributes irrigated area. The study shows 98% of total water use in crop production is due to green water use (received from rainfall) and remaining 2 % is due to blue water use received from irrigation (surface and ground water as source). Potato has 22% blue water proportion and contributes 85% share on total blue water use in the basin. Maize and rice together hold 77% share of total water use in crops production. The average annual water footprint of crop production in KRB is 1248m3/ton with the variation of 9% during the period 2005-2014 Sunsari, Dhankuta districts have lower water footprint of crop production. The coefficient of variation of water footprint of millet crop production is lower as compared to those of other crops considered for study whereas sugarcane has a higher variation of water footprint for its production.

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LIST OF ABBREVIATIONS AND SYMBOLS

CWU_b	Blue crop water use
CWU_g	Green Crop water use
ET_a	Actual evapotranspiration
ET_g	Evapotranspiration green
ET_b	Evapo-transpiration blue
BWP	Blue Water Proportion
CBS	Center Bureau of Statistic
CV	Coefficient of Variation
CWR	Crop Water Requirement
CWU	Crop Water Use
CWU:	Total crop water use,
DADO	District Agricultural Development Office
dec	Decade
DHM	Department of Hydrology and Metrology
et al.:	And others
ET	Evapotranspiration
etc.	Etcetera
FAO	Food and Agricultural Organization
i.e.	That is
KRB	Koshi River Basin
MCM	Million Cubic Meter
MOAC	Ministry of Agriculture and Co-operatives
NARC	Nepal Agricultural Research Council
SD	Standard Deviation

UNEP	United National Environmental Programme
VWC	Virtual Water Content
WECS	Water and Energy Commission Secretariat
WF	Water Footprint
WF_{prod}	Total water footprint of a crop production
$WF_{prod,blue}$	Blue water footprint of a crop production
$WF_{prod,green}$	Green water footprint of a crop production
WFN	Water Footprint Network
WFP	Water Footprint Proportion
Y*	Yield of a crop
Yr	Year

CHAPTER 1
INTRODUCTION

1.1. BACKGROUND

Annual availability of freshwater is limited and becoming a scarce resource. Human growth and their activities for economical and industrial developments are leading factors for increasing in water resource consumption and deterioration. Proper water resource management is needed to quantify available water sources and utilize it effectively due to its key role in sustainable economic development, environmental stability and poverty reduction.

Agriculture, domestic, industrial and other uses are consuming a large quantity of water worldwide (Clay 2004). Nepalese conditions are also similar. Water consumption is increasing. According to Water and Energy Commission Secretariat (WECS Nepal), of the 225 billion cubic meters of surface water in country available annually, only 15 billion cubic meters (less than seven percent) is utilized in different sectors. Around 95.9% of the total water consumed is used for agriculture, 3.8 % for domestic propose and only about 0.3% is used for industry in 2011. Competition for access to water resources remains due to the result of increasing population and industrial expansion along with the growing demand from urbanization and irrigation sector. According to Food and Agricultural Organization (FAO), global water consumption for agriculture is 70% and its share in individual countries varies depending upon the economic activities of the country. As per World Data Atlas of FAO, agriculture water withdrawal of Nepal in the year 2014 is 98.14% of the total fresh water withdrawal, which is up by 0.69% from the year 2000.

Population growth and their activities are responsible for decreasing water availability by degrading of water quality and quantity. In Nepal, agriculture sector is contributing to 35% of Gross Domestic Product (MoF, 3013) and employing two-thirds of the country's population. The country has more than 6000 rivers. Many of the larger rivers have fertile lands with each basin and sub-basin falling into a distinct physiographic region due to altitudinal variation. Despite the abundance of water resources, the distribution is uneven during the year and there is water stress in the dry season as well as challenges due to flooding during monsoon. About seventy percent of the river basin's population depends on rain-fed agriculture. It is influenced by human activities such as varied agricultural practices, soil water management practices and different levels of natural degradation.

Furthermore, spatial and temporal distributions of fresh water are highly sensitive to climate change. Variation in evapotranspiration and soil moisture deficit due to the fluctuation of temperature can have a considerable impact on agriculture production and food security. Water availability is the main component of food security (McGuign, 2002). Variability of rainfall during monsoon season has a major impact on water availability which influences the crops production. Diversified agriculture and level of heterogeneity in the yield of any basin are due to the availability of water in the basin.

Water footprint is an indicator of freshwater used; it indicates water consumption by sources and polluted volume by types of pollution (Hoekstra, 2003). The water footprint of a good or a service is the total amount of water, external and internal, that is required to produce it. It is based on virtual water concept. Virtual water concepts speak about the amount of water that is embedded in food or other products needed for its production and doesn't say which type of water is being used for production. Furthermore, this concept does not distinguish between water use for manufacturing/producing the products for domestic consumption and water use for manufacturing/producing the export product. Water footprint gives spatiotemporal explicit information regarding how water is appropriate for meeting the various human demands. Water footprint consists of an assessment of the quantity of water and mapping of green, blue and grey water, and evaluating the efficiency, equitability and sustainability of water use.

Since from few years, water footprint studies have been carried out for different purposes and are applied in different context and level largely depends on the focus of interest like process, step, product, consumers and group of consumers, sector and administrative unit, national and global. Fewer studies have been reported at river basin level to evaluate water footprint of agriculture crop production, livestock production, domestic sector and industrial sector.

So far, no study has been carried out for Nepal to evaluate the water foot print at river basin scale. In this context, it is important to assess water footprint of crop production at basin level as crop productions have been reported from most of the river basins. Evaluation and understanding of water footprint of agricultural crop support production as well as trade decision by promoting crop production in mostly suited environment and by adopting water-efficient technology.

1.2. OBJECTIVES OF THE STUDY

The study has been taken up with the following specific objectives:

1. Assessment of monsoon variability and water stress in Koshi river basin of Nepal.
2. Assessing green and blue water footprints of crops production at basin level with a bottom-up approach.
3. Exploring spatial and temporal variation of water footprint of crops production within the basin.

1.3. ORGANIZATION OF THESIS

Thesis has been organized into the following chapters:

- **Chapter 1** cover introduction and objectives of the study as mentioned above. Remaining part of the report can be summarized in chapter 2 to 6.
- **Chapter 2** include literature review about water footprint concept, factors affecting water footprint, the water footprint of the river basin and the crops production, and water footprint applied at a different level.
- **Chapter 3** includes a description of the study area and data availability.
- **Chapter 4** includes the methodology for conducting this study and performance evaluation criteria.
- **Chapter 5** explains the results obtained from this study and their discussions.
- **Chapter 6** includes summery and conclusions of the study.

This chapter encompasses the detail of the concept of water footprint, its components, water footprint of the river basin, the water footprint of crop production and factor affecting the water footprints of crops production. Further, it will examine similar studies carried out previously in other countries about water footprint assessment of crop production. Also, it will review the monsoon variability and water stress.

2.1. WATER FOOTPRINT CONCEPT

Water foot print concept was first introduced by Hoekstra in 2002 as an indicator of water use (Hoekstra, 2003). It indicates water consumption by sources and polluted volume by types of pollution. Water footprint concept is based on the concept of 'virtual water' (Allan 1998) and is defined for the stage of production or consumption of a product /goods/services consumed by an individual or a community (Hoekstra and Hung 2003, 2005). Where water footprint can be defined as volume of fresh water used to produce a particular product measured at the production point (Hoekstra et al. 2011; Chapagain and Hoekstra 2011).

Water footprint of the product is defined as the volume of fresh water used to produce the product measured over the full supply chain. The concept was brought into water management science in order to show the importance of consumption pattern and the global dimension in good water governance (Hoekstra and Mekonnen 2012, Galli et al. 2012, Vanham and Bidoglio 2013a). It is regarded as a multidimensional tool for the measurement of water availability and water degradation. It is an indicator of fresh water use which includes both the direct water use of the consumers or producer and the indirect water use. Water footprint is considered as a comprehensive indicator of fresh water resources appropriation, next to the traditional and restricted measure of water withdrawal. The water footprint also tells how much water is being consumed by a particular country or globally in a specific river basin or from an aquifer.

2.2. COMPONENTS OF WATER FOOTPRINT

Water footprint of a process step has three components namely green water footprint (evaporation of water supplied from the rain), blue water footprint (evaporation of the irrigation water from surface and renewal of ground water sources) and grey water footprint (volume of fresh water polluted in the production process). As per the definition of Rockstorm et al. (2009), green water is the soil water held in the unsaturated zone formed by the precipitation and available to plants, while blue water refers to liquid water in rivers lakes, wetlands and aquifer. Irrigated agriculture receives blue water (from irrigation) as well as green water (from precipitation) while rainfed agriculture only receives green water. Thus, the green water footprint is the rainwater consumed by the crops. Falkenmark & Rockstorm (1993) has introduced the distinction between green and blue water whereas Chapagain et al. (2006) introduced the grey component. The grey water footprint is an indicator of the degree of water pollution (Hoekstra et al. 2011). All components of total water footprint are specified geographically and temporally. Schematic representation of the components of a water footprint is given in Figure 2.1. Components of agricultural water footprint: green, blue and grey are given in Figure 2.2.

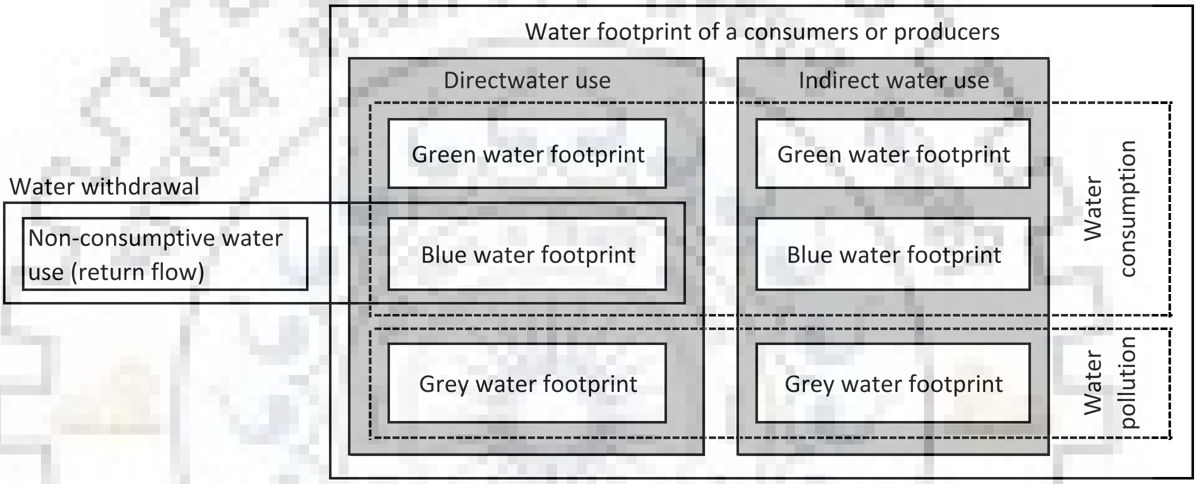

Figure 2. 1: Schematic representation of the components of a water footprint (Source: The Water Footprint Assessment Manual)

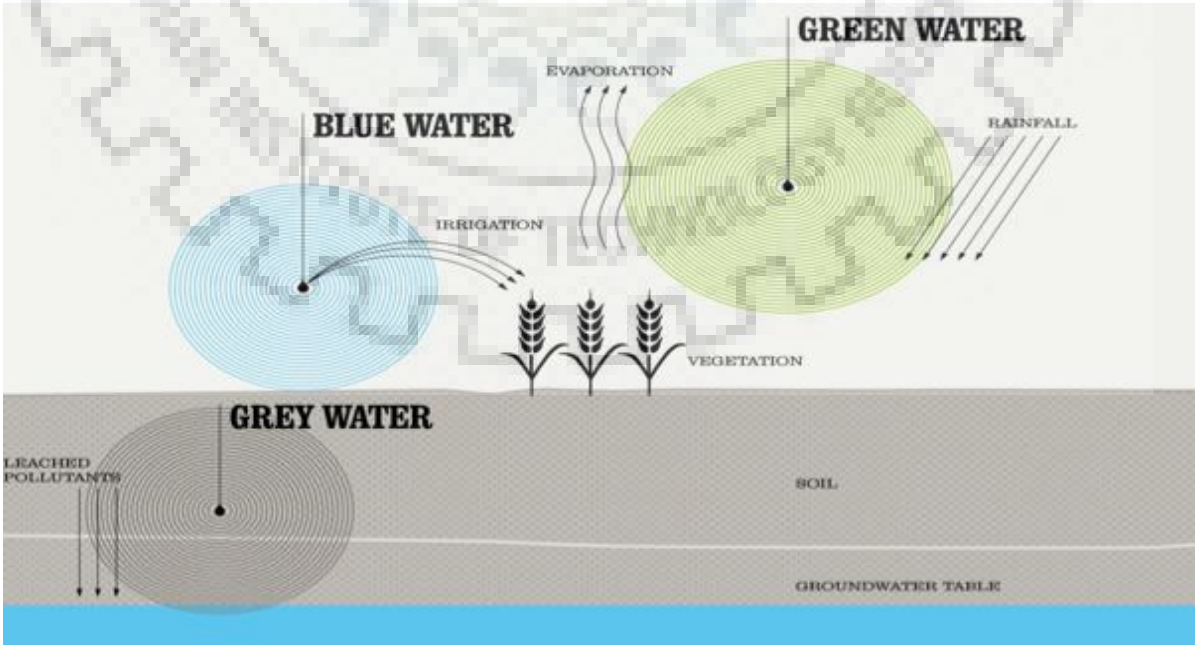

Figure 2. 2: Components of agricultural water footprint: green, blue and grey (source: SAB Miller and WWF, 2009)

2.3. WATER FOOTPRINT OF THE RIVER BASIN

Water footprint of river basin falls under water footprint of the geographically delineated area. Water footprint of the river basin is defined as the total freshwater consumption and pollution within the boundaries of the basin. It is calculated by taking the sum of the process water footprints of all water using process in the basin and is expressed as water volume per unit time.

$$WF_{\text{river basin}} = \sum_{q} WF_{\text{proc}}(q) \qquad \left(\frac{volume}{time}\right) \qquad \text{… … … (2.1)}$$

Where, WF_{proc} (q) refers to the water footprint of a process q within a river basin. The above equation sums all water consuming or polluting process taking place in the river basin.

2.4. WATER FOOTPRINT OF CROPS PRODUCTION

Crop production is a process in river basin. Water footprint of the crops production consists of the green, blue and grey component. Green component of water is used from the rain water stored in the soil as soil moisture, blue component water is used from surface and ground water, and grey component water is used to dilute the pollutants/fertilizer/insecticides to a satisfactory level or above agreed on water quality standards. Total water footprint (WF_{proc}) of the process of growing agricultural crops is the sum of the three components: green, blue and grey component.

$$WF_{\text{proc}} = WF_{\text{proc,green}} + WF_{\text{proc,blue}} + WF_{\text{proc,grey}} \qquad \left(\frac{volume}{mass}\right) \qquad \text{… … … (2.2)}$$

Process water footprint of agriculture crops usually expresses as m^3/ton. Green component of water footprint depends on crop yield and green component of crop water use which is the function of daily green evapotranspiration over the complete crop growing period. Similarly, the blue component of water footprint depends on crop yield and blue component of crop water use which is the function of daily green evapotranspiration over the complete crop growing period. Grey component of water footprint depends on the yield of the crop and pollutant like fertilizer, pesticides and insecticides used during crop growing period.

2.5. FACTORS AFFECTING WATER FOOTPRINT OF CROP PRODUCTION

Water footprint varies depending upon which level of study is being focused like process, step, product, consumers, and a group of consumers, sector, and administrative unit, national and global. Suppose water footprint study is focused on process level of growing agriculture crops, then factors affecting water footprint of crop production depends upon those parameters which affect blue and green crop water use. Furthermore, types of pollutant, quantity, level of water quality standard that affects grey component are also responsible for affecting water footprint of crop production. Water footprint of agricultural crop production depends upon water requirement of crops over entire growing periods from planting to harvesting and the crop yield under cultivation land. It is influenced by several factors like crop, soil, a climatic parameter in crop water use especially on crop evapotranspiration. Fertilizer uses, irrigation practices, not receiving optimum water are the crop yield influencing parameter. Change of these parameters leads to change in water footprint of a crop production. If chemical or pollutants are not applied for the crop production or dilution is not required, the water foot print of crop production depends upon the green and blue component of water footprint only.

$$\mathrm{WF_{proc}} = \mathrm{WF_{proc,green}} + \mathrm{WF_{proc,blue}} \quad \left(\frac{volume}{mass}\right) \qquad \ldots\ldots\ldots(2.3)$$

$$\mathrm{WF_{proc}} = \frac{(\text{Crop Water Use}_{\text{green}} + \text{Crop Water Use}_{\text{blue}}\ )}{\text{Crop Yield}} \qquad \ldots\ldots\ldots(2.4)$$

$$\mathrm{WF_{proc}} = \frac{(10 * \sum \text{Evapotranspiration}_{\text{green}} + 10 * \sum \text{Evapotranspiration}_{\text{blue}}\ )}{\text{Crop Yield}} \ldots\ldots(2.5)$$

$$\mathrm{WF_{proc}} = \frac{\text{Crop Water Use}\left(\frac{\text{m3}}{\text{ha}}\right)}{\text{Crop Yield}\left(\frac{\text{ton}}{\text{ha}}\right)} \qquad \ldots\ldots\ldots(2.6)$$

Where, $\text{Evapotranspiration}_{\text{green}} = \min(\text{Crop Evapotranspiration}, \text{Effective Rainfall})$ and

$$\text{Evapotranspiration}_{\text{blue}} = \min(\text{Crop Irrigation Requirement}, \text{Actual Irrigation})$$

As mention above, the water footprint of an agricultural crop production is the sum of green crop water use per unit crop yield and blue crop water use per unit crop yield; green water footprint includes green water evapotranspiration and green water incorporation to the crop. Blue water footprint considers blue water evapotranspiration and blue water incorporation to the crop. It is a function of crop irrigation requirement and actual irrigation. Green crop evapotranspiration depends upon crop evapotranspiration and effective rainfall where effective rainfall is the function soil, climate and land characteristics. So, the main factors that affect green water footprint (water footprints of crops production) are:

2.5.1. Soil factors

A well distributed and light shower rainfall leads more effective rainfall which promotes soil moisture development and up taking to plants as a result water footprint will be more. Soil characteristic like infiltration rate, storage capacity (soil depth), and initial water content influence the effective rainfall which intern determines the green water evapotranspiration of the crop. Vegetative cover leveled land and plowed land also promotes the effectiveness of rainfall but the sloppy land cause more runoff resulting less effective rainfall.

2.5.2. Climatic factor

High intensity and long duration rainfall cause less effective rainfall and resulting in less green water footprint. Higher the evapotranspiration, higher will be the water footprint and vice versa. Crop water requirement of the crop is also influenced by climatic parameter like sunshine hours, solar radiation, temperature and humidity.

2.5.3. Crop factor

Crop characteristic i.e. more crop root zone depth, complete ground cover, and active vegetative growth uptakes more water resulting in more effective rainfall and more water footprints. Moreover, Surface condition of soil, canopy, soil cover nature of mulch, use of fertilizer, cropping practice, irrigation practice have influences on crop yield which effects on water footprint of a crop production.

Water footprints of the crop are most sensitive to reference evapotranspiration and crop coefficient followed by crop calendar and precipitation. In rainfed agriculture, water footprint of crops mainly determined by the minimum value of effective rainfall or crop evapotranspiration. Rainfed agriculture receives only green water from precipitation. Part of the rainfall that stored as soil water in the unsaturated zone and is available to plants i.e. effective rainfall and crop evapotranspiration is considered for water footprint of agricultural crops production in the rainfed area. In case of irrigated agriculture, crops receive both component of green water and blue water.

2.6. MONSOON VARIABILITY AND WATER STRESS

Rainfall is one of the most important climatic factors that affect crop production as well as water footprint of crops. It is the source for both green water and blue water. When water is harvested or allows runoff it will be the source of blue water. If it is retained on unsaturated soil zone, acts as source of green water. Their variability over the basin cause greatest impact on water resources. Rainfall in Nepal mostly (80 %) occurs from June to September during monsoon (Nayava, 1974; Aryal, 2011). The monsoon weather systems mainly travel from the Bay of Bengal northward causing precipitation on the southern slopes of Mahabharat Range and Himalayas whereas leaving distinct rain shadow behind Mahabharat range and on the Tibetan Plateau. Precipitation increases from the Low River Valleys to the Mountains and then decreases in regions of higher elevation like the High Mountains and Himalayas. Maximum precipitation is observed in the Mountains while minimum precipitation is observed in the Himalayas. During this period intense precipitation occurs allowing greater runoff and sometimes causing landslides. Extensive research has been done to understand the relationship between elevation and precipitation in the Himalayas (Dhar and Rakhecha, 1981; Bookhagen and Burbank, 2006; Shrestha et al., 2012). Similarly, the temperature decreases from South to North with elevation (Kattel et al., 2013). The annual mean temperatures in this region have shown an increasing trend (Shrestha et al., 1999).

Water stress occurs when the demand for water exceeds the available water at a certain period of time as well as when water quality is poor and not viable its use. Deterioration of available water's quality and quantity due to factors affecting available water indicates water stress. Factor affecting available water may be agriculture crops production, livestock production, domestic or industrial use. Agriculture sector holds a large share of water use. Water stress index measures the water scarcity.

2.7. APPLICATION OF WATER FOOTPRINT VARIOUS LEVEL

The concept of considering water use along a supply chain has been increasing after the introduction of water footprint concept by Hoekstra in 2002 (Hoekstra, 2003). Water footprint studies generally focused on various levels of process, step, product, consumers, and a group of consumers, sector, and administrative unit, national and global. Water footprint of individual or group of consumers consist direct (i.e. at home or garden) and indirect water use (i.e. the water use in production and supply). Chapagain et al. (2006) focused at the process level and evaluated water footprint of cotton production for different processes. Mekonnen and Hoekstra (2011) focused the product level and estimated the green, blue and grey water footprint of one hundred and twenty-six crops all over the world for the period 1996 to 2005. Similarly, water footprint of coffee and tea (Chapagain and Hoekstra, 2007), pasta and pizza (Aldaya and Hoekstra, 2010) was also analyzed. Water footprint of domestic, industrial and agricultural sectors have been analyzed by Aldaya et al. (2010) at sector level in Spain and found that water scarcity in Spain has been led by the inefficient allocation of water resource and mismanagement of agricultural sector. Many studies have been carried out to evaluate water footprint at the national level. Water footprint of China (Liu and Savenije, 2008; Ma et al., 2006), India (Kampman et al., 2008), UK (Chapagain and Orr,2008), Netherlands (Van Oel et al., 2009), Indonesia (Bulsink et al., 2010) France (Ercin et al., 2012) and Nepal (Shrestha at al., 2013) have been assessed at the national level. Some studies have been carried out at the global level. Water footprint of goods and services consumed by humans have been accessed by Hoekstra and Chapagain (2007), and Hoekstra and Mekonnen (2012) globally. An assessment of water footprint of primary crop production of Nepal also has been evaluated (Shrestha et al., 2013) at national level. Review of water footprint applied at different level is presented in Table 2.1

Table 2. 1: water footprint applied at different level

Researcher(s) and Year	Region	Area of interest at	Results/Remarks/Conclusion
Chapagain et al. (2006)	worldwide	Process level (Cotton)	The evaluated water footprint of cotton production for different processes. Result shows Global consumption of cotton products was 256 Gm3 of water per year (42% blue water, 39% green water and 19% dilution waste) and the impacts on water were typically cross-border.
Chapagain and Hoekstra (2007)	Dutch Society	Product-level (Coffee and Tea)	Evaluated water footprint of coffee and tea consumption amounts to 2.7 billion cubic meters of water per year (37% of the annual Meuse runoff) and suggested to value green water use.
Kampman et al. (2008)	India	National level (Agricultural goods consumption)	Evaluated water use in relation to the consumption of agricultural goods in the Indian states.
Chapagain and Orr (2008)	UK	National level (Agricultural, Industrial, Household)	Evaluated that total WF of the UK was found 102 Gm3 per year, equal to 49 times the annual flow of the Thames River. This was made up of agricultural products (74.8 Gm3/yr or 36 times the annual flow); industrial products (24.0

			Gm3/yr or 11.5 times the annual flow); and household water use (3.3 Gm3/yr or 1.5 times the annual flow) and found that National WF was contributed by 38% internal and 62 % external WF.
Chapagain and Orr (2009)	Spain	Product-level (Spanish Tomato)	Estimate virtual water in Spanish tomato and suggested that Spain to reduce the local water use in tomato production by increasing the irrigation efficiencies so that the losses are no more than necessary for diluting polluted return flows. Reducing non-evaporative water losses beyond this point should be done in an appropriate combination of increased irrigation efficiencies and reduced pollution load.
Van Oel et al. (2009)	Netherlands	National level (Agricultural, Industrial, Household)	Estimated external water footprint to be about 2300 m3 of which 67% relates to the consumption of agricultural goods, 31% to the consumption of industrial goods, and 2% to domestic water use
Aldayaet et al. (2010)	Spain	Sector level (Agriculture)	water footprint and virtual water trade in Spain water footprint of domestic, industrial and agricultural sectors and found that water scarcity in Spain has been led by the inefficient allocation of water resource and mismanagement of agricultural sector such as the use of large amounts of blue water in virtual water intensive but low economic value crops.
Aldaya et al. (2010)	Gaudiana River Basin	Basin level	Evaluated the virtual water and water footprint of the basin as in most arid and semiarid regions. Main green and blue

			water consuming sector was irrigation, with about 95% of total water consumption in the basin as a whole.
Zhao et al. (2010)	Haihe River Basin	Basin level	The findings show that the WF was 1768 million m3/ yr in the HRB over 2004–2006. Agricultural production was the largest water consumer, accounting for 96 % of the WF (92 %for crop production and 4 % for livestock production). The remaining 4 % was for the industrial and domestic sectors. WF of human activities was achieved at a cost of violating environmental flows of natural freshwater ecosystems, and such a WF pattern is not sustainable.
Hoekstra and Chapagain (2007), and Hoekstra and Mekonnen (2012)	Worldwide	Global level	Water footprint of goods and services consumed by humans have been accessed
Mekonnen and Hoekstra (2011)	Worldwide	Product-level	Estimated the green, blue and grey water footprint of one hundred and twenty-six crops all over the world for the period 1996 to 2005 with spatial resolution.
Feng et al. (2012)	Yellow River Basin	Basin level	Regional virtual water flows and water footprints were accesses at the consumption-based approach and input-output model. Results show that net virtual water exporter, i.e. production and consumption activities outside the basin also put pressure on the water resources in the YRB. The results

			suggest a reduction of the export of virtual blue water that could instead be used for producing higher value-added but lower water-intensive goods.
Shrestha et al. (2013)	Nepal	National level	Evaluated green, blue and grey water footprint of primary crops production in the entire district of country and suggested suitability of some crop production in Terai hill and mountains.

Previous water footprint studies were mainly focused at the process level, product level, sector level, national level and global level. However, there are few studies of water footprint considering specific river basins (UNEP, 2011). Assessment of water footprint at river basin level is important to understand the influence of human activities like agricultural crop/livestock production, domestic and industrial water use on natural water cycles. It serves a basis for integrated water resource management and sustainable use. Due to lack of statistical data at the river basin level, literature focusing on water footprint assessment at river basin are rare. Water footprint of some river basin such as Gaudiana River Basin (Aldaya et al., 2010), Haihe River Basin (Zhao et al., 2010) and Yellow River Basin (Feng et al.,2012) for which input-output model was developed and evaluated. There are so many river basins whose water footprint estimation still remaining and it is necessary to test bottom-up approach (Hoekstra et al., 2011) promoted by Water Footprint Network.

Water footprint gives spatiotemporal explicit information regarding how water is appropriated for various human purposes. It varies depending upon the crop/product, climate (i.e. on ETc), fertilizer use, irrigation practice, not receiving optimal water, soil etc. Water footprint studies may have a various purpose and can be applied in a different context (largely depends on the focus of interest). The important facts from the previous studies have been considered in this study.

CHAPTER 3
DESCRIPTION OF STUDY AREA AND DATA AVAILABILITY

3.1 STUDY AREA

Koshi River Basin (KRB) of Nepal is situated in the Eastern part of Nepal and is the largest watershed of the country. It provides a reliable water source for irrigation. The Koshi river flows through China, Nepal and India and confluence on Ganges in India with total drainage area of 69300 km^2 (WWF, 2009: Gosain et al., 2010). A part of the Koshi River Basin (KRB), at the upstream of Chatara in the mountainous region of eastern Nepal and southern border of China, was chosen for the study. The KRB consists of three major sub-basins (Sunkoshi, Arun, Tamor) covering about 25936 km^2 (16 districts i.e. administrative boundaries) from the Himalayas to agricultural lowland of Terai plains. The basin area lies within latitudes $26^0 51'$ and $29^0 59'$ N, and longitudes $85^0 24$ and $88^0 57'$E. The altitude of the basin ranges from 65 mamsl (meters above mean sea level) in the Terai Plains to over 8000 m. amsl in the High Himalayas (Dixit et al., 2009). Most of the area in the Koshi basin falls under the Mountains, followed by the Hills, Himalayas, High Mountains, Terai Plains and Low River Valleys.

The climate of the Koshi basin ranges from tropical in the Terai Plains and Low River Valleys to arctic conditions on mountain peaks and passes through warm temperate, cool temperate and alpine conditions as elevation increases (Dixit et al., 2009). The mean annual temperature is 20^0C in the Hills and 16^0C in the Mountains. In general, the temperature decreases from South to North. Precipitation in the Koshi basin increases from the Low River Valleys to the Mountains and then decreases in regions of higher elevation like the High Mountains and Himalayas. Maximum precipitation is observed in the Mountains while minimum precipitation is observed in the Himalayas. Average annual precipitation of 36 years from 1980 to 2015 was 2397 mm out of which 76% of the annual rainfall in the KRB has occurred during monsoon. Most of the population (almost 70%) in the basin is dependent on rainfed agriculture for its livelihood (Dixit et al., 2009). Study area contributes 5770.72 km^2 as agricultural land which is about 22 % of the study area and the majority of agricultural land is under rainfed agriculture. 50 % of the study area consist forest, 13% shrubs and grassland, 9% snow and glacier, and the remaining 6 % are occupied by barren land, water bodies and built up area. The hills and the Terai Plains contribute the maximum area to agriculture in the basin. Location map of the study area is shown in Figure3.1

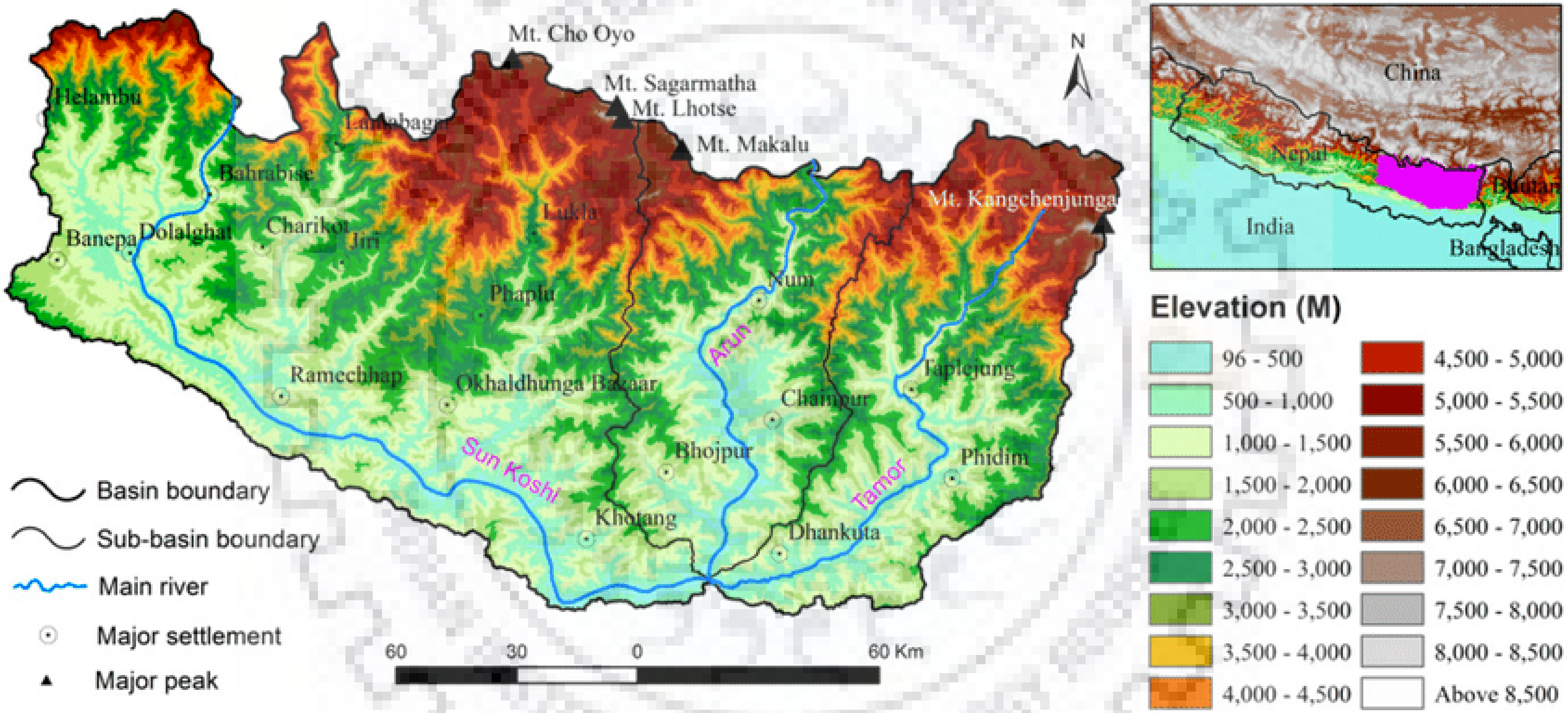

Figure 3. 1: Location of Koshi River Basin (KRB) in Nepal

Statistical data of the administrative boundaries (e.g. districts, regions) has been considered. Since data are not available at river basin level, they were collected from different sources, from recent literature and publication of central bureau of statistics and agriculture atlas of Nepal.

3.2 CLIMATE DATA

Daily rainfall data of 16 weather stations for the period of 1980-2015 (36 years) are acquired from the department of hydrology and metrology (DHM). Other climatic data that included daily data for the minimum and maximum temperature, relative humidity (minimum and maximum), sunshine, wind speed for the period 2005-2014 (10 years) of the same station are taken from the same department along with geographic coordinates (altitude, latitude, longitude). Some missing values within the collected data are estimated taking simple averages of the days before and after the missing value. These data have been processed as per requirement of the study. Figure 3.2 shows the administrative boundaries within or crossing and meteorological station within or nearby KRB. The figure 3.3, 3.4 and 3.5 illustrate the climatic data for different temporal scales computed from the daily available climatic data over the considered period.

3.3 CROP DATA

Agricultural data regarding crop types, crops production and crop sowing area of the period 2005-2014 (10 years) within or nearby basin were accessed from Center Bureau of Statistics and Regional Agricultural Directorate. Crop calendar and cropping pattern have been collected from District Agricultural Development Division (DADO/Ministry of Agriculture and Co-operatives (MoAC). Generalized crop calendar for paddy, maize and wheat received from agriculture atlas of Nepal are given in table 3.1. Similarly, crop coefficients and soil parameters are derived from Food and Agriculture Organization of United Nations (FAO) and used in CROPWAT Model.

3.4 CROPWAT 8.0 MODEL

CROPWAT Model developed by land and water development division of UN, Food, and Agriculture Organization (FAO, 2009) has been used as decision support tool. Based on climate soil and crop data, this program calculates crop water requirements and irrigation requirements. Calculation procedures applied in the model are based on FAO publications of the Irrigation and Drainage series: No. 56 “Crop evapotranspiration guidelines for computing crop water requirements" (Allen et al., 1998) and No. 33, (yield response to the water" (Doorenbos and Kassam, 1979)

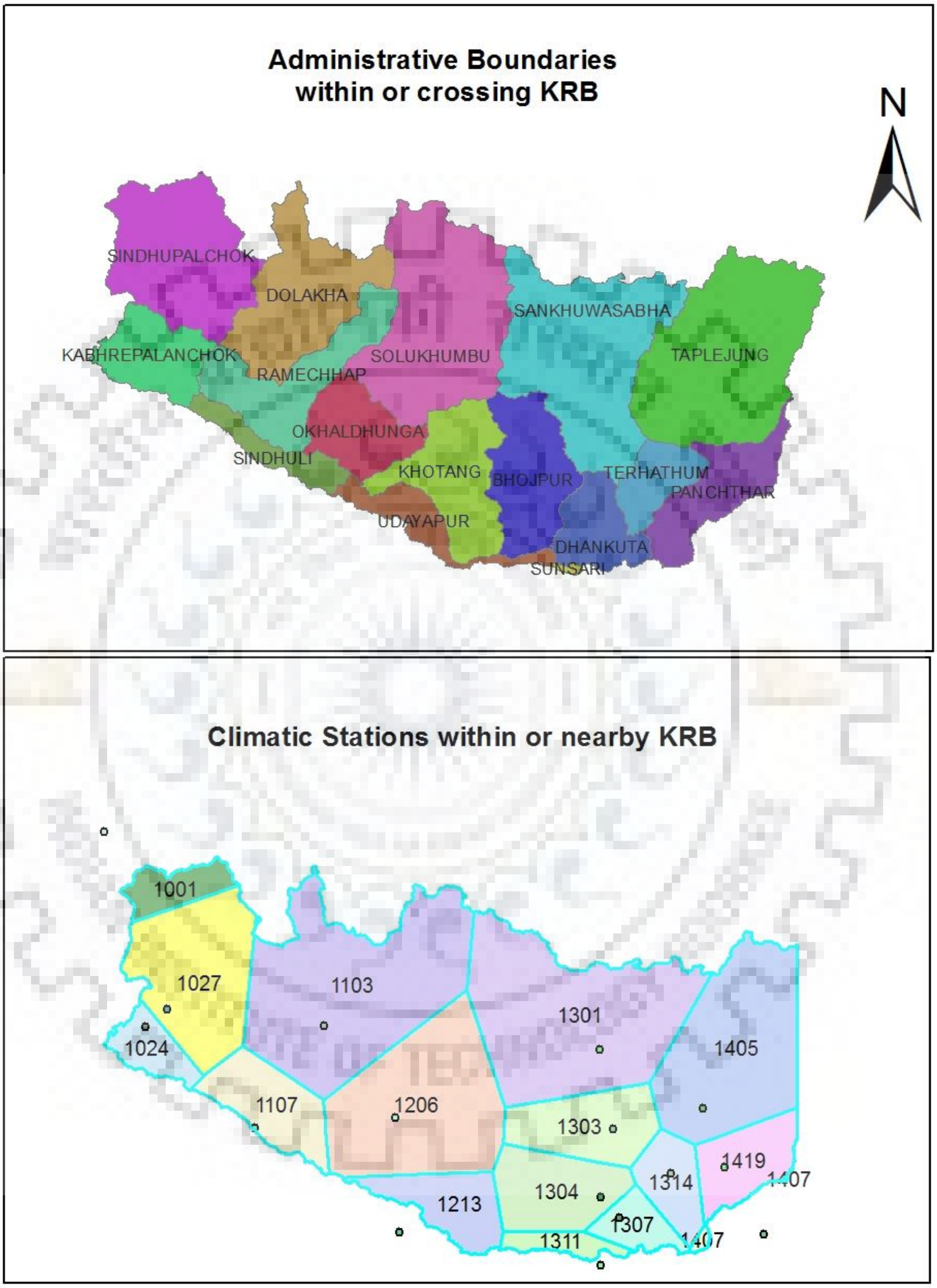

Figure 3.2: Administrative boundaries within or crossing and meteorological station within or nearby KRB

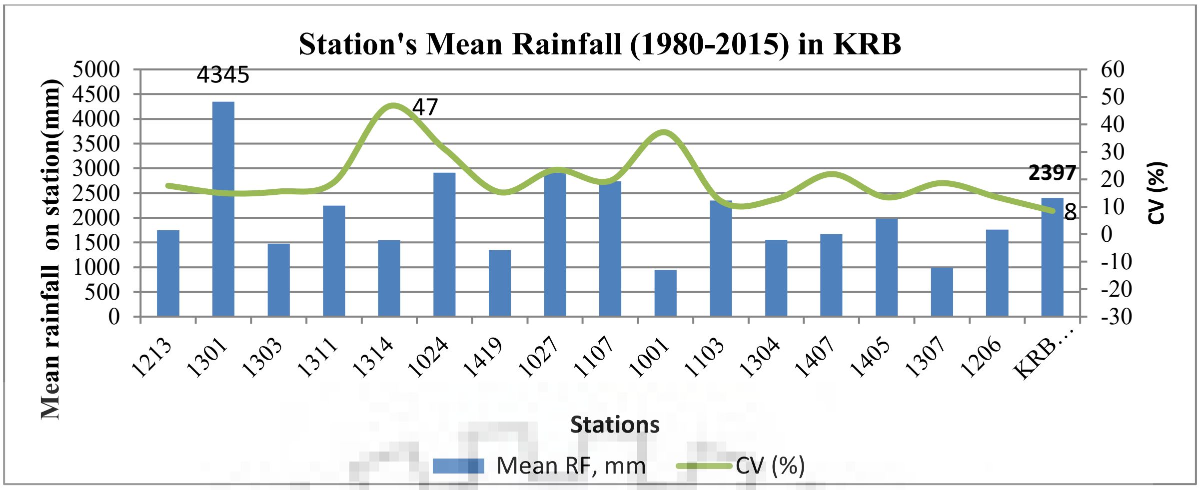

Figure 3.3: Mean rainfall of 36 years (1980-2015) at different stations in KRB

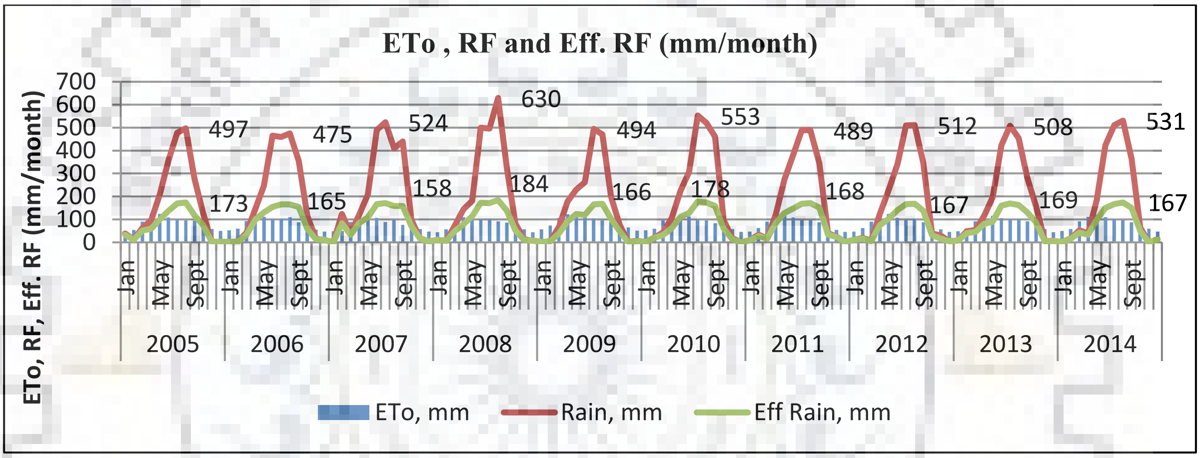

Figure 3. 4: Monthly ETo, rainfall and effective rainfall in the year 2005 -2014

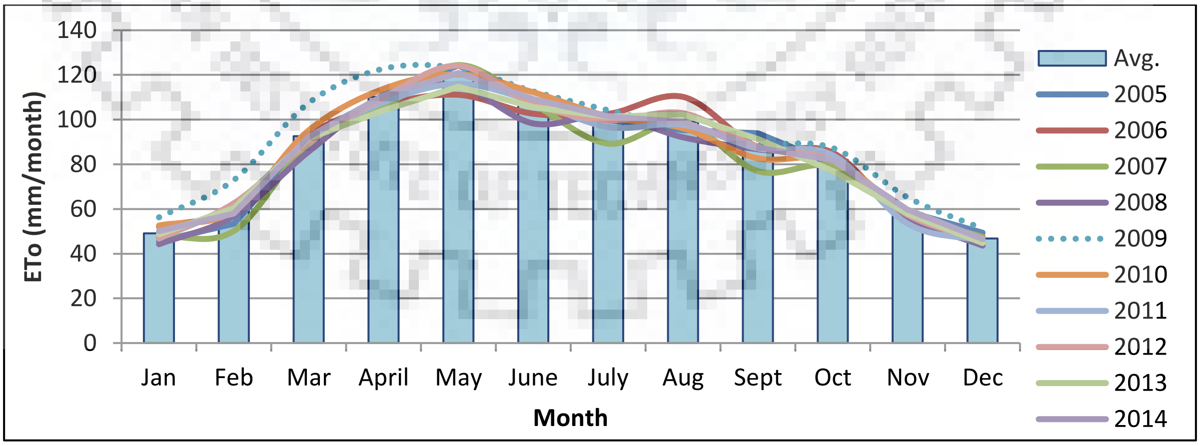

Figure 3. 5: Estimated Monthly and mean monthly ETo in the year 2005 -2014

Table 3. 1: Generalized crop calendar for paddy, wheat and maize

Crop	Ecological belt	Irrigation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Season
Paddy	Hill	Partly					TPL	TPL			H	H			Summer
		Year-round			TPL	TPL			H	H					Spring
	Terai	Rainfed						TPL	TPL		H	H	H		Summer
		Year-round			TPL	TPL			H	H	H				Spring
									TPL	TPL			H	H	Late Summer*
Maize	Mountain	I./Rainfed			S	S				H	H	H			Summer
	Hill	Rainfed			S	S				H	H				Summer
		Irrigated		S	S			H	H						Spring
	Terai	Rainfed				PL	PL			H	H				Summer
		Year-round		S	S			H	H						Spring
				H	H							S	S		Winter
Wheat	Mountain	Rainfed					H	H					S	S	Winter
	Hill	Rainfed			H	H	H					S	S	S	Winter
	Terai	Rainfed			H	H						S	S		Winter

S= Sowing; PL=Planting; TPL=Transplanting; H=Harvesting; Late Summer*= Practice of boro paddy cultivation; I=Irrigated

Note: It is generalized crop calendar which represents the common practices within each zone. It differs based on cropping pattern and availability of favorable environment in the locality.

Source: Agriculture atlas of Nepal, 2012

CHAPTER 4
METHODOLOGY

This chapter covers the methodology adopted in this study to calculate water footprint of crops production at Koshi river basin using statistical data and information of the administrative boundaries, crop area and production, and climatic data as input to CROPWAT has been described.

4.1. SCOPE OF WATER FOOTPRINT ACCOUNTING

The study is focused on assessment of water footprint of crop production in Koshi river basin (KRB). Both green and blue component of water footprint of the crop production has been assessed. The green water footprint of crop production ($WF_{prod,green}$) and blue water footprint of crop production ($WF_{prod,blue}$) accounting is mainly based on standard methods proposed by Water Footprint Assessment Manual (Hoekstra et al., 2011). Statistical data and information of the administrative boundaries (e.g. districts, regions) have been used since data are not available at river basin level. Framework for the assessment of water footprint in the Koshi River Basin is shown in Figure 4.1.

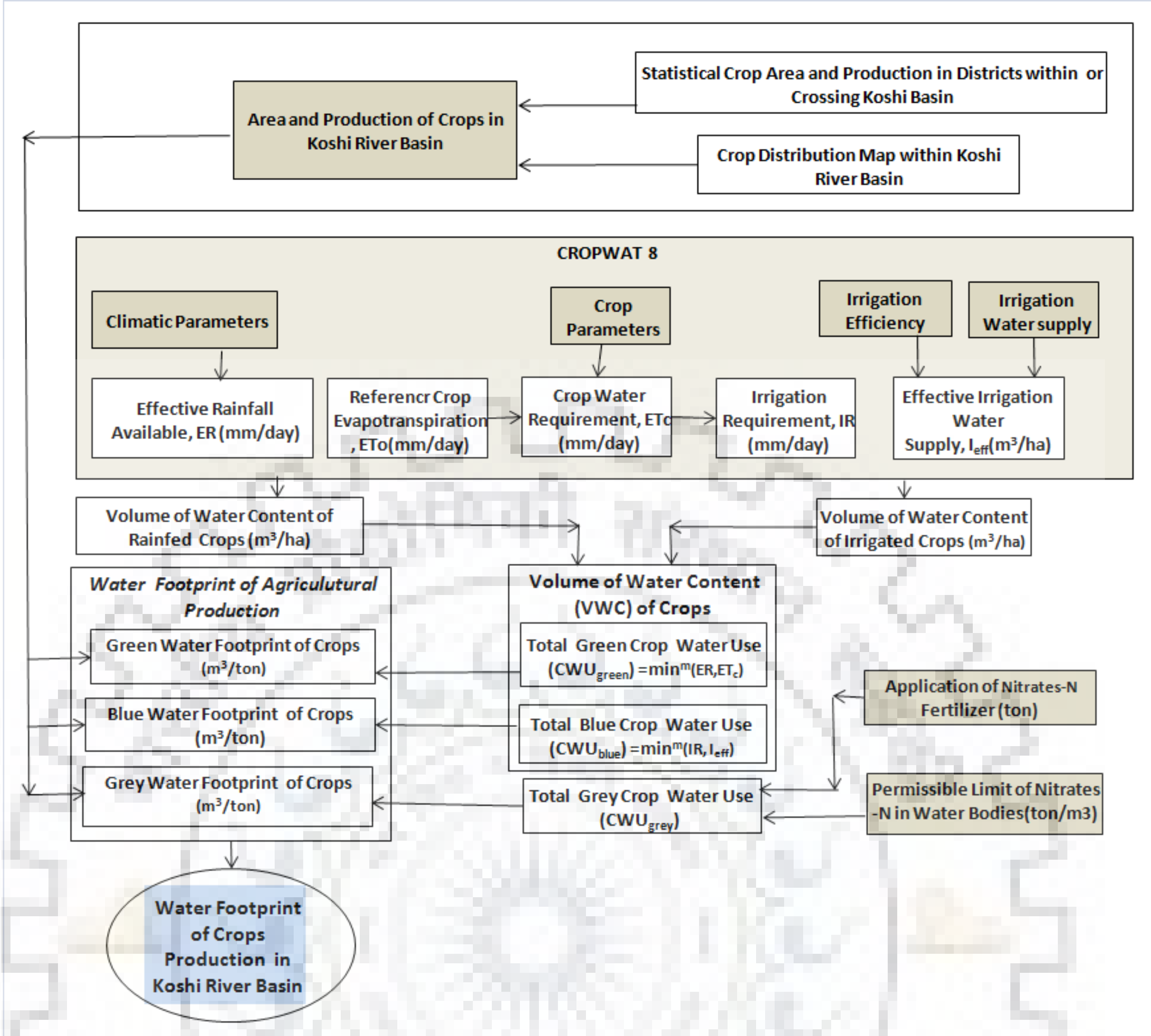

Figure 4. 1: Framework for the assessment of water footprint in the Koshi River Basin

There are 16 districts across or within KRB. Crop harvested area and crop production of these districts during 2004-2014 are collected from related District Agricultural Development Division (DADO)/Regional Agricultural Directorate /Center Bureau of Statistics CBS) and area of these administrative regions located within KRB are calculated. Digital Elevation Model from USGS and country's administrative map are used in ArcGIS environment to define study area of the KRB. Land shared by each district within KRB are evaluated and proportionately crop harvested area for each crop in each district are taken to estimate KRB's crop harvested area. Similar approach is used to estimate crop production within KRB. The result of crop harvested area and crop production within KRB for the year 2005 to 2014 are shown in Table 4.1.

Table 4. 1: Crop production within KRB during the period 2005-2014

Crops/years	Harvested Area (ha)						
	Barley	Maize	Millet	Potato	Rice	Sugarcane	Wheat
2005/06	2778	215673	92668	37151	128574	312	56791
2006/07	2840	216573	91580	37388	119946	301	57092
2007/08	2795	218689	92556	38488	129985	301	57268
2008/09	2662	220445	92392	50539	131467	301	56069
2009/10	2662	217907	92877	54062	123872	272	56157
2010/11	2918	219988	94993	54078	133362	293	46760
2011/12	2835	227954	99320	57065	138107	303	51698
2012/13	2751	220604	99269	55816	129960	307	52475
2013/14	2602	251875	96797	55816	131937	247	47058
2014/15	2493	240888	96431	53441	117602	279	48931
Avg.	**2734**	**225060**	**94888**	**49384**	**128481**	**292**	**53030**
Crops/years	Production (ton/year)						
	Barley	Maize	Millet	Potato	Rice	Sugarcane	Wheat
2005/06	2715	406186	99738	452559	294987	7894	105977
2006/07	2840	427379	96687	456979	260706	7269	100551
2007/08	2929	455789	98273	448282	292868	7524	102236
2008/09	2651	462692	100477	629278	294555	7524	78406
2009/10	2615	451698	104710	717630	263558	7365	79937
2010/11	2998	466881	104321	721347	297272	9141	94309
2011/12	2925	544423	115925	757757	336329	11115	93161
2012/13	3391	498472	111664	706398	318701	11434	102677
2013/14	2856	574072	111748	706398	351586	9260	91148
2014/15	2718	529250	112097	669146	295446	10855	93433
Avg.	**2864**	**481684**	**105564**	**626577**	**300601**	**8938**	**94184**

Based on data availability, a total of seven crops were selected. These include maize, rice, wheat, barley and millet as cereals crops, potato and sugarcane as cash crops. Among them, cereals crops account for 90% crop production while 10 % is for other crops within the KRB during the study period. Water footprint of crop production in KRB for ten years are calculated and compared to each other. Some of the administrative boundaries (districts) crossing the KRB have a fewer portion of Terai plains and most of the districts are full of hills. The adopted ecological belt and date of crop planting and harvesting in this study are given in Table 4.2.

Table 4. 2: Adopted ecological belt and date of crop planting/harvesting for study

Crops	Ecological Belt	Irrigation	Date of Planting/Harvesting		Crop Periods
			PL	H	
Maize	Hill	Irrigated /Rainfed	27-Feb	1-Jul	125 days
Paddy			29-Jun	26-Oct	150 days
Wheat			3-Nov	12-Mar	130 days
Barley			3-Nov	2-Mar	120 days
Millet			15-Aug	27-Nov	105 days
Pulse			15-Aug	2-Dec	110 days
Potato			1-Dec	9-Apr	130 days
Sugarcane			3-Dec	2-Dec	365 days

4.2. WATER FOOTPRINT OF CROP PRODUCTION

The amount of water (m^3) needed to produce a product per unit of the crop (ton) during their growing period refers to Virtual Water Content (VWC) of that crop. By multiplying VWC of each crop with its production and then summing up all crops, the water footprint of crop production is calculated. The VWC of crops is the sum of green VWC (VWC_{green}) and blue VWC (VWC_{blue}). The ratio of effective rainfall (ER, m^3/ha) or irrigation (I, m^3/ha) to the crop yield (Y, t/ha), gives the green and blue component of VWC. ER refers green component of crop water use (CWU_{green}) whereas I represent a blue component of crop water use (CWU_{blue}).

$$VWC_{green} = \frac{ER}{Y} = \frac{CWU_{green}}{Y} = \frac{10 * \sum_{d=1}^{lgp} ET_{green}}{Y} = WF_{prod,green} \qquad \dots \dots \dots (4.1)$$

$$VWC_{blue} = \frac{I}{Y} = \frac{CWU_{blue}}{Y} = \frac{10 * \sum_{d=1}^{lgp} ET_{blue}}{Y} = WF_{prod,blue} \qquad \dots \dots \dots (4.2)$$

$$VWC = VWC_{green} + VWC_{blue} = WF_{prod} \qquad \dots \dots \dots (4.3)$$

To calculate ER and me, the CROPWAT model (FAO, 2010b: Allen et al., 1998) is used where in irrigation schedule option, the rainfed condition is considered for ET_{green}(by selecting no irrigation option) and irrigated conditions are considered for ET_a (actual evapotranspiration) estimation by simulating soil water balance with daily time step following Water footprint Assessment Manual (Hoekstra et al., 2011). Difference of ET_a and ET_{green}in two conditions gives ET_{blue}. By multiplyingET_{green} and ET_{blue}(which are in mm) by 10, ER and I in m^3/ha are calculated. Green and blue water incorporated into the crop are not taken into account as they contribute for very small (e.g. 0.1% to 1 % of the evaporated water) (Hoekstra et. al., 2011). The climatic data regarding monthly averages for the minimum and maximum temperature, relative humidity (minimum and maximum), sunshine, wind speed, rainfall and geographic coordinates (altitude, latitude, longitude) for the period 1980–2015were taken from the department of hydrology and meteorology (DHM), Nepal. Data from 16 climate stations within or nearby the KRB are considered. Similarly, Crop parameters like crop coefficients, the planting and harvest dates rooting depths, lengths of each crop development stage are based on CROPWAT (FAO, 2010a). Default values in CROPWAT were taken (FAO, 2010a) for maximum rooting depth, initial soil moisture content at the start of the growing season and available soil water content for medium soil.

Influencing area of each climatic station over KRB is identified by superimposing Thiessen polygons over the basin. Portions of the harvested area of each district within KRB that falls under stations polygon are identified (figure 3.2). WF_{prod} for each crop of the influence portion in the district is calculated by considering influencing climatic station. Taking weighted averages of WF_{prod} of crops of each portion in the districts, WF_{prod} of crops of that district have been evaluated. Similar approach was followed to calculateWF_{prod} of crops in the KRB for the study year 2005 to 2014).For a particular year, If $WF_1, WF_2 \ldots WF_n$ are the water footprint of a crop in the portion of a crop harvested land $\left(\frac{A_1}{A_D}, \frac{A_2}{A_D}, \ldots \frac{A_n}{A_D}\right)$of a district,where A_D represents total harvested area of a crop in a district, then

$$WF_{prod} \text{of a crop in a district} = WF_{prod\_C\_D} = \frac{(WF_1 * A_1 + WF_2 * A_2 + \cdots + WF_n * A_n)}{(A_1 + A_2 + \cdots A_n)} \quad \ldots \ldots \ldots (4.4) \text{ and}$$

$$WF_{prod} \text{of a crop in a Basin} = WF_{prod\_C\_B}$$
$$= \frac{\left(WF_{prod\_C\_D1} * A_{D1} + WF_{prod\_C\_D1} * A_{D1} + \cdots + WF_{prod\_C\_Dn} * A_{Dn}\right)}{(A_{D1} + A_{D2} + \cdots A_{Dn})} \quad \ldots \ldots \ldots (4.5)$$

Here, the value of n ranges from 1 to 16, depending upon numbers of particular crop harvested district. This has been applied to the calculation of both components of the water footprint of crop production. Similar process is applied to others crop. Then, each component of the water foot print of all crops have been averaged to getWF_c of crops production in the basin.

4.3 MONSOON VARIABILITY ASSESSMENT

Areal average rainfall of the entire basin has been evaluated from the area weighted average rainfall of 16 meteorological stations. Those evaluated monthly rainfall and the daily rainfall over the period (1980-2014) has been used to study the monsoon rainfall variability on different time scales. Rainfall statistics like mean $(\bar{X})$, standard deviation(SD), cthe oefficient of variation (CV), highest and lowest value and their percentage departure from the mean have been evaluated on seasonal, monthly, decadal and daily scale for inter annual variability assessment.

$$\text{Mean}(\bar{X}) = \frac{1}{n}\left(\sum_{1}^{n} X_{\mathrm{i}}\right) = \frac{(X_1 + X_2 + X_3 + \cdots + X_n)}{n} \qquad \ldots\ldots\ldots (4.6)$$

$$\text{Standard Deviation (SD)} = \sqrt{\left[\frac{\sum_1^{\mathrm{n}}(X_{\mathrm{i}} - \bar{\mathrm{X}})^2}{n-1}\right]} = \sigma_{\,n-1} \qquad \ldots\ldots\ldots (4.7)$$

$$\text{Coefficient of Variation (CV)} = \frac{100 * \sigma_{\,n-1}}{\bar{X}} \qquad \ldots\ldots\ldots (4.8)$$

$$\text{Percentage Departure from the Mean (PDM)} = \frac{100 * (X_i - \bar{X})}{\bar{X}} \qquad \ldots\ldots\ldots (4.9)$$

Where, $X_1, X_2, \ldots X_{\mathrm{n}}$ are rainfall values in known time and X_{i} represents rainfall magnitude in thei^{th}station.

CHAPTER 5
RESULTS AND DISCUSSION

This chapter includes results, analysis and discussion as per objectives. For monsoon variability, rainfall data of 36 years (1980-2015) have been used and for water footprint assessment climatic data from 2005 to 2014 have been used. Water footprint analysis has been done considering individual crop and the climate during the growth of the same crop in the basin. Analyses are based on percentage departure of mean, the coefficient of variation and correlation coefficient.

5.1. MONSOON VARIABILITY ASSESSMENT AND WATER STRESS IN KRB

Daily rainfall data of periods 1980-2015 (36 years) of 16 climatic stations within or near by the Koshi basin have been analyzed for monsoon days considering daily, decade, monthly and monsoon season. Mean monthly rainfall is almost zero in the month of January and gradually increases to reach a maximum in July then start decreasing having lower values in the month of November and December. It is observed that about 76% of the total rainfall within the basin has occurred during monsoon season during June to September (figure 5.1). Minimum and maximum monsoon rainfalls in the basin are found to be 1425 and 2044 mm whereas average annual rainfall varies between 1952mm to 2758 mm.

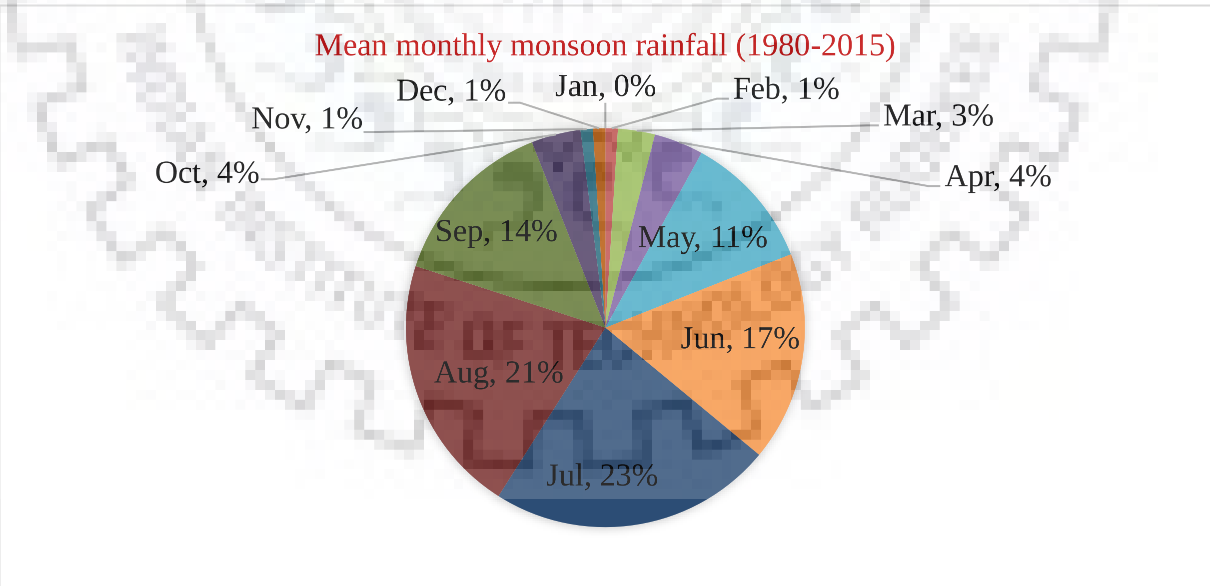

Figure 5. 1: Mean monthly monsoon rainfall during 1980-2015

The co-efficient of variation in annual monsoon rainfall in Koshi river basin is found to be 8%. Figure 5.2 shows the inter-annual variability of monsoon in KRB during period

1980-2015. The departure of the annual monsoon rainfall from the mean annual monsoon rainfall indicates that the monsoon rainfall in the year 2009 and year 1981 are lower than the average annual monsoon rainfall. The annual monsoon rainfall departure from the average annual monsoon rainfall has been normalized as percentage of the average annual monsoon rainfall. The normalized values vary between -22% to +12%. If the normalized value of the monsoon rainfall in any year is less than -10 % of the average annual monsoon rainfall, then that particular year is considered be deficient monsoon rainfall year. However, if the normalized value of the monsoon rainfall in any year is greater than + 10 % of the average annual monsoon rainfall, then that particular year is considered to be excess rainfall year. From the monsoon departure analysis, it has been observed that there are seven deficient year and three excess year during1980-2015.

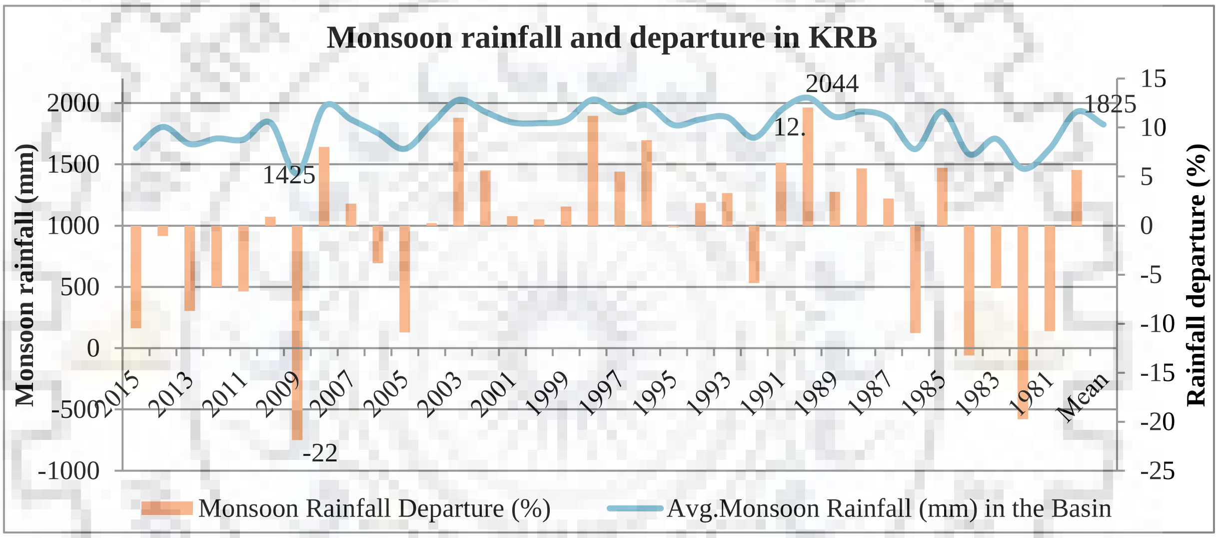

Figure 5.2: Inter annual variability of monsoon in KRB during period 1980-2015.

Figure 5.3 shows the variation of mean monsoon rainfall observed at different rain gauge stations located within KRB or nearby areas during 1980-2015. The monsoon rainfall at different rain gauge stations varies between 714 mm to 3096mm. Station ID 1301 has the highest value of mean monsoon rainfall followed by station ID 1024 and 1027. Station ID 1307 has the lowest mean monsoon rain. The percentage co-efficient of variation of monsoon rainfall at different rain gauge stations vary between 14 to 55 %. The minimum value of the percentage co-efficient of variation of the monsoon rainfall is for station ID 1103, 1304 and 1206 each having 14% and the highest value of the percentage co-efficient of variation of the monsoon rainfall is observed at station 1314 (CV 55%) followed by station 1001 (CV 45%).

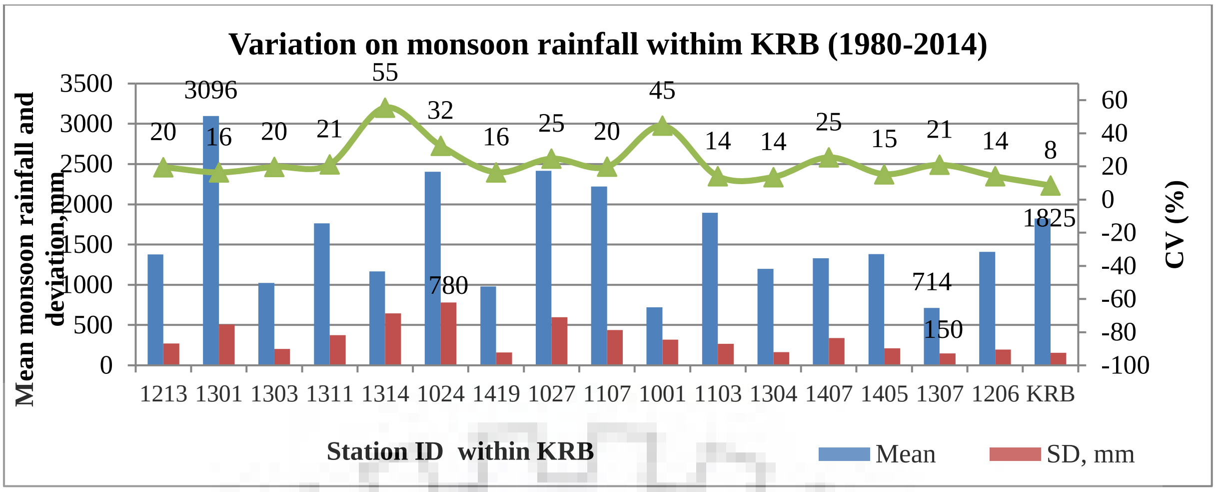

Figure 5. 3: Variation of mean monsoon rainfall within KRB during 1980-2015

The mean monthly rainfall values have been computed for each of months during the monsoon season. For each month, the departure of monthly rainfall values from the mean monthly rainfall values of respective months have been computed to represent inter annual variability of monthly monsoon rainfall during 1980 to 2015. Table 5.1 shows the lowest and highest values of inter-annual variability of monthly monsoon rainfall along with the years during 1980-2015 in KRB. Monthly rainfall in KRB is maximum in July and minimum in the month of September during this period. The co-efficient of variation for monthly rainfall values for different months of the monsoon season vary between 13% to 19%. From the table 5.1, it is observed that the co-efficient of variation of July rainfall has minimum value of 13% whereas it is highest for September month i.e. 19%. The percentage departure from the mean monthly rainfall values has been computed for each month of the monsoon season. It is found that the percentage departure from the mean for July month varies between –31% to +26% during the 36 years of records available. The lowest and highest rainfall observed in July month is 393 mm and 716 mm during the year 2001 and 2002 respectively. Mean monthly rainfall for September month i.e.339 mm is minimum as compared to the mean monthly rainfall of other monsoon months and the percentage departure of the rainfall vary between -42% to +41% in this month. The lowest and highest rainfall observed in September month are198 mm and 477 mm during the year 1984 and 1998 respectively.

Table 5. 1: lowest and highest values of inter annual variability of monthly monsoon rainfall (mm) along with the year during 1980 to 2015 in KRB

Monsoon month	Mean	SD	CV (%)	lowest (% of mean) and year	Highest (% of mean) and year
Jun	412	74	18	262 (-36%) in 2009	547 (33%) in 1990
July	568	74	13	393 (-31) in in 2001	716 (26%) in 2002
August	506	82	16	300 (-41%) in1984	671(33%) in1998
September	339	66	19	198 (-42%) in 2009	477 (41%) in 2003

The mean decadal rainfall values have been computed for each of decades during the monsoon season. For each decade, the departure of decadal rainfall values from the mean decadal rainfall values of respective decades have been computed to represent inter annual variability of decadal monsoon rainfall during 1980 to 2015. Table 5.2 presents the lowest and highest values of inter annual variability of decadal rainfall along with the year during 1980-2015 in KRB. The lowest mean decadal rainfall observed in third decade of September is 93mm and highest mean decadal rainfall observed in the third decade of July (21^{th}-30^{th} of July) is 191mm. Co-efficient of variation for mean decadal rainfall values for a different decade of the monsoon season vary between 19 % to 42%. Third decade of June has co-efficient variation of mean decadal rainfall of 19%, and both the first decade of June and second decade of September each has 42% co-efficient of variation of as indicated by table 5.2. The percentage departure from the mean decadal rainfall values has been computed for each decade of the monsoon season. It has been found that lowest value of decadal rainfall departure ranges between -31% to -78% during 1980 to 2015 Sept_3rd Decade in the year 1982 has rainfall of 20mm showing -78% departure from its mean value of 93mmwhere as June_3rd Decade in the year 2002 has rainfall of 114mm with 31% departure from its mean value of 165mm. Similarly, excess decadal rainfall departure has been found in the range between 43% to 100% during 36 years. June_2nd Decade in the year 2015 has rainfall of 271mm, with the departure of 100% from its mean value of 136mm and June_3rd Decade in the year 2003 has rainfall of 235mm with the departure of 43% from the mean value of 165mm

Table 5. 2: Lowest and highest values of Inter-annual variability of decadal monsoon rainfall (mm) along with the year during 1980 to 2015 in KRB

Days	Mean	SD	CV (%)	lowest (% of mean) and year	Highest (% of mean) and year
June_1st Decade	110	46	**42**	50 (-55%) in 2005	210 (91%) in 1995
June_2nd Decade	136	48	35	41 (-70%) in 1983	**271 (100%) in 2015**
June_3rd Decade	165	31	**19**	**114 (-31%) in 2002**	**235 (43%) in 2003**
July_1st Decade	183	49	27	66 (-64%) in 2001	267 (46%) in 2004
July_2nd Decade	182	39	21	111 (-39%) in 2015	300 (65%) in1996
July_3rd Decade	**191**	45	24	125 (-34%) in 2002	347 (82%) in 196
Aug_1st Decade	156	44	28	49 (-68%) in 1984	235 (51%) in 2000
Aug_2nd Decade	175	39	22	94 (-46%) in 1984	251 (43%) in 1997
Aug_3rd Decade	172	41	24	76 (-56%) in 1997	270 (57%) in 2001
Sept_1st Decade	137	37	27	78 (-43%) in 1997	246 (79%) in 2007
Sept_2nd Decade	110	46	**42**	32 (-70%) in 1998	204 (86%) in 1984
Sept_3rd Decade	**93**	37	39	**20 (-78%) in 1982**	157 (70%) in 2003

The mean daily rainfall values have been computed for each of days during the monsoon season. For each day, the departure of daily rainfall values from the mean daily rainfall values of respective days have been computed to represent inter annual variability of daily monsoon rainfall during 1980 to 2015. The figure 5.4 shows mean and coefficient of variation of daily rainfall in Koshi river basin from 1 June to 30 September during 1980-2015. Thin line represents co-efficient of variation and thick line represents mean of the daily rainfall. Daily rainfall increases gradually from 1 June (9mm) and attains a maximum at 2 July (22mm) than gradually decreases to 30 September (8mm). Co-efficient of variation of daily rainfall ranges from 40% to 106%. Both the mean daily rainfall and its co-efficient of variation shows sharp peaks and throughout the monsoon season. From the study of monsoon variability on monthly, decadal and daily scale, it can be concluded that monsoon variability is high in Jun and September and low in July and August in each scale of the study. Daily mean and its variation shows the effect of heavy rainfall and monsoon disturbance in some years due to which sharp peak and trough have been resulting. These disturbances can be observed more in an excess year than the deficit years. This monsoon variability in different time scale will affect on resultant of water resources in basin.

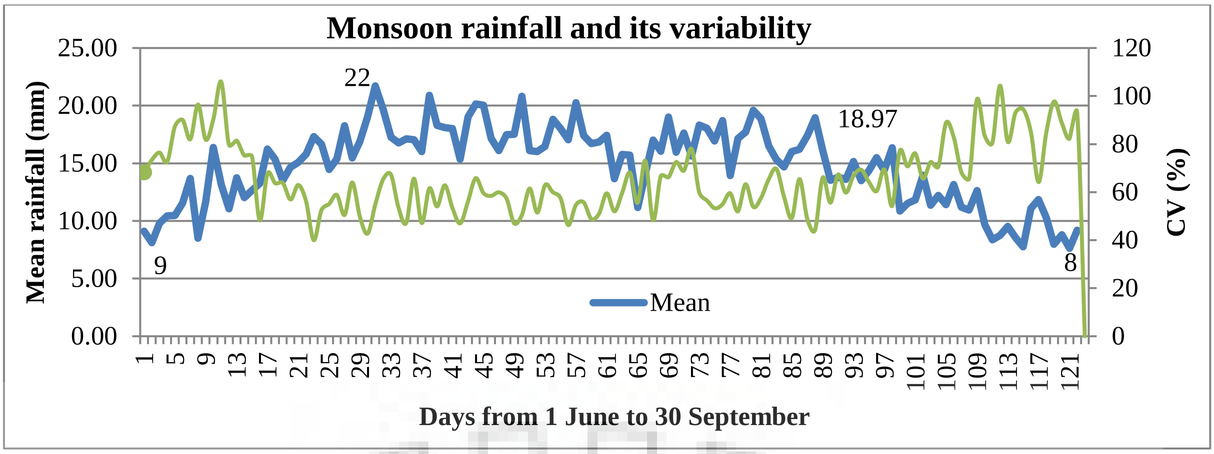

Figure 5. 4: Mean and coefficient of variation of daily rainfall in Koshi river basin from 1 Jun to 30 September during 1980-2015

5.2. GREEN AND BLUE WATER FOOTPRINT OF CROPS PRODUCTION AT BASIN LEVEL

The Volume of Water Content (VWC), or WF_{prod}(m^3/ton), of seven crops (rice, sugarcane, wheat, potatoes, maize, barley, millet) at basin level have been evaluated for ten different years i.e. from the year 2005 to 2014. $WF_{prod,green}$ and $WF_{prod,blue}$ of seven crops from sixteen districts within Koshi River Basin (KRB), Nepal for the year 2005 to 2014 have been estimated separately to get a weighted average WF_{prod} (m^3/ton) at KRB for each respective year. WF_{prod} of each crop is the sum of their $WF_{prod,green}$ and $WF_{prod,blue}$. The table 5.3 provides the scenario of water footprint production of crops in the basin during the study period. The result showed WF_{prod} of rice in the basin was higher among other crops in each year and its average WF_{prod} during 2005-2014 was 1872m^3/ton which was followed by millet (1744m^3/ton), maize (1739m^3/ton) and barley (1569m^3/ton) respectively. Potato had the lowest average WF_{prod} followed by sugarcane; 207m^3/ton and 580m^3/ton respectively. The coefficient of variance (CV) analysis of WF_{prod} showed that WF_{prod} of sugarcane had highest CV value 33%, variation of 33m^3/ton WF_{prod} of Sugarcane in the mean 580m^3/ton WF_{prod}, indicating more variation in WF_{prod} of Sugarcane. Maize and rice had 9% CV. WF_{prod} of millet had lowest CV (4%) followed by potato (7%).

The green water footprint ($WF_{prod,green}$) of each crop production in the basin varies in each year for each crop. The CV of crops in the basin ranges from 4% to 32% whereas blue water foot print production of the crop ($WF_{prod,blue}$) had the range 41 % to 316% during the study period. Blue Water Proportion (BWP), the ratio of $WF_{prod,blue}$ of a crop to the WF_{prod}

of that crop, of the potato was high in each year as compared to those for other crops and the average value over the period 2005 -2014 was 22% (Table 5.4) whereas millet had lowest BWP equal to zero in each year. Sugarcane, maize, rice, wheat, and barley each had less than 1% BWP. Crops having lower BWP are mainly rainfed. The share of the irrigated area and the crop characteristics are the two factors which play keys role for irrigation water requirements, influenced on BWP of a crop.

Average values of the water footprint of all crops in KRB (WF_C)during the study period were found to be varying from 1135m^3/ton to 1493m^3/ton and had mean WF_C as 1248 m^3/ton with CV 9%. The average of water foot print for seven crops production is WF_C. $WF_{C-green}$ i.e 1238 m^3/ton and WF_{C-blue} i.e. 10m^3/ton had contributed to WF_C. It gives average water foot print of crops production in the Koshi river basin over the period of 2005-2014.In WF_C, the water footprint of all crops production in the basin ranges 0.31 % to 0.86 % BWP during the study years giving mean BWP as 0.74% over this period.

Total water footprints in terms of the volumetric unit (cubic meter) were also estimated by multiplying $WF_{prod,green}$and $WF_{prod,blue}$(m^3/ton) by its production in the respective year for each crop production during the year 2005 to 2014. The average value was obtained over the years to get average water footprint production of crops (WF_{c-prod}). It is the average volume of water content (VWC)for the crop productions in KRB during that period. Figure 5.5 shows the average WF_{c-prod}(Mm^3/yr) in the KRB for period 2005-2014. It was contributed by 2% $WF_{c-prod,blue}$ (33Mm^3/yr) and 98% $WF_{c-prod,green}$ (1724Mm^3/yr). The potato had more contribution to $WF_{c-prod,blue}$ which was about 85% of the total blue water use whereas maize and rice had lower contributions i.e. 10% and 5% respectively. It was observed that Barley, wheat and sugarcane were not using blue water. In case of $WF_{c-prod,green}$maize had largest green water share (47%) followed by rice (31.5%), millet (10%) and Potato (5%). Barley and sugarcane together had less than 1% share in green water use. Water footprint proportion (WFP), ratio of water footprint production of a crop to total water footprint of crops production in the basin during 2005-2014, as shown in figure 5.5. From this figure, it is observed that the maize, rice and millet had WFP 46%, 31%, and 10% respectively and they were major contributors in the total water footprint of crop production. On the other hand, Potato and wheat had 7% and 5% WFP whereas barley and sugarcane together had less than 1% WFP.

Table 5. 3: Water Footprint of crop production in Koshi River Basin during 2005-2014

Crops	$WF_{prod,green}$ (m³/ton)										Mean $WF_{prod,green}$ (m³/ton)	SD	CV (%)
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**			
Barley	1627	1613	1486	1469	1988	1640	1549	1405	1482	1424	1568	170	11
Maize	1974	1751	1696	1662	1982	1770	1517	1681	1597	1691	1732	148	9
Millet	1802	1847	1743	1677	1819	1825	1666	1752	1674	1640	1744	76	4
Potato	180	160	173	160	151	145	152	152	176	160	161	12	7
Rice	1919	2114	1889	1871	2092	1924	1760	1748	1629	1715	1866	158	8
Sugarcane	717	812	642	631	708	765	344	349	372	402	574	187	32
Wheat	899	1027	879	1118	1514	948	1038	912	972	945	1025	187	18
Avg. $WF_{prod,green}$ of all crops in KRB ($WF_C - green$)	**1302**	**1332**	**1215**	**1227**	**1465**	**1288**	**1147**	**1143**	**1129**	**1140**	**1239**	**109**	**9**

Crops	$WF_{prod,blue}$ (m³/ton)										Mean $WF_{prod,blue}$ (m³/ton)	SD	CV (%)
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**			
Barley	0	0	0	0	11	0	0	0	0	0	1	4	304
Maize	1	0	1	1	41	8	0	10	1	12	7	13	171
Millet	0	0	0	0	0	0	0	0	0	0	0	0	NA
Potato	24	54	30	29	89	57	44	54	34	47	46	19	41
Rice	3	5	0	0	18	6	7	5	6	3	5	5	96
Sugarcane	0	1	1	1	24	17	1	2	0	7	5	9	156
Wheat	0	0	0	0	10	0	0	0	0	0	1	3	316
Avg. $WF_{prod,blue}$ of all crops in KRB ($WF_C - blue$)	**4**	**9**	**5**	**4**	**28**	**13**	**7**	**10**	**6**	**10**	**10**	**7**	**74**

Crops	WF_{prod} (m^3/ton)										Mean WF_{prod} (m^3/ton)	SD	CV (%)
	2005	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**			
Barley	1627	1613	1486	1469	2000	1640	1549	1405	1483	1424	1569	173	11
Maize	1974	1751	1698	1662	2022	1778	1517	1691	1598	1704	1739	156	9
Millet	1802	1847	1743	1677	1819	1825	1666	1752	1674	1640	1744	76	4
Potato	204	214	203	189	240	202	196	205	209	207	207	13	7
Rice	1922	2119	1889	1871	2111	1929	1768	1753	1635	1719	1872	159	9
Sugarcane	718	812	642	631	733	782	346	351	372	409	580	190	33
Wheat	899	1027	879	1118	1524	948	1038	912	972	945	1026	190	18
Avg. WF_{prod} of all crops in KRB (WF_C)	**1307**	**1340**	**1220**	**1231**	**1493**	**1301**	**1154**	**1153**	**1135**	**1149**	**1248**	**114**	**9**

Table 5. 4: Blue water proportion of the crops production within Koshi River Basin (KRB) over 2005-2014

Crops	Blue Water Proportion (BWP) in Percentage										Mean BWP (%)
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	
Barley	0.00	0.00	0.00	0.00	0.57	0.00	0.00	0.00	0.02	0.00	0.06
Maize	0.03	0.00	0.08	0.04	2.01	0.44	0.00	0.56	0.03	0.71	0.39
Millet	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Potato	11.84	25.38	14.81	15.47	37.10	28.20	22.22	26.19	16.08	22.69	22.00
Rice	0.16	0.21	0.00	0.00	0.86	0.29	0.41	0.27	0.38	0.20	0.28
Sugarcane	0.06	0.06	0.08	0.09	3.33	2.23	0.37	0.67	0.00	1.78	0.87
Wheat	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.00	0.00	0.00	0.07
Avg. WF_{prod} of all crops in KRB (WF_C)	0.31	0.63	0.37	0.35	1.85	0.96	0.64	0.87	0.51	0.86	0.74

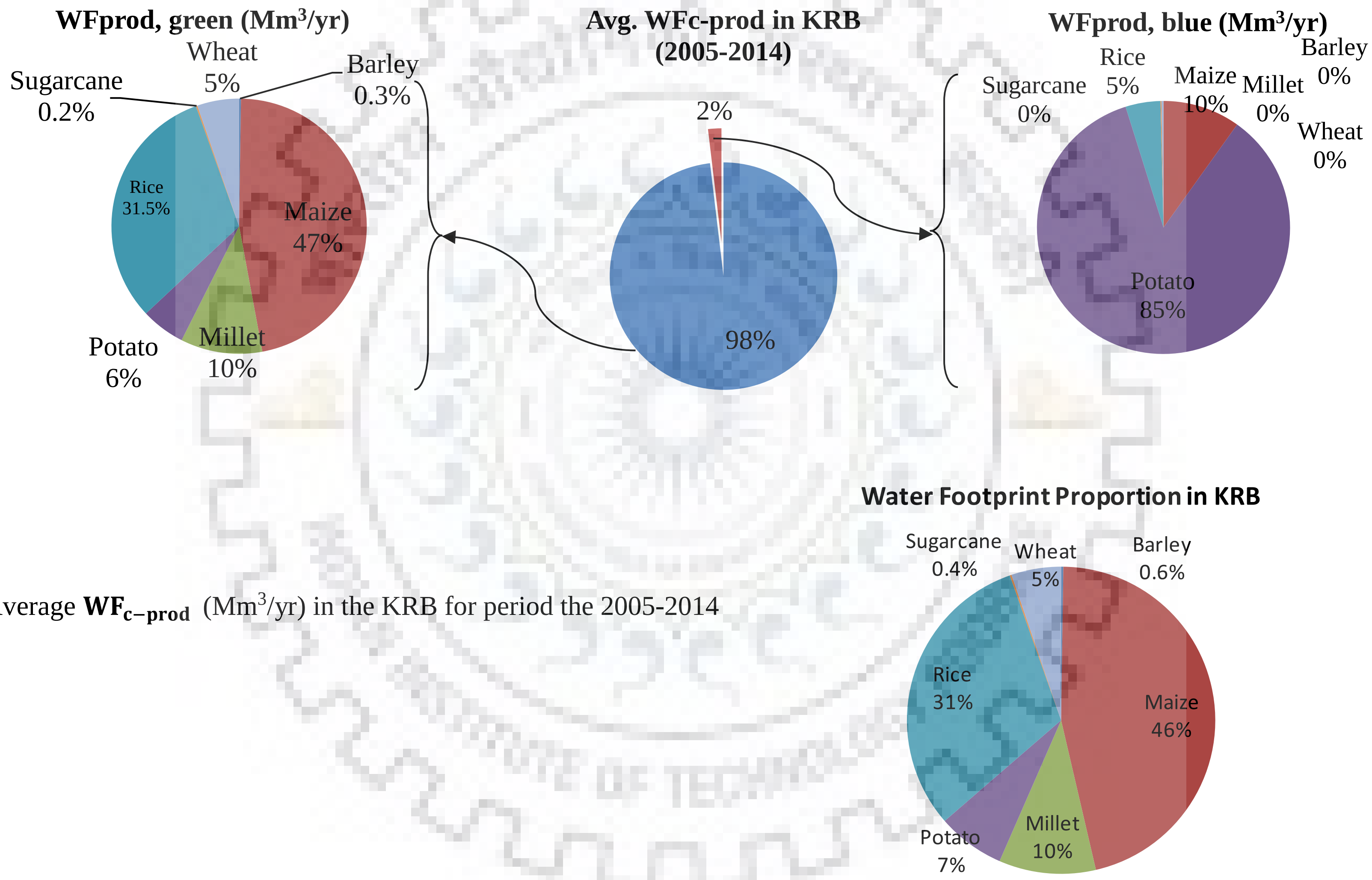

Figure 5. 5: Average $\mathbf{WF_{c-prod}}$ (Mm^3/yr) in the KRB for period the 2005-2014

5.3. SPATIAL-TEMPORAL VARIATION OF WATER FOOTPRINT OF CROPS PRODUCTION IN KRB

The average annual water footprint of crop production (WF_C) in KRB is about 1248m^3/ton during the study period (table 5.3). For each district of Koshi river basin, the averaged value of water footprint production of all crops have computed over the year 2005 to 2014 as illustrated in - figure 5.6 which shows that the lowest water footprint of crop productions are in the Sunsari (1103m^3/ton), Dhankuta (1160m^3/ton) and Kavrepalanchok (1160m^3/ton) districts.

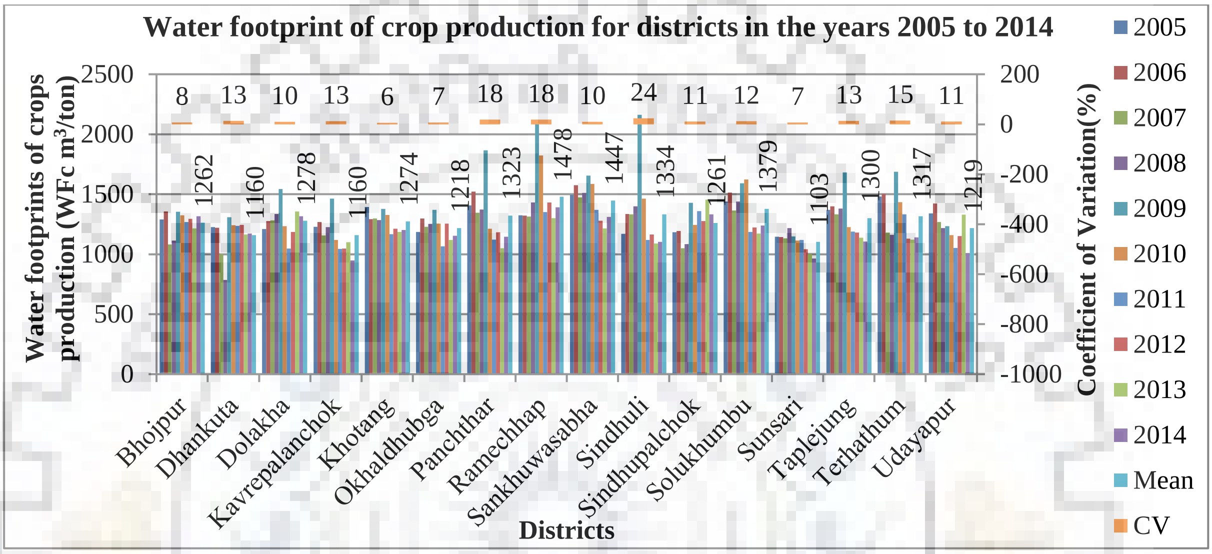

Figure 5. 6: Average situation of the WF_C in different district of Koshi river basin during 2005-2014

Highest water footprints of crop production are found for Ramechhap (1478m^3/ton) and Shankhuwasabha (1485m^3/ton). The remaining other 11 districts have WFc ranging from 1218 m3/ton to 1379m^3/ton. The Co-efficient of variation of WF_C is found to be higher in Sindhuli (CV 24%) Ramechhap (CV 18%) and Panchthar (CV 18%) districts as compared to these for Khotang (CV6%), Okhaldhunga (CV 7%) and Sunsari (CV 7%) districts. From the table 5.5, it is observed that Blue water proportion of crops production in Sindhuli district is highest with BWP value 2.2% which is followed by Ramechap (1.4%), Udayapur (1.2%), Sunsari (1.2%) and Panchthar (1%) districts. Shankhuwasabha district has lowest BWP of 0.3 % for crop production as given in Table 5.5.

The lower BWP indicates lower use of blue water in the crop production in the districts and it also indicates, high proportion of green water use. Natural climatic condition, crops seasons, crops types, crops productions and other factors are responsible for the variation of water footprint of crops production in the districts. Sunsari, Dhankuta and kavrepalanchok could have favored by the climatic condition. Sunsari and Dhankuta have market access, they could have using a higher yielding variety or some water conservation measure or fertilizer. Untimely rainfall or irrigation, unmanaged farming practices, lack of water conservation measures and unsuitability of soils may be the reasons for higher water footprint of the crop production in Ramechhap and Shankhuwasabha districts.

Table 5. 5: Estimated water footprint of crop production ($\mathbf{WF_C}$) for districts within KRB during 2005-2014 (avg. values)

Districts within or crossing	$WF_{C-green}$ (m^3/ton)	WF_{C-blue} (m^3/ton)	WF_C (m^3/ton)	BWP (%)
Bhojpur	1252	10	1262	0.7
Dhankuta	1149	11	1160	0.9
Dolakha	1272	7	1278	0.5
Kavrepalanchok	1154	6	1160	0.5
Khotang	1263	11	1274	0.8
Okhaldhubga	1210	9	1218	0.7
Panchthar	1308	15	1323	1.1
Ramechhap	1457	21	1478	1.4
Sankhuwasabha	1485	5	1447	0.3
Sindhuli	1304	29	1334	2.2
Sindhupalchok	1251	10	1261	0.7
Solukhumbu	1373	6	1379	0.4
Sunsari	1089	14	1103	1.2
Taplejung	1294	7	1300	0.5
Terhathum	1303	14	1317	1
Udayapur	1203	16	1219	1.2

5.3.1. BARLEY

Barley is most common winter crop in the KRB, usually planted in summer and harvested in winter. On average, it occupies 0.4% of total harvested land and 0.1% of total production in the basin during the study period. It is favorable by cool and warm climate. The average minimum and maximum temperature for barley production were 8°C (CV 8%) and 20 °C (CV 3%). It was favorable by average 75% relative humidity (CV 4%) and 2m/s wind speed (CV 11%). The average annual water footprint of barley production in the basin during 2005-2014 is 1569 m^3/ton with the co-efficient of variation of 11%. The WF_{prod} of barley in 2009 is highest in KRB than the other years and is lowest in 2012 (Table 5.3). The result shows average annual WF of barley production is lowest in Bhojpur district (1302m^3/ton) followed by Okhaldunga (1407m^3/ton) and Kavrepalanchok (1436m^3/ton) districts. Ramechhap district has highest water footprint of barley production (2023m^3/ton) followed by Khotang (1843m^3/ton) and Udayapur (1737m^3/ton) districts (figure 5.7). Coefficient of variation in WF of barley production is lower in Sindhupalchok, Taplejung and Solukhumbu. They have CV 7% each. Sindhuli, Ramechhap and Terhathum have higher variation in WF of barley production. They have 32 %, 29 % and 20 % CV respectively. Sunsari district is not producing barley during study period whereas in some years, Sindhupalchok district is also lacking in producing barley.

On an average, total WF_{prod} of barley in KRB is 1569m^3/ton; with $WF_{prod,green}$ and $WF_{prod,blue}$ contributing 99.92% and 0.08% respectively. Average annual water required for barley production during the period 2005-2014 was4.1MCM. This contributes 0.2% of the total water use for the crop production in the basin, which is totally green water. In general, barley is rainfed crops in KRB.

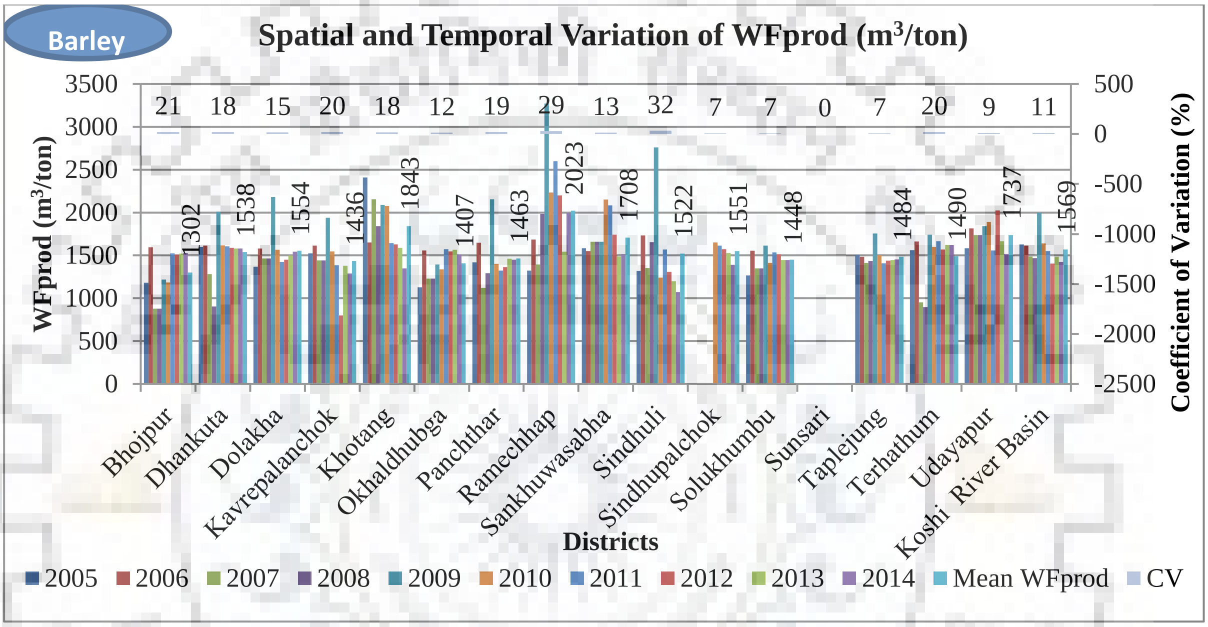

Figure 5. 7: Water footprint of barley in districts within KRB

5.3.2. MAIZE

Maize is a major crop in the KRB. Maize harvested land and production are not same in the year 2005 to 2014. On average, it occupies 40.6% of total crop harvested land and 29.7% of total crop production in the basin during the study period. Average annual Maize yield of 2.14ton/ha was observed with the variation of 6.76 % from the mean. The average minimum and maximum temperature for maize production were 14°C (CV 3.5%) and 26 °C (CV 2.4%). It was favorable by average 75.48% relative humidity (CV 6%),3m/s wind speed (CV 19.7%) and 784 mm/period rainfall (CV 10 %). The average annual water footprint of maize production in the basin during 2005-2014 is 1739m^3/ton with the co-efficient of variation of 9%. WF_{prod} of maize in 2009 is highest in KRB than the other years and is lowest in 2011 (Table 5.3). The result shows average annual WF of maize production is lower in Taplejung district (1491m^3/ton) followed by Dhankuta (1547 m^3/ton) and Vhojpur (1667m^3/ton) districts.

Panchthar district has highest water footprint of maize production (2305m^3/ton) followed by Shankhuwasabha (2238m^3/ton) and Terhathum (1893 m^3/ton) districts (figure 5.8). Coefficient of variation (CV) in WF of maize production is lower in Sindhuli, Okhaldhunga and Dolakha districts with value 7%, 10% and 10% respectively whereas Sindhuli, Taplejung and Ramechhap districts have higher variation. They have 25%, 23% and 20% CV respectively.

On an average, total $WF_{prod}$of maize in KRB is 1739m^3/ton; with $WF_{prod,green}$ and $WF_{prod,blue}$contributing 99.58% and 0.42% respectively. Average annual water required for maize production during the period 2005-2014 was 811MCM. This contributes 56.1% of the total water use for the crop production in the Basin. In general, maize is rainfed crops in KRB.

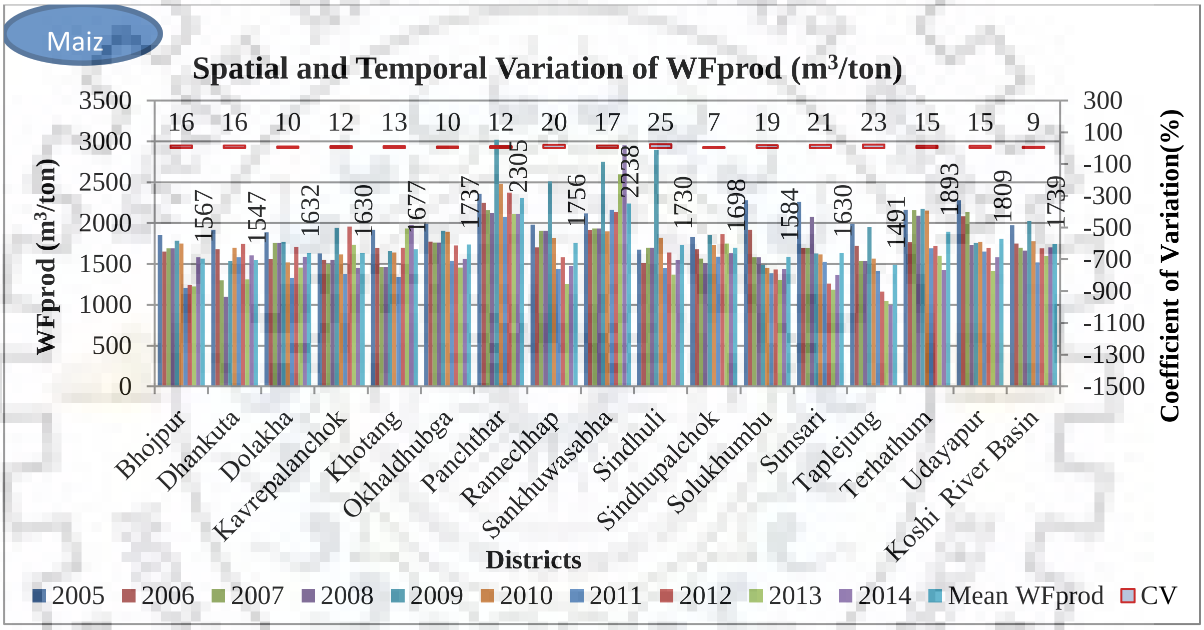

Figure 5. 8: Water footprint of maize in districts within KRB

5.3.3. MILLET

Millet is a minor crop in the KRB. Millet harvested land and production are not same in the year 2005 to 2014. On average, it occupies 17.1% of total crop harvested land and 6.1% of total crop production in the basin during the study period. Average annual millet yield of 1.11ton/ha was observed with the co-efficient of variation of 3.7 % from the mean. The average minimum and maximum temperature for millet production were 15°C (CV 3.3%) and 25 °C (CV 1.2%). It was favorable by average 84% relative humidity (CV 5%), 1.87m/s wind speed (CV 13.38%) and 784 mm/period rainfall (CV 10 %). The average annual water footprint of millet production in the basin during 2005-2014 is 1744m^3/ton with the co-efficient of variation of 4.4%. $WF_{prod}$of millet in 2006 is highest in KRB than the other years and is lowest in 2014 (Table 6). The result shows average annual WF of millet production is lower in Panchthar district (1245m^3/ton) followed by Okhaldhunga (1293m^3/ton) and Udayapur (1487m^3/ton) districts. Sindhuli district has highest water footprint of millet production (2218m^3/ton) followed by Sunsari (2197m^3/ton) and Ramechhap (2118m^3/ton) districts (figure -5.9). Coefficient of variation (CV) in WF of millet production is lower in Shankhuwasabha, kavrepalanchok, Sindhupalchok, and sunsari with value 4 %, 8%, 9% and 9% respectively. Ramechhap, Udayapur and Panchthar have higher variation in millet production. They have 40%, 28% and 18% CV respectively.

On an average, total WF_{prod} of millet in KRB is 1744m^3/ton; with $WF_{prod,green}$ contributing 100%. Average annual water required for millet production during the period 2005-2014 was 178.6MCM. This contributes 10.2% of the total water use for the crop production in the Basin. In general, millet is rainfed crops in KRB.

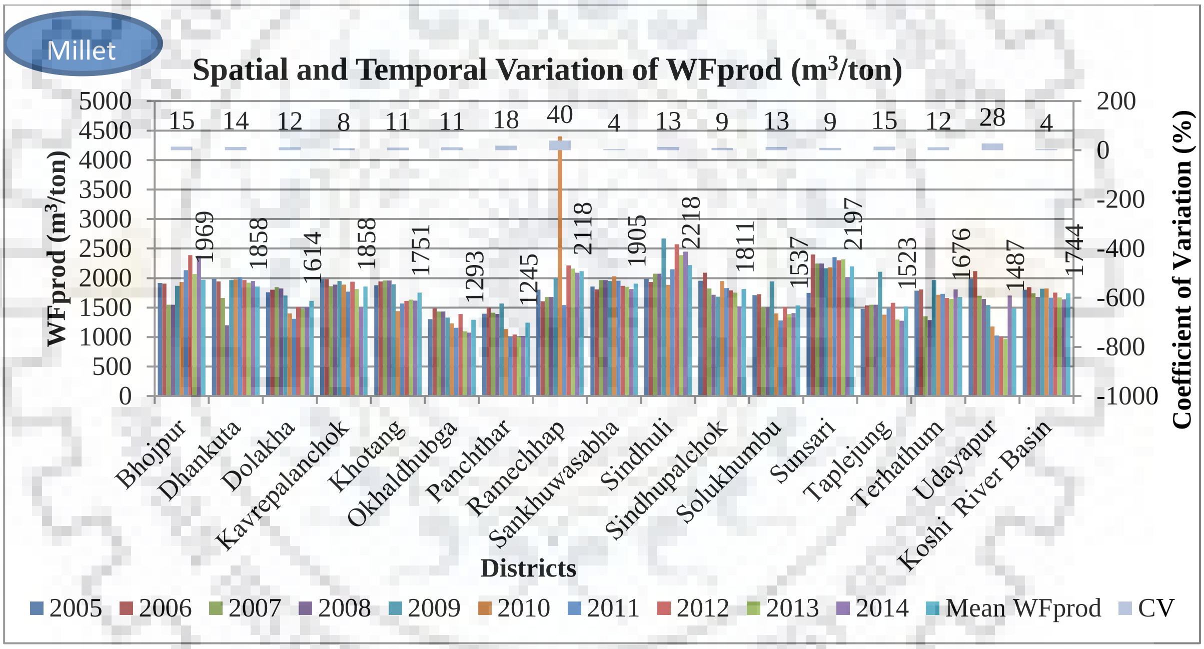

Figure 5. 9: Water footprint of millet in districts within KRB

5.3.4. POTATO

Potato is one of the major vegetable crop generally planted in winter season and can be cultivated in any cropping system. Harvested land and production of potato are changing year to year during the study period. On average, it occupies 8.9% of total crop harvested land and 38.6% of total crop production in the basin during 2005-2014. Average annual potato yield of 12.62ton/ha was observed with the co-efficient variation of 4.3 % from the mean. The average minimum and maximum temperature for potato production were 8°C (CV 7.4%) and 21 °C (CV 3.3%). It was favorable by average 73% relative humidity (CV 4.3%), 2.6m/s wind speed

(CV 12%) and 158 mm/period rainfall (CV 23.6 %). The average annual water footprint of potato production in the basin during 2005-2014 is 207m^3/ton with the co-efficient of variation of 6.5%. ItsWF_{prod} in 2009 is highest in KRB than the other years and is lowest in 2008 (Table 5.3). The result shows average annual WF of potato production is lowest in Kavrepalanchokdistrict (142m^3/ton) followed by Dhankuta (159m^3/ton) and Solukhumbu (186 m^3/ton) districts. Sindhuli district has highest water footprint of potato production (288m^3/ton) followed by Ramechhap (272m^3/ton) and Udayapur (248m^3/ton) districts (figure5.10). Coefficient of variation (CV) in WF of potato production is lower in Sindhuli, Okhaldhunga and Dolakha with value 7%, 10% and 10% respectively. Sindhuli, Taplejung and Ramechhap have higher variation WF production of potato. They have 25%, 23% and 20% CV respectively in WF production of potato.

On an average, total WF_{prod} of potato in KRB is 207m^3/ton; with $WF_{prod,green}$ and $WF_{prod,blue}$contributing 77.69% and 22.31% respectively. Average annual water required for potato production during the period 2005-2014 was 124.6 MCM. This contributes 7.1% of the total water use for the crop production in the Basin.

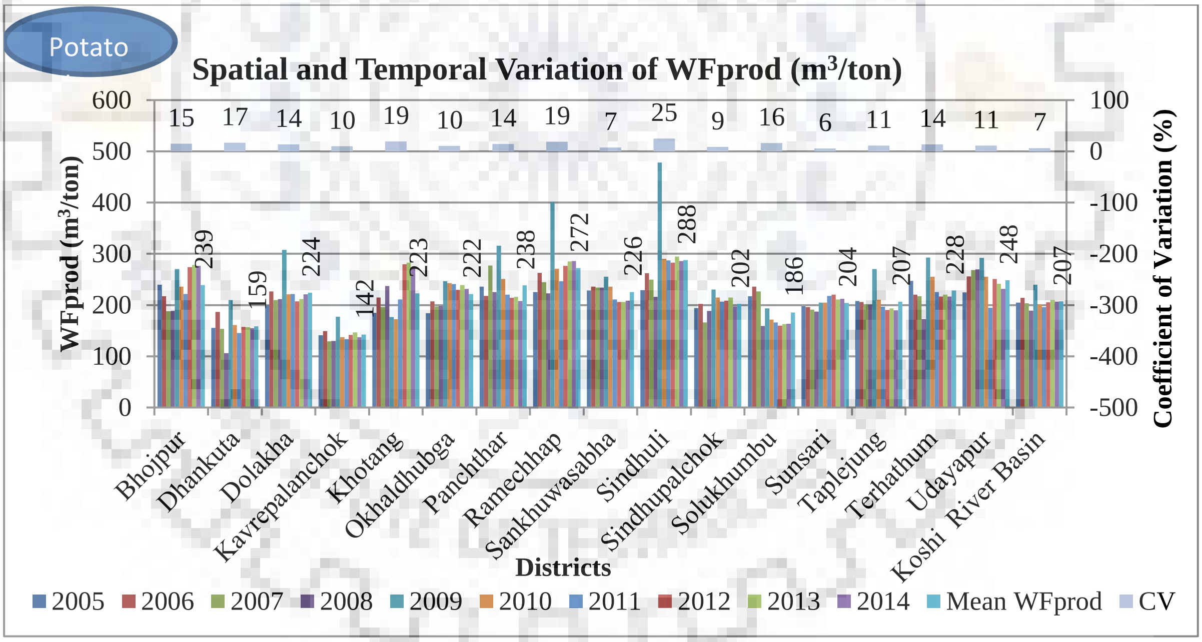

Figure 5. 10: Water footprint of potato in districts within KRB

5.3.5. RICE

Rice is the primary crop in the KRB. On average, 23.1 % paddy harvested land of the KRB supplies 18.5% of total crops production during the study period. It requires sufficient amount of water with favorable climate. Average annual yield of rice as observed during study period was 2.34ton/ha with the variation of 4.3 % from the mean. The average minimum and maximum temperature for rice production were 17.7°C (CV 1.8%) and 27 °C (CV 1%). It was favorable by average relative humidity of 84% (CV 6.4%), wind speed of 2.25 (CV 22.5%) and rainfall of 1518 mm/period (CV 7.7 %). On an average, WF_{prod} of rice in KRB is 1872m^3/ton; with $WF_{prod,green}$contributing 99.71% and $WF_{prod,blue}$contributing 0.29% in the year2005-2014.Its WF_{prod} in 2006 is highest in KRB than the other years and is lowest in 2013 (Table 5.3). The result shows average annual WF of rice production is lowest in Kavrepalanchok district (1427m^3/ton) followed by Udayapur (1497m^3/ton), Dhankuta (1648m^3/ton) and Sunsari (1649m^3/ton) districts. Shankhuwasabha district has highest water footprint of rice production (2229m^3/ton) followed by Taplejung (2112 m^3/ton) and Panchthar(2096m^3/ton) districts (figure5.11). Coefficient of variation (CV) in WF of rice production is lower in kavrepalanchok followed by khotang and Bhojpur. They have CV value 7%, 8% and 9% respectively in WF_{prod} of rice. Sindhupalchok and Taplejung show 9 % co-efficient of variation in WF production of rice from the mean WF_{prod} of respective district. Ramechhap, Sindhuliand Udayapur have higher variation WF production of rice. They have 29%, 28% and 19% CV respectively in WF production of potato.

On average, water requirements in KRB to produce rice was 544.5 MCM. It contributes 31 % of the total water use for the crop production in the Basin.

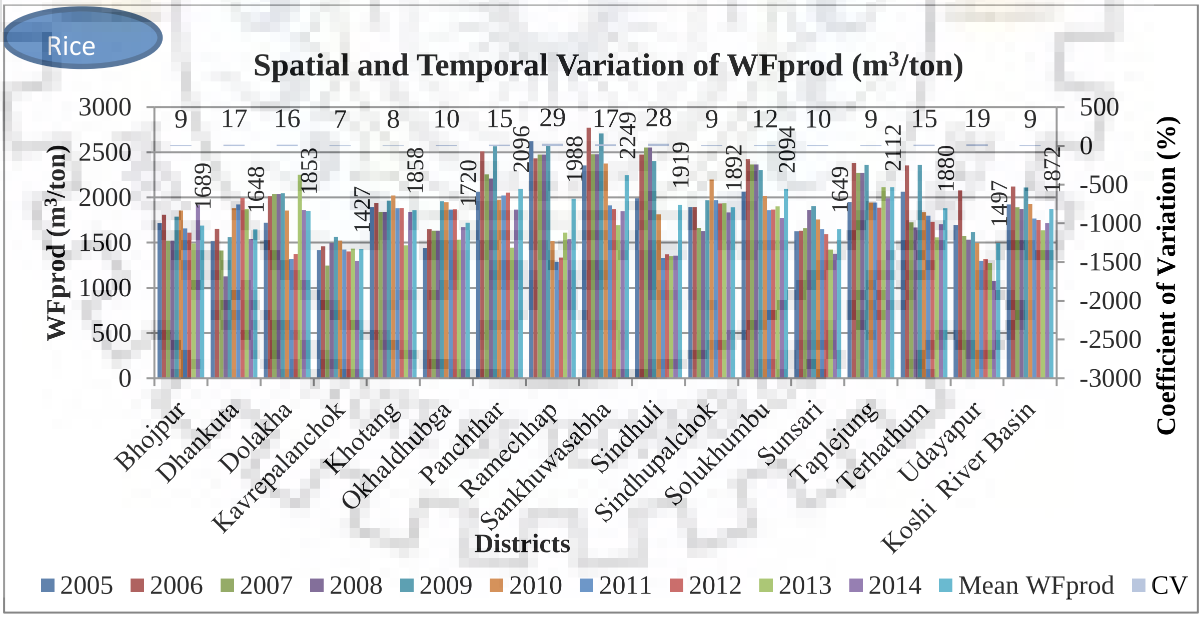

Figure 5. 11:Water footprint of rice in districts within KRB

5.3.6. SUGARCANE

Sugarcane occupies very less land in the basin. Its average annual yield of was 31ton/ha with the variation of 19.9 % during period 2005-2017. Out of 16 districts, only 6 districts were regularly producing sugarcane during study year. Other remaining districts had irregular production. The average minimum and maximum temperature for sugarcane production were 15°C (CV 5.9%) and 26 °C (CV 1.5%). It was favorable by average 80% relative humidity (CV 4.4%), 3.2m/s wind speed (CV 9.35%) and 2182 mm/period rainfall (CV 14 %). The average annual water footprint of sugarcane production in the basin during 2005-2014 is 580m^3/ton with the variation of 32.71%. Its WF_{prod} in 2010 is highest and is lowest in 2008 (Table 5.3). The result shows average annual WF of sugarcane production is lowest in Sunsari district (208m^3/ton) followed by Panchthar (323m^3/ton) and Terhathum (368m^3/ton) districts. Solukhumbu district has highest water footprint of sugarcane production (2806m^3/ton) followed by Okhaldhunga (1117m^3/ton) districts (Figure 5.12). Coefficient of variation (CV) in WF of sugarcane production is lower in Panchthar, Sunsariand Dhankuta districts with value 3%, 11% and 12% respectively. Sindhuli, Udayapur and Kavrepalanchok districts have higher variation WF production of sugarcane. They have 118%, 96% and 57% CV respectively in WF production of sugarcane.

On an average, total WF_{prod} of Sugarcane in KRB is 580m^3/ton; with $WF_{prod,green}$ and $WF_{prod,blue}$contributing 99% and 1% respectively. Average annual water required for sugarcane production during the period 2005-2014 was 3.2 MCM. It contributes 0.2% of the total water use for the crop production in the Basin.

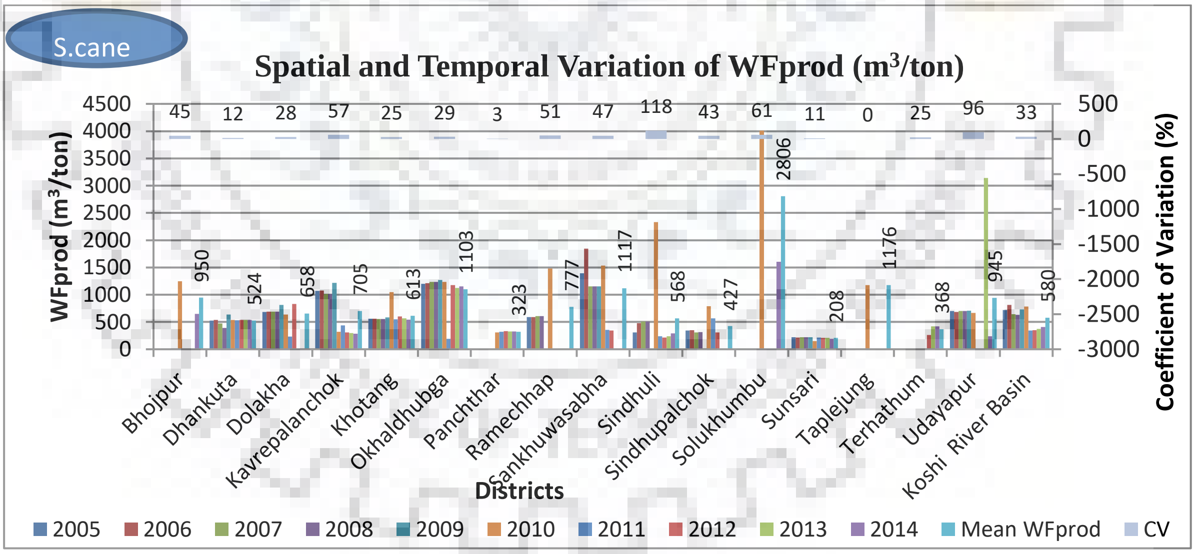

Figure 5. 12: Water foot print of sugarcane in districts within KRB

5.3.7. WHEAT

On average, wheat occupies 9.5% of total harvested land and 5.8% of total production in the basin during the study period. The average minimum and maximum temperature for barley production were 7°C (CV 9.4%) and 21 °C (CV 3.9%). It was favorable by average 76.5% relative humidity (CV 4.3%), 2.5m/s wind speed (CV 11.25%) and 70 mm/period rainfall. The average annual water footprint of barley production in the basin during 2005-2014 is 1025m3/ton with the variation of 18.24%. The WF_{prod} of wheat in 2009 is highest in KRB and is lowest in 2007 (Table 5.3). The result shows average annual WF of wheat production is lowest in Sunsari district (729 m^3/ton) followed by Udayapur (775m^3/ton) and Dhankuta (845m^3/ton) districts. Dolakha district has highest water footprint of wheat production (1277m3/ton) followed by Solukhumbu (1148m^3/ton) and Sindhupalchok (1132m^3/ton) districts (Figure 5.13). Coefficient of variation in WF of wheat production is lower in Sunsari, Shankhuwasabha and Khotang. They have CV in WF production 9%, 15% and 16% respectively. Sindhupalchok Solukhumbu and Taplejung show higher variation in WF of wheat production. They have 40 %, 35 % and 31 % CV respectively.

On an average, total WF_{prod} of wheat in KRB is 1025m^3/ton; with $WF_{prod,green}$ and $WF_{prod,blue}$ contributing 99.9% and 0.1% respectively. Average annual water required for wheat production during the period 2005-2014 was 91.7MCM. This contributes 5.2% of the total water use for the crop production in the basin.

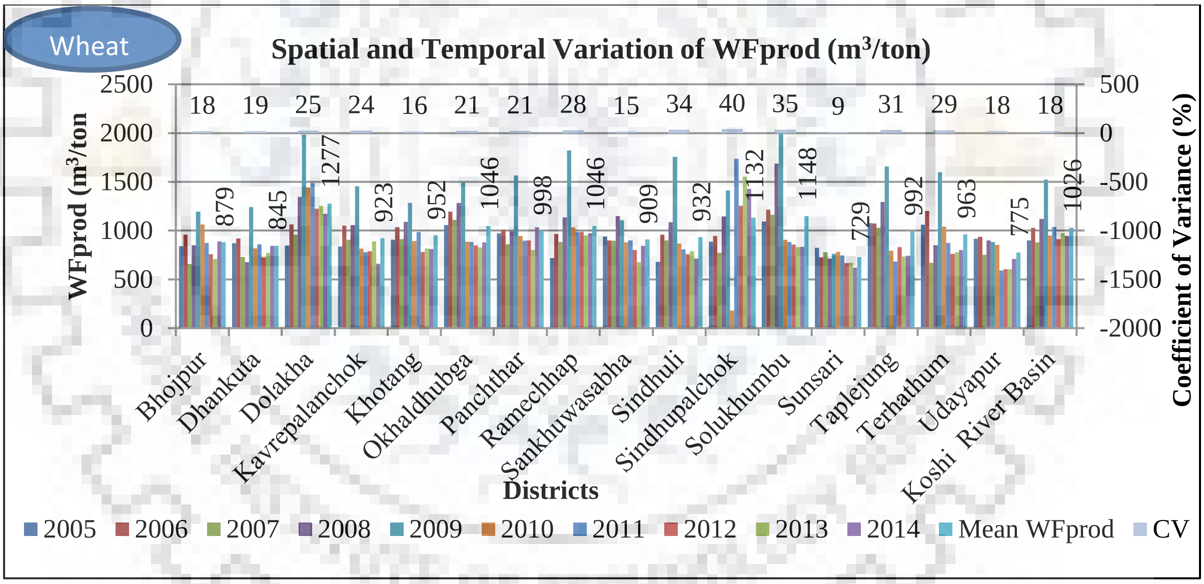

Figure 5. 13: Water footprint of wheat in districts within KRB during 2005-2014

5.4. INTER-ANNUAL VARIABILITY OF WATER FOOTPRINT FOR CROP PRODUCTION IN KRB

Inter-annual variability of water footprint production for barley, maize, wheat, rice, millet, sugarcane and potato crops in terms $WF_{prod,green}$ and $WF_{prod,blue}$ have been evaluated and analyzed separately for Koshi River Basin (KRB).

5.4.1. INTER-ANNUAL VARIABILITY OF WATER FOOTPRINT FOR BARLEY PRODUCTION IN KRB

Inter-annual Variability of $WF_{prod,green}$ of barley

Inter-annual variability of $WF_{prod,green}$ between 2005 and 2014 for barley production is shown in Figure 5.14. During study period, it showed decreasing trend of 19.71(m^3/ton) per year. However, the trend appears to be insignificant. It is due to the crop yield which had rising trend but the green crop water use (CWU_g) had almost no trend. Due to the combined influence of these two factors, $WF_{prod,green}$ had a downward trend during study period. The departure percent from the average $WF_{prod,green}$ showed that $WF_{prod,green}$ had the highest value in the year 2009 and lowest value in 2012.

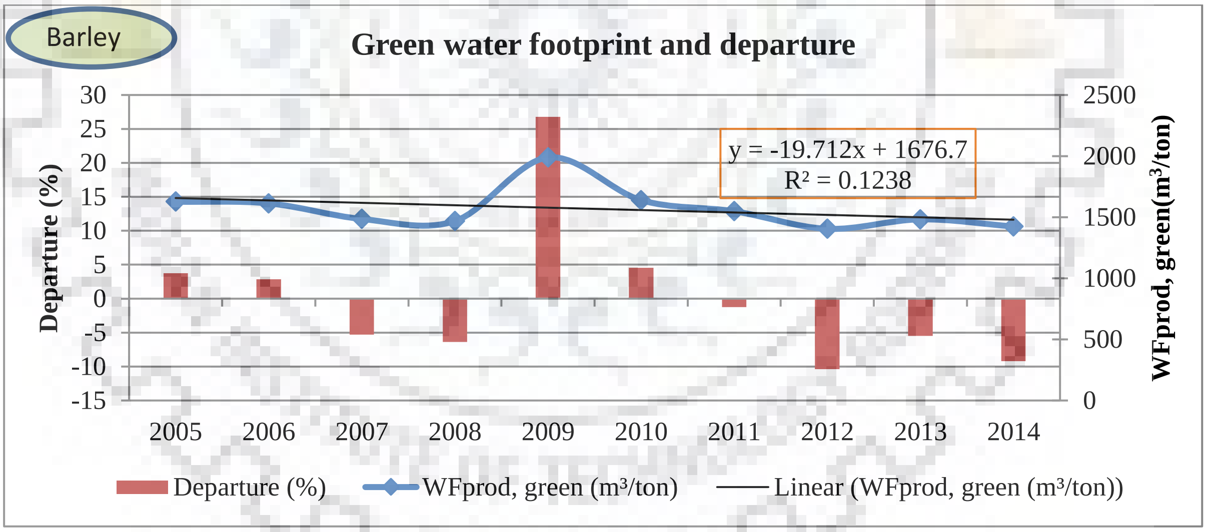

Figure 5.14: Inter-annual variability of $WF_{prod,green}$ between 2005 and 2014 for barley production,

The cross-correlation analysis was carried out correlating the various climatological factors. A correlation matrix providing the correlation coefficients among the various variables is given as Table 5.6. It is observed from this table that the correlation between $WF_{prod,green}$ and its influence factors indicate that $WF_{prod,green}$ was positively correlated with ET_g, CWU_g, and ET_O, whereas a negative correlation was observed between $WF_{prod,green}$ and wind. Average temperature and wind showed good correlation (+ve and –ve respectively) with reference crop evapotranspiration (ET_O) and effective rainfall showed good positive correlation with green water evapotranspiration (ET_g). The positive correlation indicates an increase in dependent variable i.e. $WF_{prod,green}$ with increase in independent variable i.e. climatological variables whereas negative correlation shows reduction in dependent variable with an increase in independent variable.

Inter-annual variability of $WF_{prod,blue}$ of barley

Inter-annual variability of $WF_{prod,blue}$ of barley from 2005 to 2014 is shown in Figure 5.15. The $WF_{prod,blue}$ exhibits no trend during study period. In 2009, it had highest value as indicated by percent departure of $WF_{prod,blue}$ which was due to occurrence of less rainfall and high evapotranspiration during barley growth period. Table 5.6 presents the correlation between $WF_{prod,blue}$ and it's influence factors. ET_O was positively correlated with $WF_{prod,blue}$ with correlation co-efficient 0.93 whereas no any other factors are showing significant correlations. ET_O had strong positive correlation with ET_b and CWU_b for increasing or decreasing $WF_{prod,blue}$ but itself had also good –ve correlation with wind and good +ve correlation with average temperature as a result there was no significant change in the trend of $WF_{prod,blue}$.

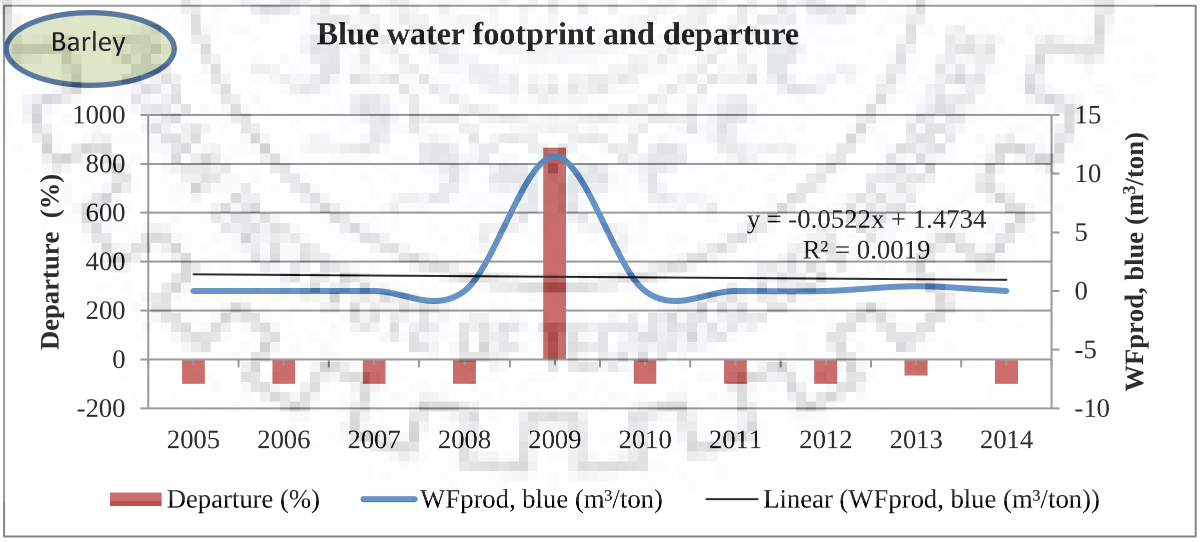

Figure 5. 15:Inter-annual variability of $WF_{prod,blue}$ of barley from 2005 to 2014

Table 5. 6: Correlation coefficient among water footprint production of barley and influencing factors (climate and yield**)**

Factors	ET_g (mm/period)	ET_b (mm/period)	ET (mm/period)	CWU_g (m^3/ha)	CWU_b (m^3/ha)	CWU (m^3/ha)	Y* (ton/ha)	$WF_{prod,green}$ (m^3/ton)	$WF_{prod,blue}$ (m^3/ton)	WF_{prod} (m^3/ton)	Total Rain(mm/period)	Tot Eff Rain(mm/period)	Avg. Temp(°C)	Humidity (%)	Wind (m/sec)	Sun(hours)	Rad(MJ/m²/day)	ET_o (mm/day)
ET_g (mm/period)	1																	
ET_b (mm/period)	**0.89 ***	1																
ET (mm/period)	**1.00***	**0.90***	1															
CWU_g (m^3/ha)	**1.00***	**0.89***	**1.00***	1														
CWU_b (m^3/ha)	**0.89***	1.00*	**0.90***	**0.89***	1													
CWU (m^3/ha)	**1.00***	**0.90***	**1.00***	**1.00***	**0.9**	1												
Y* (ton/ha)	-0.07	-0.22	-0.07	-0.07	-0.22	-0.07	1											
$WF_{prod,green}$ (m^3/ton)	**0.86***	**0.87***	**0.86***	**0.86***	**0.87***	**0.86***	-0.53	1										
$WF_{prod,blue}$ (m^3/ton)	**0.89***	**1.00***	**0.90***	**0.89***	**1.00***	**0.90***	-0.22	**0.87***	1									
WF_{prod} (m^3/ton)	**0.86***	**0.87***	**0.86***	**0.86***	**0.87***	**0.86***	-0.52	**1.00***	**0.87**	1								
Total Rain(mm/period)	-0.53	-0.27	-0.52	-0.53	-0.27	-0.52	-0.37	-0.24	-0.27	-0.24	1							
Tot Eff Rain(mm/period)	-0.6	-0.36	-0.59	-0.6	-0.36	-0.59	-0.37	-0.31	-0.36	-0.31	**0.99***	1						
Avg. Temp(°C)	**0.65#**	0.44	0.65	**0.65#**	0.44	**0.65#**	-0.17	0.57	0.44	0.57	-0.6	-0.62	1					
Humidity (%)	-0.01	-0.11	-0.01	-0.01	-0.11	-0.01	-0.1	0.06	-0.11	0.05	0.45	0.44	0.02	1				
Wind(m/sec)	-0.49	-0.55	-0.49	-0.49	-0.55	-0.49	0.24	-0.6	-0.55	-0.6	-0.15	-0.1	-0.18	-0.65	1			
Sun(hours)	0.49	0.17	0.49	0.49	0.17	0.49	0.51	0.09	0.17	0.09	**-0.78***	**-0.77***	0.5	-0.29	0.21	1		
Rad(MJ/m²/day)	0.52	0.2	0.52	0.52	0.2	0.52	0.5	0.12	0.2	0.12	**-0.79***	**-0.79***	0.51	-0.31	0.2	**1.00***	1	
ET_o (mm/day)	**0.98***	**0.93***	**0.98***	**0.98***	**0.93***	**0.98***	-0.1	**0.86***	**0.93***	**0.87***	-0.43	-0.51	**0.66#**	0.07	-0.59	0.4	0.42	1

* Significant at P<0.05 and #Significant at P<0.01

Inter-annual variability of total WF_{prod} of barley

Total water footprint is a comprehensive indicator that can reflect water consumption, types, quantities and degree of fresh water pollution during crop growth periods. In this study total water footprint of crop production comprises green and blue water footprints. Grey water, which is also the part of total water footprint of crop production, is not considered here as the data about grey water uses are not available. So, the degree of fresh water pollution during growth period of barley is not included. The inter-annual variability of WF_{prod} of barley as in Figure 5.16 shows that WF_{prod} of barley had fluctuating and decreasing tendency over study period from 2005 to 2014. The percent departure of WF_{prod} showed that it had higher value between 2008 and 2010 and had downward trend of a 19.76 (m^3/ton) per year. However, the trend is not significant as the R^2 value is about 0.12 which is very less.

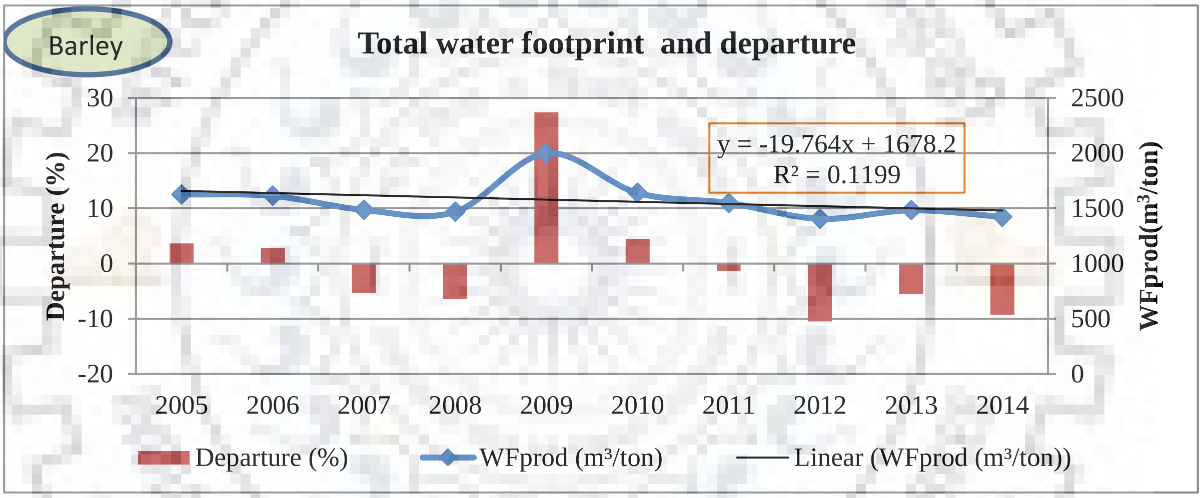

Figure 5. 16: Inter-annual variability of WF_{prod} of barley

The $WF_{prod,green}$ and $WF_{prod,blue}$ components in relation to total WF_{prod} of barley between 2005 and 2014 are in Figure 5.17. From the figure it has been observed that ,$WF_{prod,green}$ occupied almost 100% in proportion. It indicates the barley crop is rainfed.

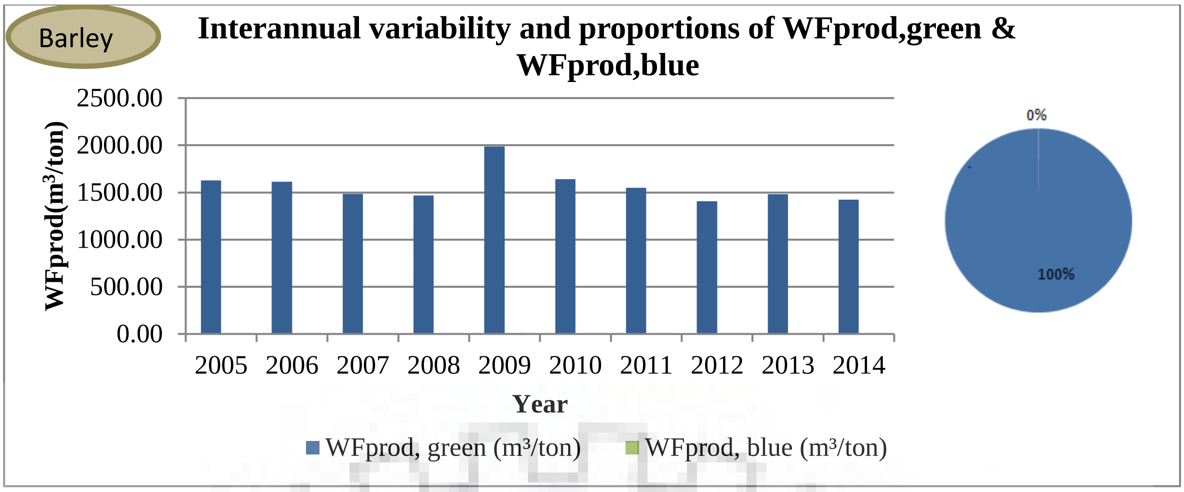

Figure 5.17: $WF_{prod,green}$ and $WF_{prod,blue}$ component in relation to total WF_{prod} of barley between 2005 and 2014

5.4.2. INTER-ANNUAL VARIABILITY OF WATER FOOTPRINT FOR MAIZE PRODUCTION IN KRB

Inter-annual Variability of $WF_{prod,green}$ of maize

Inter-annual variability of $WF_{prod,green}$ between 2005 and 2014 for maize production is shown in Figure 5.18. During study period, it is showing decreasing trend of 26.30(m^3/ton) per year. However, the trend appears to be non-significant. The percentage departure of annual green water from the average annual green water $WF_{prod,green}$ showed that $WF_{prod,green}$ had the highest value in the year 2009 and lowest value in 2011.

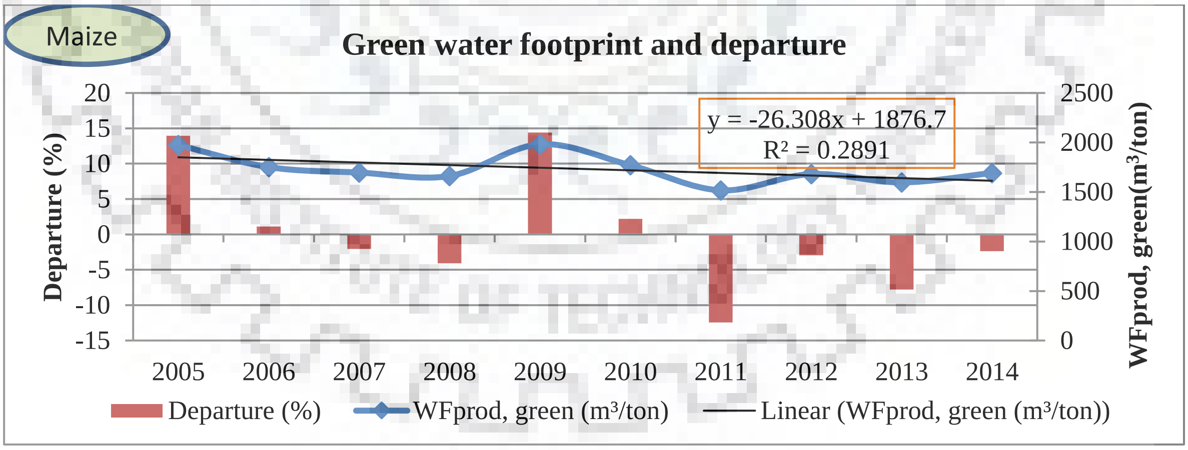

Figure 5.18: Inter-annual variability of $WF_{prod,green}$ between 2005 and 2014 for maize production

Table 5. 7: Correlation coefficient among water footprint production of maize and influencing factors (climate and yield)

Factors	ET_g (mm/period)	ET_b (mm/period)	ET (mm/period)	Y* (ton/ha)	$WF_{prod,green}$ (m^3/ton)	$WF_{prod,blue}$ (m^3/ton)	WF_{prod} (m^3/ton)	Total Rain(mm/period)	Tot Eff Rain(mm/period)	Avg. Temp(°C)	Humidity (%)	Wind (m/sec)	Sun(hours)	Rad(MJ/m²/day)	ET_o (mm/day)
ET_g (mm/period)	**1**														
ET_b (mm/period)	**0.86***	**1**													
ET (mm/period)	**1.00***	**0.89***	**1**												
Y* (ton/ha)	-0.12	-0.05	-0.11	**1**											
$WF_{prod,green}$ (m^3/ton)	**0.69#**	0.56	**0.68#**	**-0.79***	**1**										
$WF_{prod,blue}$ (m^3/ton)	**0.86***	**1.00***	**0.89**	-0.05	0.56	**1**									
WF_{prod} (m^3/ton)	**0.72#**	0.61	**0.72#**	**-0.76***	**1.00***	0.62	**1**								
Total Rain(mm/period)	**-0.72#**	-0.52	**-0.71#**	0.01	-0.44	-0.5	-0.46	**1**							
Tot Eff Rain(mm/period)	**-0.65#**	-0.46	-0.64	0	-0.39	-0.44	-0.4	**0.97***	**1**						
Avg. Temp(°C)	0.59	0.59	0.6	-0.18	0.49	0.58	0.51	**-0.77***	-0.69	**1**					
Humidity (%)	0.17	0.06	0.16	0.13	0.02	0.06	0.03	-0.19	-0.06	0.29	**1**				
Wind(m/sec)	-0.06	-0.21	-0.08	-0.16	0.01	-0.24	-0.01	-0.18	-0.27	0.14	-0.34	**1**			
Sun(hours)	0.53	0.39	0.52	0.3	0.09	0.37	0.11	**-0.74#**	**-0.77**	0.39	-0.38	0.3	**1**		
Rad(MJ/m²/day)	0.54	0.37	0.53	0.24	0.14	0.36	0.16	**-0.75#**	**-0.78**	0.36	-0.39	0.31	**1**	**1**	
ET_o (mm/day)	**0.93***	**0.90***	**0.94***	-0.07	0.62	**0.89***	**0.67#**	**-0.72#**	-0.6	0.76	0.33	-0.17	0.42	0.41	**1**

* Significant at P<0.05 and #Significant at P<0.01

The correlations between $WF_{prod,green}$ and climatic factors indicate that $WF_{prod,green}$ was positively correlated with ET_g, CWU_g, and ET_O whereas negative correlation was observed between $WF_{prod,green}$ and yield (Table 5.7). ET_O, ET_g, CWU_g and yield of barley reached statistically significant level (<0.01).

Inter-annual variability of $WF_{prod,blue}$ of maize

Inter-annual variability of $WF_{prod,blue}$ of maize from 2005 to 2014 is shown in Figure 5.19. The $WF_{prod,blue}$ exhibited no trend during study period. Percentage departure was computed as the ratio of difference between the annual blue water foot print & average annual blue water foot print and average blue water foot print multiplied by 100. From figure 5.19, it is observed that the percentage departure of $WF_{prod,blue}$ had highest positive value for the year 2009 which was due to occurrence of less rainfall and high evapotranspiration during barley growth period. Table 5.7 presents the correlation analysis between $WF_{prod,blue}$ and the climatic factors. ET_O and ET_b were positively correlated with $WF_{prod,blue}$ and reached a statistically significant level (<0.01), whereas the climatic factors were not showing statistically significant negative correlation.

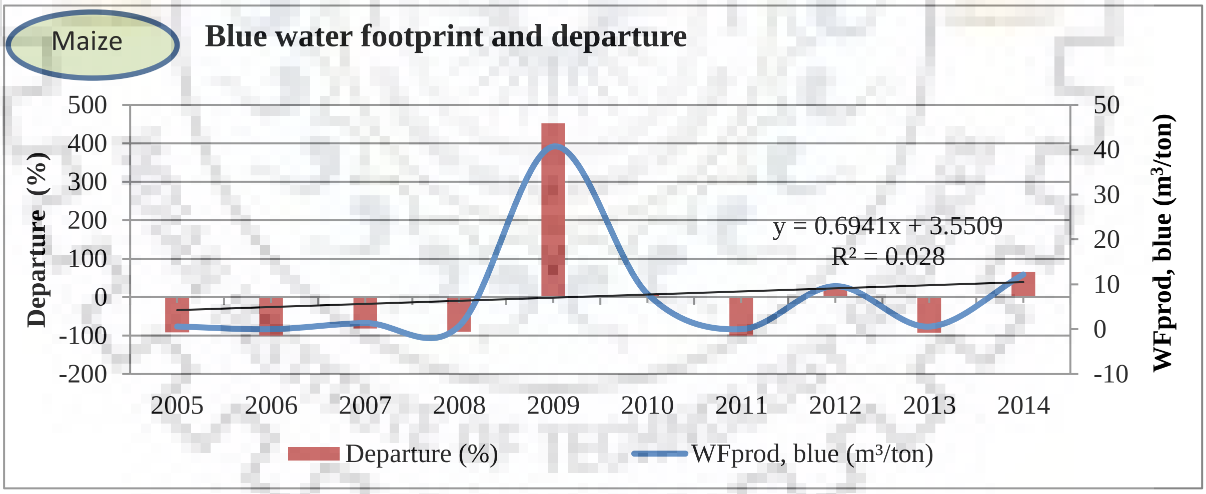

Figure 5.19: Inter-annual variability of $WF_{prod,blue}$ of maize from 2005 to 2014

Inter-annual variability of total WF_{prod} of maize

Total water footprint is a comprehensive indicator that can reflect water consumption, types, quantities and degree of fresh water pollution during crop growth periods. In this study total water footprint of crop production comprises green and blue water footprints. Grey water, which is also the part of total water footprint of crop production, is not considered here as the data were not available for the grey water uses. So, the degree of fresh water pollution during growth period of maize is not included. Inter-annual variability of WF_{prod} of maize during 2005 to 2014 is shown in Figure 5.20 which has been found to be fluctuating and decreasing trend over study period. The percent departure of WF_{prod} showed that it had higher value between 2008 and 2010, and had downward trend of 25.61 (m3/ton) per year. However, the trend is not significant as the R^2 value is about 0.25 which is very less.

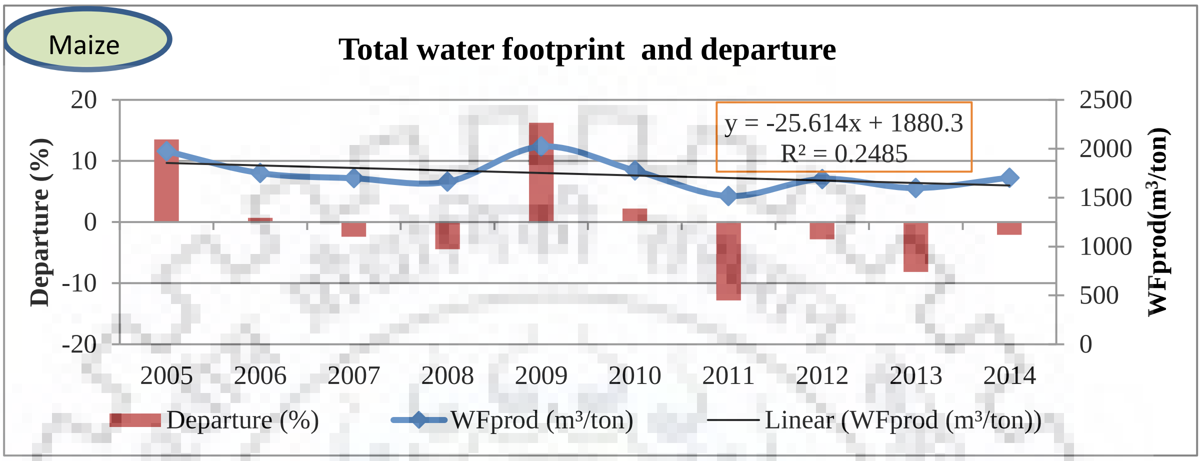

Figure 5.20: Inter-annual variability of $\mathbf{WF_{prod}}$ of maize during 2005 to 2014

The $WF_{prod,green}$ and $WF_{prod,blue}$ component in relation to total WF_{prod} of maize between 2005 and 2014 are shown in Figure 5.21. $WF_{prod,green}$ occupied almost 100% proportion. It indicates the maize crop is rainfed.

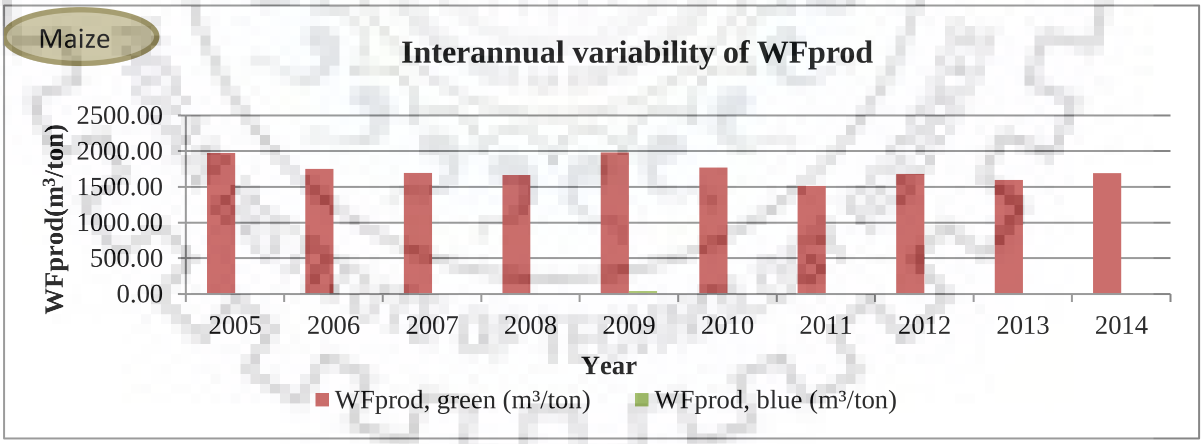

Figure 5.21: $WF_{prod,green}$ and $WF_{prod,blue}$ component in relation to total WF_{prod} of maize between 2005 and 2014

5.4.3. INTER-ANNUAL VARIABILITY OF WATER FOOTPRINT FOR MILLET PRODUCTION IN KRB

Inter-annual Variability of $WF_{prod,green}$ of Millet

Inter-annual variability of $WF_{prod,green}$ between 2005 and 2014 for Millet production is shown in Figure 5.22. During the study period, it is showing decreasing trend of 16.06(m^3/ton) per year. However, the trend appears to be non-significant. The percentage departure of annual green water from the average annual green water $WF_{prod,green}$ showed that $WF_{prod,green}$ had the highest value in the year 2006.

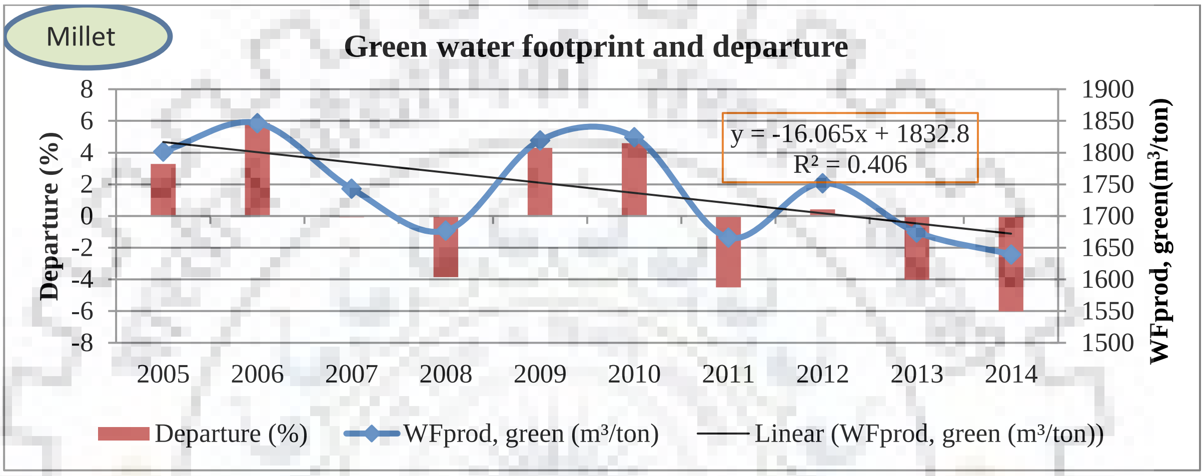

Figure 5.22: Inter-annual variability of $WF_{prod,green}$ of millet between 2005 and 2014.

The correlation between $WF_{prod,green}$ and climatic factors indicate that $WF_{prod,green}$ was positively correlated with ET_g, CWUg and ET_o, where as negative correlation was observed between $WF_{prod,green}$ and yield (Table 5.8). These ET_o, ET_g, CWUg and yield reached statistically significant level (<0.05).

Inter-annual variability of $WF_{prod,blue}$ of Millet

There was no Inter-annual variability of $WF_{prod,blue}$ from 2005 to 2014. Millet during the study period was not using any blue water. Correlation between $WF_{prod,blue}$ and climatic factors had no any relationships between them.

Table 5. 8: Correlation coefficient among water footprint production of millet and influencing factors (climate and yield)

Factors	ET_g (mm/period)	ET (mm/period)	CWU_g (m^3/ha)	CWU (m^3/ha)	Y* (ton/ha)	$WF_{prod,green}$ (m^3/ton)	WF_{prod} (m^3/ton)	Total Rain(mm/period)	Tot Eff Rain(mm/period)	Avg. Temp(°C)	Humidity (%)	Wind (m/sec)	Sun(hours)	Rad(MJ/m²/day)	ET_o (mm/day)
ET_g (mm/period)	1														
ET (mm/period)	**1.00***	1													
CWU_g (m^3/ha)	**1.00***	**1.00***	1												
CWU (m^3/ha)	**1.00***	**1.00***	**1.00***	1											
Y* (ton/ha)	-0.05	-0.05	-0.05	-0.05	1										
$WF_{prod,green}$ (m^3/ton)	**0.65#**	**0.65#**	**0.65#**	**0.65#**	**-0.65#**	1									
WF_{prod} (m^3/ton)	**0.65#**	**0.65#**	**0.65#**	**0.65#**	**-0.65#**	**1.00***	1								
Total Rain(mm/period)	**-0.70#**	**-0.70#**	**-0.70#**	**-0.70#**	-0.27	-0.07	-0.07	1							
Tot Eff Rain(mm/period)	-0.59	-0.59	-0.59	-0.59	-0.26	-0.08	-0.08	0.76	1						
Avg. Temp(°C)	0.28	0.28	0.28	0.28	-0.35	0.62	0.62	0.26	0.28	1					
Humidity (%)	0.3	0.3	0.3	0.3	0.2	0.3	0.3	-0.01	0.26	0.43	1				
Wind(m/sec)	-0.27	-0.27	-0.27	-0.27	**-0.66#**	0.25	0.25	0.2	0.41	-0.13	-0.02	1			
Sun(hours)	0.17	0.17	0.17	0.17	0.04	-0.09	-0.09	-0.43	-0.57	-0.1	-0.61	-0.32	1		
Rad(MJ/m²/day)	0.2	0.2	0.2	0.2	0.04	-0.06	-0.06	-0.43	-0.55	-0.06	-0.56	-0.33	**1.00***	1	
ET_o (mm/day)	**0.76***	**0.76***	**0.76***	**0.76***	0.1	0.47	0.47	-0.59	-0.43	0.51	0.43	-0.36	0.38	0.44	1

* Significant at $P<0.05$ and #Significant at $P<0.01$

Inter-annual variability of totalWF_{prod} of Millet

Total water footprint is a comprehensive indicator that can reflect water consumption, types, quantities and degree of fresh water pollution during crop growth periods. In this study total water footprint of crop production comprises green and blue water footprints. Grey water, which is also the part of total water footprint of crop production, is not considered here as the data were not available for the grey water uses. So, the degree of fresh water pollution during the growth period of millet is not included. Inter-annual variability of totalWF_{prod} of millet totally controlled by $WF_{prod,green}$ as there was no use of green water during study periothe d. The $WF_{prod,green}$ and $WF_{prod,blue}$ components in relation to total WF_{prod} of millet betweethe n 2005 and 2014 have been shown in Figure 5.23. $WF_{prod,green}$occupied almost 100% proportion. It indicates the millet crop is rainfed.

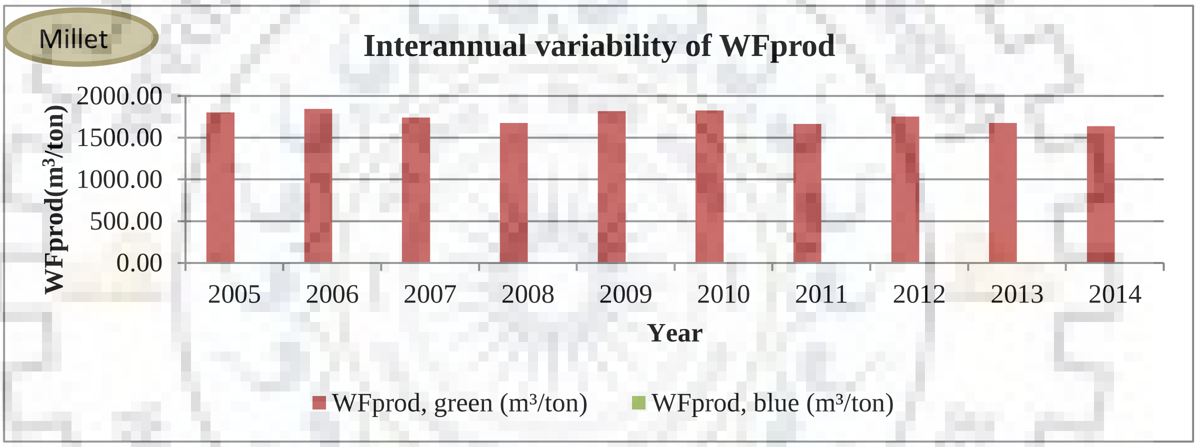

Figure 5.23:$WF_{prod,green}$ and $WF_{prod,blue}$ component in relation to total WF_{prod} of millet between 2005 and 2014 in KRB

5.4.4. INTER-ANNUAL VARIABILITY OF WATER FOOTPRINT FOR POTATO PRODUCTION IN KRB

Inter-annual Variability of $WF_{prod,green}$ of Potato

Inter-annual variability of $WF_{prod,green}$ between 2005 and 2014 for potato production in KRB is shown in Figure 5.24. During study period, it is showing decreasing trend of 1.26(m^3/ton) per year. However, the trend appears to be non-significant. The percentage departure of annual green water from the average annual green water $WF_{prod,green}$showed that $WF_{prod,green}$had the highest value in the year 2005 and lowest value in 2010.

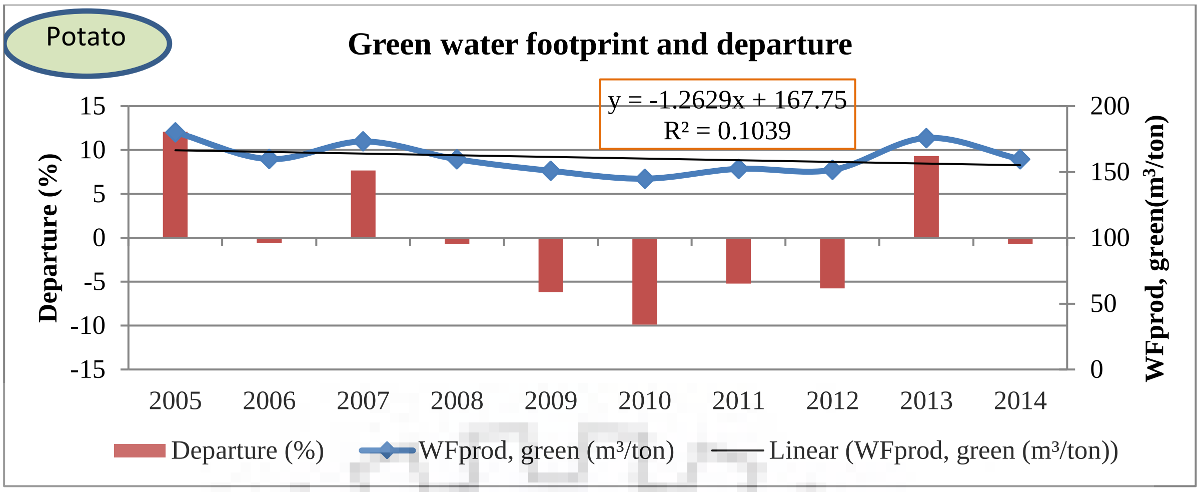

Figure 5.24: Inter-annual variability of $\mathbf{WF_{prod,green}}$ between 2005 and 2014 for Potato production in KRB

The correlation between $WF_{prod,green}$ and climatic factors indicate that $WF_{prod,green}$ was positively correlated with ETg, CWUg, and effective rainfall, whereas a negative correlation was observed between $WF_{prod,green}$ and sun hours, solar radiations and yield (Table 5.9). ET_g crop water use reached statistically significant level (<0.01) while, sun hours, solar radiations and yield reached statistically significant level (<0.05).

Table 5. 9: Correlation coefficient among water footprint production of potato and influencing factors (climate and yield)

Factors	ET_g (mm/period)	ET_b (mm/period)	ET (mm/period)	Y* (ton/ha)	$WF_{prod,green}$ (m^3/ton)	$WF_{prod,blue}$ (m^3/ton)	WF_{prod} (m^3/ton)	Total Rain(mm/period)	Tot Eff Rain(mm/period)	Avg. Temp(°C)	Humidity (%)	Wind(m/sec)	Sun(hours)	Rad(MJ/m²/day)	ET_O (mm/day)
ET_g (mm/period)	1														
ET_b (mm/period)	-0.55	1													
ET (mm/period)	-0.16	**0.92***	1												
Y* (ton/ha)	-0.29	**0.67#**	**0.65#**	1											
$WF_{prod,green}$ (m^3/ton)	**0.85***	**-0.73#**	-0.45	**-0.74#**	1										
$WF_{prod,blue}$ (m^3/ton)	-0.56	**1.00***	**0.90***	0.62	**-0.71#**	1									
WF_{prod} (m^3/ton)	-0.05	**0.77***	**0.88***	0.23	-0.13	**0.79***	1								
Total Rain(mm/period)	0.35	-0.19	-0.06	-0.45	0.5	-0.2	0.16	1							
Tot Eff Rain(mm/period)	0.56	-0.48	-0.3	-0.61	**0.74#**	-0.48	-0.04	**0.91***	1						
Avg. Temp(°C)	-0.25	0.72#	**0.73#**	0.45	-0.43	**0.72#**	**0.64#**	-0.43	-0.55	1					
Humidity (%)	0	0.07	0.08	-0.24	0.17	0.08	0.26	0.1	0.24	-0.01	1				
Wind(m/sec)	-0.06	-0.54	**-0.66#**	-0.39	0.14	-0.52	-0.61	0.02	0.05	-0.35	-0.66	1			
Sun(hours)	-0.35	0.52	0.45	**0.74#**	**-0.67#**	0.51	0.13	**-0.68#**	**-0.72#**	0.62	-0.28	-0.05	1		
Rad(MJ/m²/day)	-0.38	0.53	0.44	**0.76***	**-0.71#**	0.51	0.1	**-0.68#**	**-0.75#**	0.6	-0.34	-0.01	**1.00***	1	
ET_O (mm/day)	-0.25	**0.93***	**0.98***	0.59	-0.47	**0.93***	**0.90***	-0.08	-0.33	**0.75#**	0.16	**-0.69#**	0.37	0.37	1

* Significant at P<0.05 and #Significant at P<0.01

Inter-annual variability of $WF_{prod,blue}$ of potato

Inter-annual variability of $WF_{prod,blue}$ of potato during 2005-2014 is shown in Figure 5.25. The $WF_{prod,blue}$ exhibited an increasing and decreasing trend finally reaching to higher stage during study period. However, the trend appears to be non-significant. Percentage departure was computed as the ratio of difference between the annual blue water foot print & average annual blue water foot print and average blue water foot print multiplied by 100. From figure 5.25, it is observed that the percentage departure of $WF_{prod,blue}$ had highest positive value for the year 2009 which was due to occurrence of high evapotranspiration and average temperature during potato growth period. The correlation between $WF_{prod,blue}$ and climatic factors have been presented in Table 5.9. ET_O, ET_b and average temperature was positively correlated with $WF_{prod,blue}$. These ET_O and ET_b reached at statistically significant level (<0.01), whereas average temperature reached statistically significant level (<0.05).

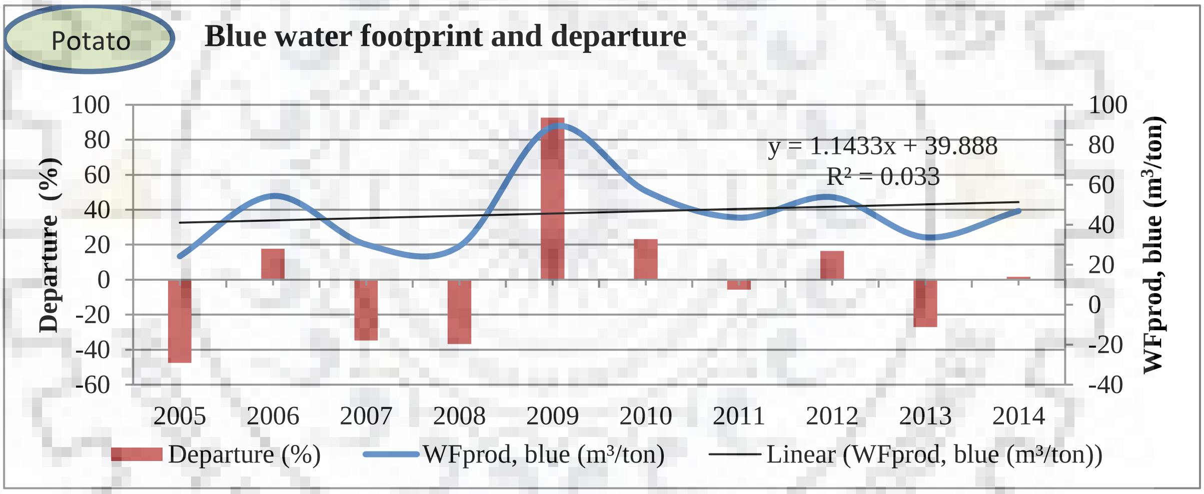

Figure 5.25: - Annual variability of $WF_{prod,blue}$ of potato during 2005-2014

Inter-annual variability of total WF_{prod} of Potato

Total water footprint is a comprehensive indicator that can reflect water consumption, types, quantities and degree of fresh water pollution during crop growth periods. In this study total water footprint of crop production comprises green and blue water footprints. Grey water, which is also the part of total water footprint of crop production, is not considered here as the data were not available for the grey water uses. So, the degree of fresh water pollution during the growth period of potato is not included. Inter-annual variability of WF_{prod} of potato during 2005-2014 is shown in Figure 5.26. It is showing insignificant trend over study period from

2005 to 2014. The percent departure of WF_{prod} showed that it had relatively ha igher value between 2008 and 2010.

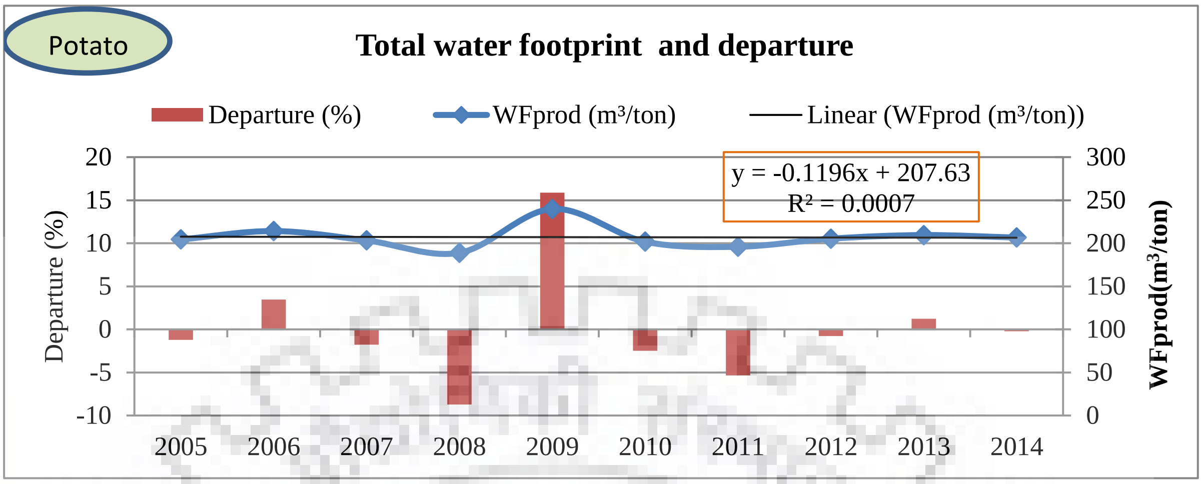

Figure 5. 26: Inter-annual variability of WF_{prod} of potato during 2005-2014

The $WF_{prod,green}$ and $WF_{prod,blue}$ a component in relation to the total WF_{prod} of barley between 2005 and 2014 have been shown in Figure 5.27. It is found that $WF_{prod,green}$ occupied 78 % proportion whereas $WF_{prod,blue}$ occupied 22 % proportion of average of the total WF_{prod} during study period.

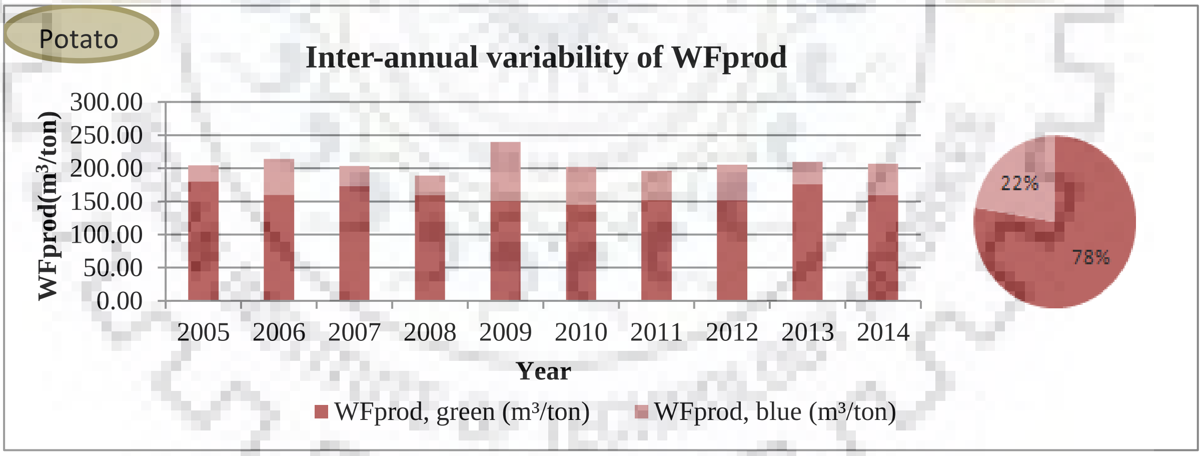

Figure 5.27:- $WF_{prod,green}$ and $WF_{pro,blue}$ component in relation to total WF_{prod} of barley between 2005 and 2014

5.4.5. INTER-ANNUAL VARIABILITY OF WATER FOOTPRINT FOR RICE PRODUCTION IN KRB

Inter-annual Variability of $WF_{prod,green}$ of Rice

Inter-annual variability of $WF_{prod,green}$ between 2005 and 2014 for rice production is shown in Figure 5.28. During the study period, it is showing decreasing trend of 39.00(m^3/ton) per year. The trend appears significant. The percentage departure of annual green water from the average annual green water $WF_{prod,green}$ showed that $WF_{prod,green}$ had higher value in the year 2006 and lowest value in 2013.

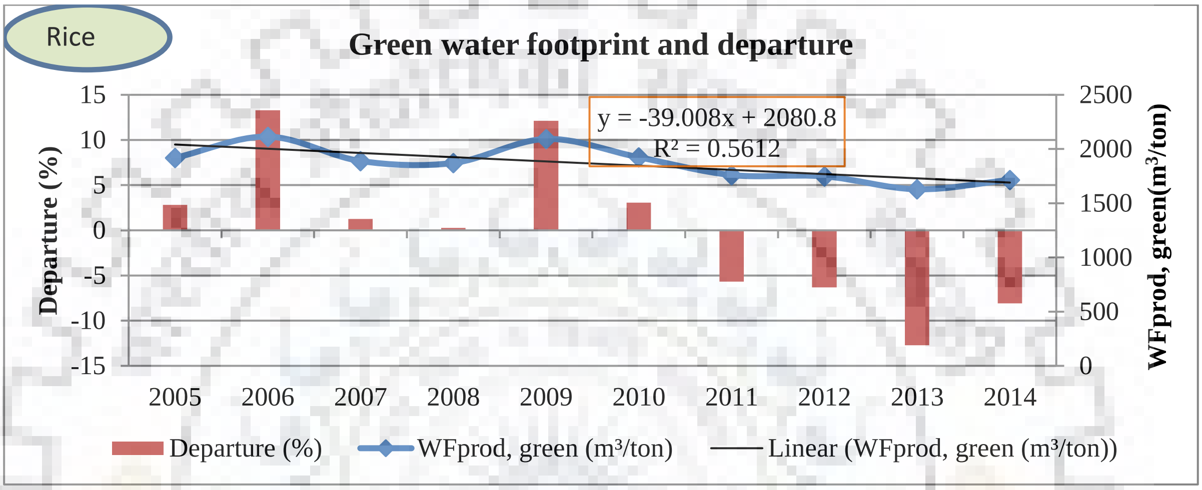

Figure 5. 28: Inter-annual Variability of $WF_{prod,green}$ of Rice during 2005-2014

The correlation between $WF_{prod,green}$ and climatic factors indicate that Yield was negatively correlated with $WF_{prod,green}$ and reached a statistically significant level (<0.01). It is observed that none of the climatic factors were significantly correlated with $WF_{prod,green}$ (Table 5.10). It is observed that production of rice has been increased significantly, as a result, there is significantly decrease in water footprint of rice production during study period.

Table 5. 10: Correlation coefficient among water footprint production of rice and influencing factors (climate and yield)

Factors	ET_g (mm/period)	ET_b (mm/period)	ET (mm/period)	Y* (ton/ha)	$WF_{prod,green}$ (m^3/ton)	$WF_{prod,blue}$ (m^3/ton)	WF_{prod} (m^3/ton)	Total Rain(mm/period)	Tot Eff Rain(mm/period)	Avg. Temp(°C)	Humidity (%)	Wind(m/sec)	Sun(hours)	Rad(MJ/m²/day)	ET_O (mm/day)
ET_g (mm/period)	1														
ET_b (mm/period)	0.55	1													
ET (mm/period)	**1.00***	**0.61***	1												
Y* (ton/ha)	-0.14	-0.12	-0.14	1											
$WF_{prod,green}$ (m^3/ton)	0.46	0.29	0.46	**-0.94***	1										
$WF_{prod,blue}$ (m^3/ton)	0.52	**1.00***	0.58	-0.19	0.33	1									
WF_{prod} (m^3/ton)	0.47	0.31	0.47	**-0.93***	**1.00***	0.36	1								
Total Rain(mm/period)	-0.44	**-0.83***	-0.49	-0.19	0.05	**-0.81***	0.02	1							
Tot Eff Rain(mm/period)	-0.22	**-0.65#**	-0.27	-0.19	0.13	**-0.65#**	0.11	**0.92***	1						
Avg. Temp(°C)	0.57	0.44	0.58	-0.03	0.2	0.43	0.21	-0.43	-0.54	1					
Humidity (%)	0.59	0.42	0.59	0.21	-0.02	0.38	-0.01	-0.48	-0.34	0.44	1				
Wind(m/sec)	-0.07	-0.24	-0.09	-0.27	0.16	-0.24	0.15	0.31	0.16	0.26	0.06	1			
Sun(hours)	0.32	0.15	0.32	0.09	0.01	0.14	0.02	-0.39	-0.43	0.18	-0.25	-0.28	1		
Rad(MJ/m²/day)	0.33	0.14	0.33	0.08	0.02	0.13	0.02	-0.4	-0.44	0.19	-0.22	-0.26	**1.00***	1	
ET_O (mm/day)	**0.78***	**0.69#**	**0.80***	0.03	0.2	**0.66#**	0.22	**-0.79***	**-0.72#**	**0.75#**	**0.77***	-0.03	0.29	0.31	1

* Significant at $P<0.05$ and #Significant at $P<0.01$

Inter-annual variability of $WF_{prod,blue}$ of Rice

Inter-annual variability of $WF_{prod,blue}$ of rice productions from 2005 to 2014 is shown in Figure 5.29. The $WF_{prod,green}$ exhibited a slightly increasing trend of 0.291 (m^3/ton) per year during study period. However, the trend appears to be non-significant. Percentage departure was computed as the ratio of the difference between the annual blue water foot print & average annual blue water foot print and average blue water foot print multiplied by 100. From figure 5.29, it is observed that the percentage departure of $WF_{prod,blue}$ had highest positive value for the year 2009. The year 2009 is monsoon deficit year and rice are tolerating water stress with the use of blue water. The correlation between $WF_{prod,blue}$ and its influencing factors i.e. climate and yield are shown in Table 5.10. The ET_b and ET_O were positively correlated with $WF_{prod,blue}$ whereas rainfall showed negative correlation with $WF_{prod,blue}$. The ET_b and rainfall reached at statistically significant level (<0.01) and ET_O reached at statistically significant level (<0.05).

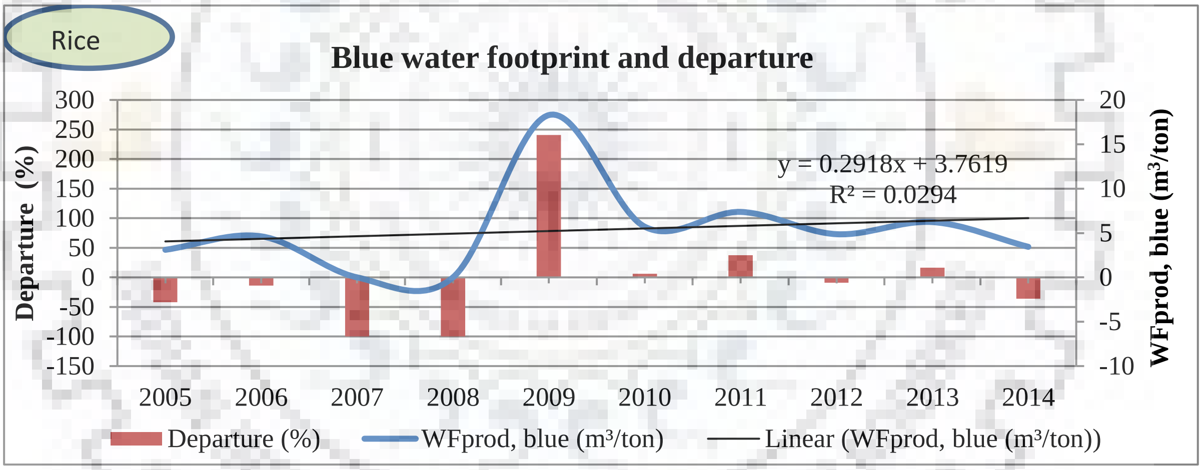

Figure 5. 29: Inter-annual variability of $WF_{prod,blue}$ of rice from 2005 to 2014

Inter-annual variability of total WF_{prod} of Rice

Total water footprint is a comprehensive indicator that can reflect water consumption, types, quantities and degree of fresh water pollution during crop growth periods. In this study total water footprint of crop production comprises green and blue water footprints. Grey water, which is also the part of total water footprint of crop production, is not considered here as the data were not available for the grey water uses. So, the degree of fresh water pollution during the growth period of rice is not included. Inter-annual variability of WF_{prod} of rice during 2005-1014 is shown in Figure 5.30. It has been observed that WF_{prod} of rice has fluctuating and decreasing tendency over study period. The percent departure of WF_{prod} showed that it had higher value between 2008 and 2010, and had downward trend of a 38.71 (m^3/ton) per year. The trend is significant as the R^2 value is about 0.54.

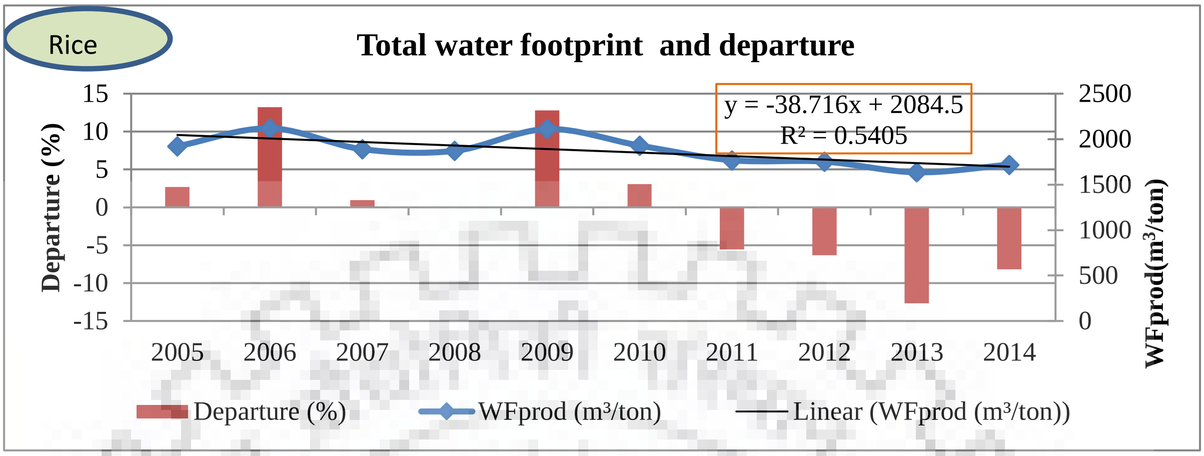

Figure 5. 30: Inter annual variability of total WF_{prod} of Rice during 2005-2014.

The $WF_{prod,green}$ and $WF_{prod,blue}$ a component in relation to the total WF_{prod} of rice between 2005 and 2014 are shown in Figure 5.31. the $WF_{prod,green}$ of rice had almost 100% proportion. It indicates rice crop is rainfed. No blue water has been used for the production of rice during 2005-2014.

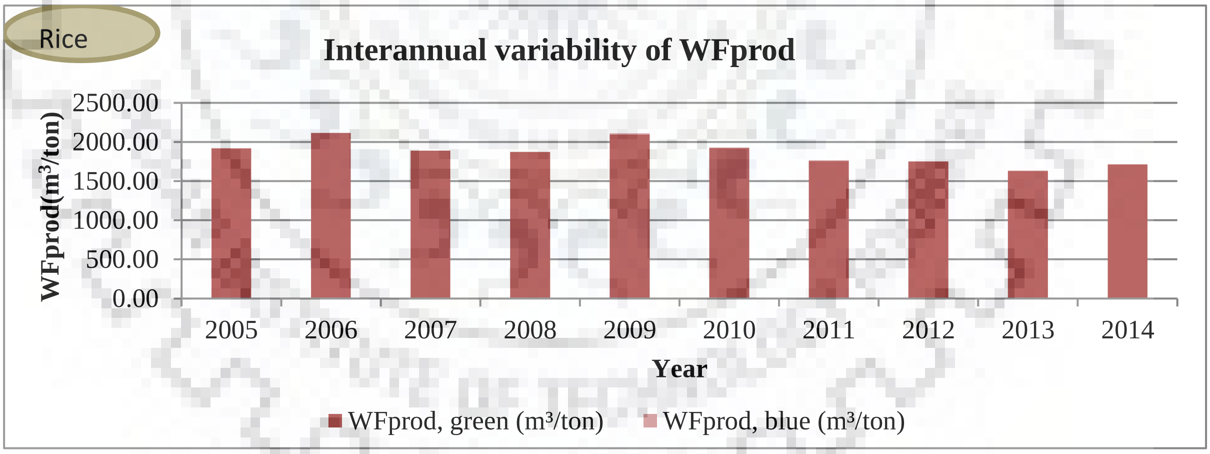

Figure 5. 31: $WF_{prod,green}$ and $WF_{prod,blue}$ a component in relation to total WF_{prod} of rice during 2005 and 2014.

5.4.6. INTER-ANNUAL VARIABILITY OF WATER FOOTPRINT FOR SUGARCANE PRODUCTION IN KRB

Inter-annual Variability of $WF_{prod,green}$ of Sugarcane

Inter-annual variability of $WF_{prod,green}$ between 2005 and 2014 for sugarcane is shown in Figure 5.32. During the study period, it is showing decreasing trend of 39.00(m^3/ton) per year. The trend appears significant as R^2 value is 0.65. The percentage departure of annual green water from the average annual green water $WF_{prod,green}$ showed that $WF_{prod,green}$ had highest value in the year 2006 and lowest value in 2013.

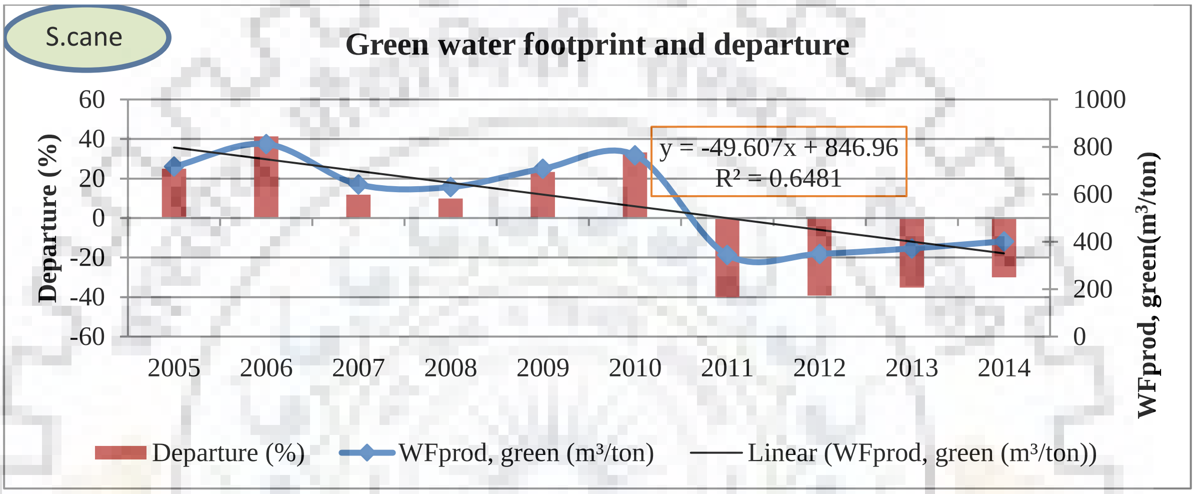

Figure 5. 32 Inter-annual variability of $WF_{prod,green}$ of sugarcane between 2005 and 2014

The correlation between $WF_{prod,green}$ and its influence factors (climatic and crop yield) as shown in table 5.11 indicate that yield and effective rainfall were negatively correlated with $WF_{prod,green}$ and reached a statistically significant level (<0.01), whereas average temperature positively correlated and reached a statically significant level (<0.05)

Table 5. 11:Correlation coefficient among water footprint production of sugarcane and influencing factors (climate and yield)

Factors	ET_g (mm/period)	ET_b (mm/period)	ET (mm/period)	Y* (ton/ha)	$WF_{prod,green}$ (m^3/ton)	$WF_{prod,blue}$ (m^3/ton)	WF_{prod} (m^3/ton)	Total Rain(mm/period)	Tot Eff Rain(mm/period)	Avg. Temp(°C)	Humidity (%)	Wind(m/sec)	Sun(hours)	Rad(MJ/m²/day)	ET_O (mm/day)
ET_g (mm/period)	1														
ET_b (mm/period)	0.07	1													
ET (mm/period)	**0.81***	0.64	1												
Y* (ton/ha)	-0.1	0.11	-0.01	1											
$WF_{prod,green}$ (m^3/ton)	-0.03	0.28	0.14	**-0.87***	1										
$WF_{prod,blue}$ (m^3/ton)	0.31	**0.95***	**0.79***	-0.03	0.33	1									
WF_{prod} (m^3/ton)	-0.01	0.32	0.18	**-0.86***	**1.00***	0.37	1								
Total Rain(mm/period)	-0.17	-0.01	-0.13	**-0.79***	**0.69#**	0.04	**0.68#**	1							
Tot Eff Rain(mm/period)	-0.19	-0.34	-0.35	**-0.76***	0.54	-0.3	0.52	**0.91***	1						
Avg. Temp(°C)	0.14	0.55	0.43	**0.65#**	-0.41	0.54	-0.38	**-0.66#**	**-0.79***	1					
Humidity (%)	0.49	0.37	0.6	-0.3	0.4	0.41	0.41	0.3	0.29	-0.17	1				
Wind(m/sec)	**-0.66#**	-0.34	**-0.71#**	-0.27	0.19	-0.42	0.16	0.5	**0.62**	-0.32	-0.26	1			
Sun(hours)	0.26	0.36	0.41	0.4	-0.2	0.32	-0.18	-0.45	**-0.68#**	0.34	-0.08	**-0.76***	1		
Rad(MJ/m²/day)	0.28	0.39	0.45	0.36	-0.16	0.35	-0.15	-0.39	-0.62	0.3	0.01	**-0.75#**	**0.98***	1	
ET_0(mm/day)	0.64	**0.74***	**0.93***	0.26	0	**0.82***	0.03	-0.38	-0.6	**0.67#**	0.45	**-0.74#**	0.58	0.59	1

* Significant at P<0.05 and #Significant at P<0.01

Inter-annual variability of $WF_{prod,blue}$ of Sugarcane

Inter-annual variability of $\mathrm{WF_{prod,blue}}$ of sugarcane during 2005 to 2014 is shown in Figure 5.33. The $\mathrm{WF_{prod,green}}$ exhibited a slightly increasing trend of 0.377(m^3/ton) per year during study period. However, the trend appears to be insignificant. Percentage departure was computed as the ratio of difference between the annual blue water foot print & average annual blue water foot print and average blue water foot print multiplied by 100. From figure 5.33, it is observed that the percentage departure of $\mathrm{WF_{prod,blue}}$ had highest positive value for the year 2009. Correlation between $\mathrm{WF_{prod,blue}}$ and its influence factors (i.e. climatic and yield) are provided in Table 5.11 From this table it is observed that $\mathrm{ET_b}$ and ET_O were positively correlated with $\mathrm{WF_{prod,blue}}$ and reached at statistically significant level (<0.01). Rainfall and other climatic factors were found to be insignificantly correlated with $\mathrm{WF_{prod,blue}}$.

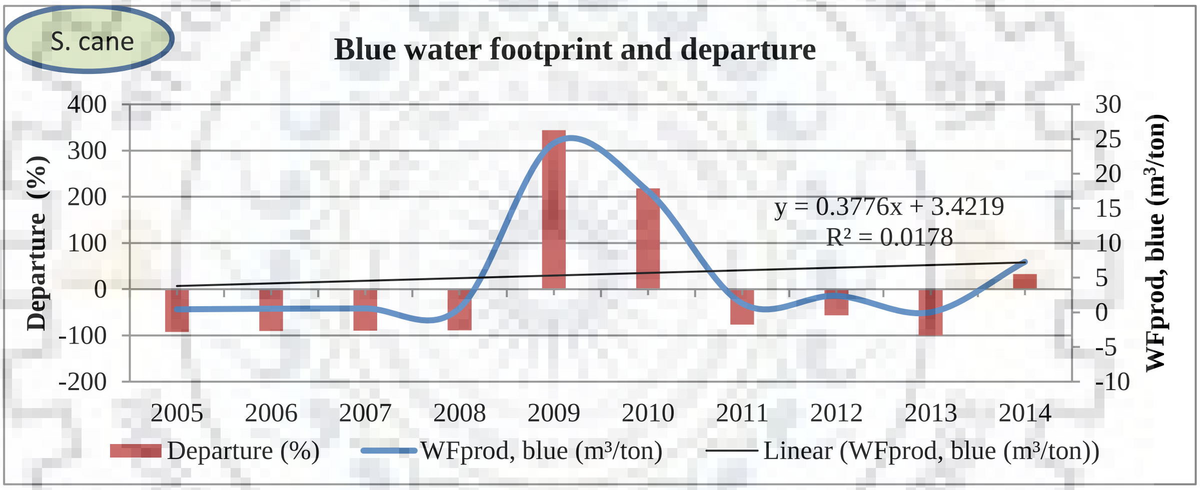

Figure 5.33: Inter-annual variability of $\mathrm{WF_{prod,blue}}$ of sugarcane during 2005 to 2014

Inter-annual variability of total WF_{prod} of Sugarcane

Total water footprint is a comprehensive indicator that can reflect water consumption, types, quantities and degree of fresh water pollution during crop growth periods. In this study total water footprint of crop production comprises green and blue water footprints. Grey water, which is also the part of total water footprint of crop production, is not considered here as the data were not available for the grey water uses. So, the degree of fresh water pollution during growth period of sugarcane is not included. Figure 5.34 shows the inter-annual variability of WF_{prod} of sugarcane which revels fluctuating and decreasing tendency of 49.23 (m^3/ton) per year over study period from 2005 to 2014. The trend appears to be significant as R^2 value is 0.62. The percent departure of $\mathrm{WF_{prod}}$ showed that it had higher value in 2006 and lower value between 2011 and 2012. The decreasing trend of is due to sum of $WF_{prod,green}$ and $WF_{prod,blue}$ where, $WF_{prod,green}$ had more influence.

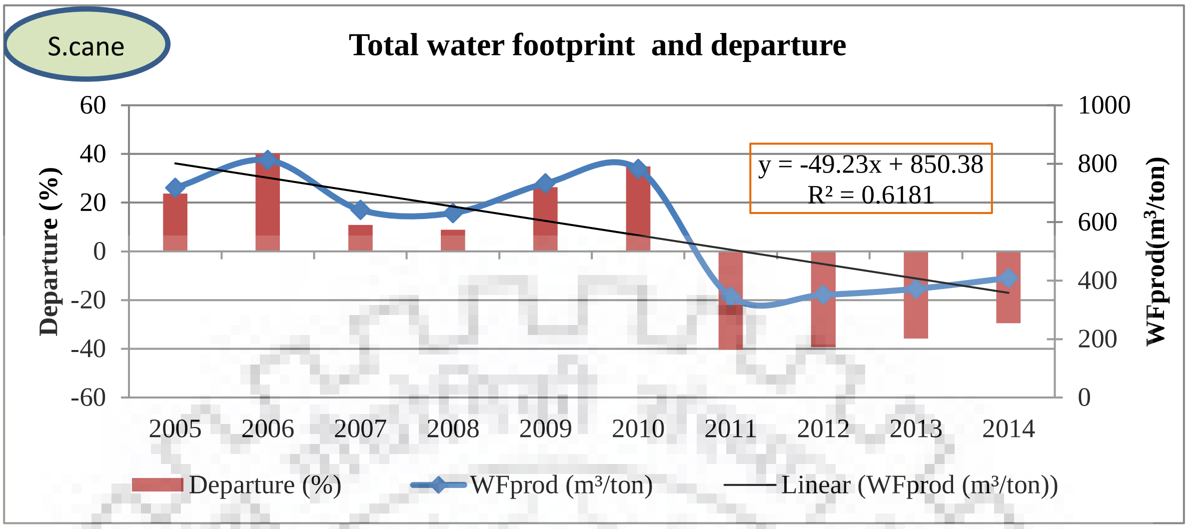

Figure 5.34: Inter annual variability of total WF_{prod} of Sugarcane during 2005-2014 in KRB

The $WF_{prod,green}$ and $WF_{prod,blue}$ and component in relation to total WF_{prod} of rice between 2005 and 2014 are shown in Figure 5.35. Result showed that $WF_{prod,green}$ had 99% proportion while $WF_{prod,blue}$ occupied 1% proportion of average WF_{prod} during the study periods. After the year 2010, WF_{prod} of sugarcane is decreasing (Figure 5.34) and yield of sugarcane seems increasing (Table 4.1). Such large improvement in the reducing WF_{prod} of sugarcane could be the result of introduction of higher yielding/diseases resistant varieties of sugarcane in the year 2010.

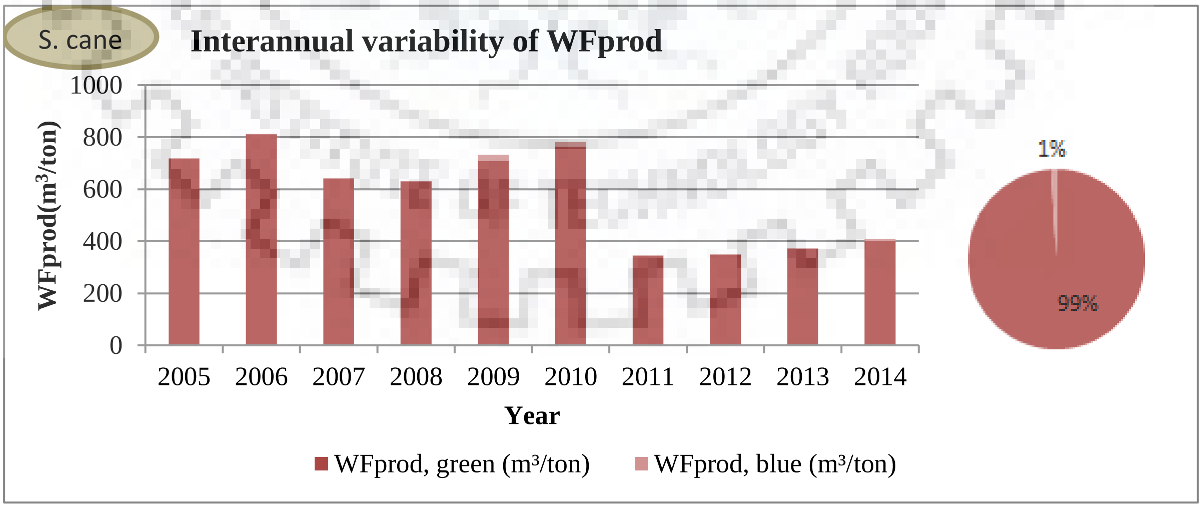

Figure 5.35: $WF_{prod,green}$ and $WF_{prod,bue}$ and component in relation to total WF_{prod} of rice between 2005 and 2014.

5.4.7. INTER-ANNUAL VARIABILITY OF WATER FOOTPRINT FOR WHEAT PRODUCTION IN KRB

Inter-annual Variability of $WF_{prod,green}$ of Wheat

Inter-annual variability of $WF_{prod,green}$ between 2005 and 2014 for Wheat production is shown on Figure5.36. During study period, it is showing decreasing trend of 3.7(m^3/ton) per year. However, the trend appears to be nonsignificant. The percentage departure of annual green water from the average annual green water $WF_{prod,green}$ showed that $WF_{prod,green}$ had the highest value in the year 2009 and lowest value in 2007.

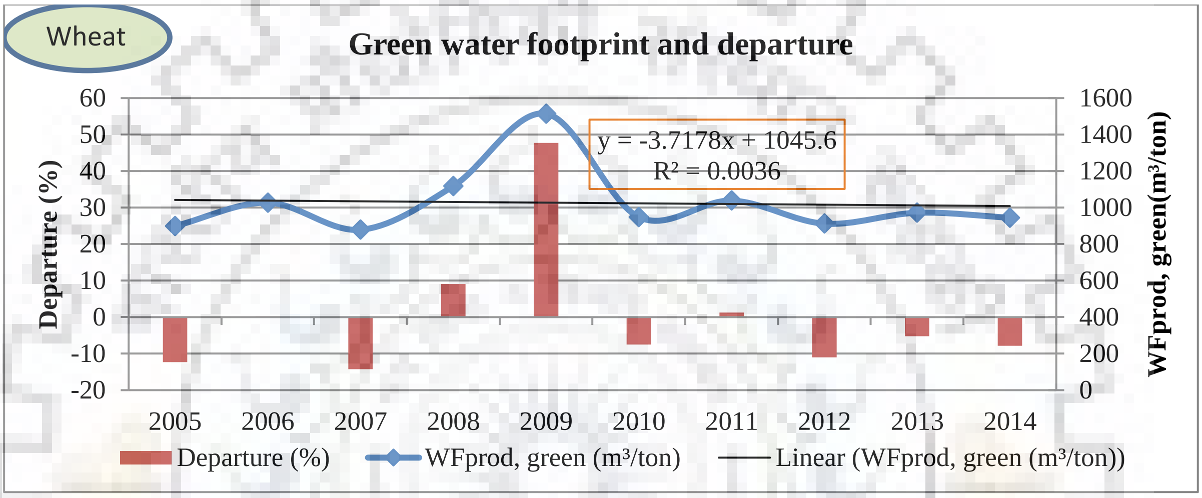

Figure 5.36: Inter-annual Variability of $WF_{prod,green}$ of Wheat in KRB during 2005-2014

The correlation between $WF_{prod,green}$ and its influence factors (i.e. climate and yield) as shown in table 5.12 indicate that Yield and effective rainfall were negatively correlated with $WF_{prod,green}$ and reached a statistically significant level (<0.01), whereas average temperature positively correlated and reached a statically significant level (<0.05).

Table 5. 12: Correlation co-efficient among water footprint production of wheat and influencing factors (climate and yield)

Factors	ET_g (mm/period)	ET_b (mm/period)	ET (mm/period)	Y* (ton/ha)	$WF_{prod,green}$ (m^3/ton)	$WF_{prod,blue}$ (m^3/ton)	WF_{prod} (m^3/ton)	Total Rain(mm/period)	Tot Eff Rain(mm/period)	Avg. Temp(°C)	Humidity (%)	Wind(m/sec)	Sun(hours)	Rad(MJ/m²/day)	ET_O (mm/day)
ET_g (mm/period)	1														
ET_b (mm/period)	**0.83***	1													
ET (mm/period)	**1.00***	**0.84***	1												
Y* (ton/ha)	-0.19	-0.6	-0.2	1											
$WF_{prod,green}$ (m^3/ton)	**0.75***	**0.92***	**0.76***	**-0.78***	1										
$WF_{prod,blue}$ (m^3/ton)	**0.83***	**1.00***	**0.84***	-0.6	**0.92***	1									
WF_{prod} (m^3/ton)	**0.75***	**0.92***	**0.76***	**-0.77***	**1.00***	**0.92***	1								
Total Rain(mm/period)	-0.58	-0.29	-0.58	-0.03	-0.37	-0.29	-0.37	1							
Tot Eff Rain(mm/period)	-0.62	-0.36	-0.62	0.03	-0.43	-0.36	-0.43	**0.99***	1						
Avg. Temp(°C)	**0.67#**	0.32	**0.66#**	0.15	0.28	0.32	0.28	-0.62	-0.61	1					
Humidity (%)	0.14	-0.05	0.13	0.52	-0.3	-0.05	-0.3	0.36	0.35	0.22	1				
Wind(m/sec)	-0.54	-0.31	-0.53	-0.43	-0.09	-0.31	-0.1	0.24	0.23	-0.39	-0.59	1			
Sun(hours)	0.44	0	0.43	0.4	0.05	0	0.05	**-0.83***	**-0.80***	0.53	-0.19	-0.22	1		
Rad(MJ/m²/day)	0.47	0.03	0.46	0.37	0.08	0.03	0.08	**-0.84***	**-0.81***	0.52	-0.19	-0.23	**1.00***	1	
ET_O (mm/day)	**0.98***	**0.86***	**0.98***	-0.17	**0.72#**	**0.86***	**0.72#**	-0.52	-0.56	**0.69#**	0.22	-0.57	0.35	0.38	1

* Significant at P<0.05 and #Significant at P<0.01

Inter-annual variability of $WF_{prod,blue}$ of Wheat

Inter-annual variability of $WF_{prod,blue}$ of wheat in KRB during 2005 to 2014 is shown in Figure 5.37. The $WF_{prod,green}$ exhibits almost same from 2005 to 2007 and 2011 to 2014. Percentage departure was computed as the ratio of difference between the annual blue water foot print & average annual blue water foot print and average blue water foot print multiplied by 100. In 2009, it had highest value as indicated by percent departure of $WF_{prod,blue}$. The correlation between $WF_{prod,blue}$ and its influence factors (climatic and crop yield) are provided in Table 5.12. It is observed that ET_b and ET_O were positively correlated with $WF_{prod,blue}$ and each reached at statistically significant level (<0.01). Rainfall and other climatic factors were found to be insignificantly correlated with $WF_{prod,blue}$

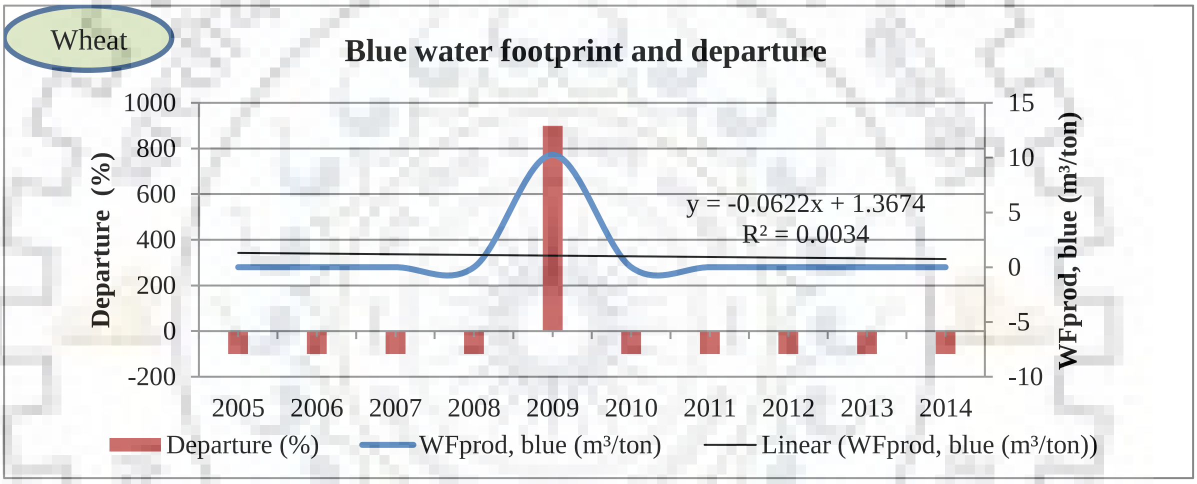

Figure 5.37: Inter-annual variability of $WF_{prod,blue}$ of wheat in KRB during 2005-2014

Inter-annual variability of total WF_{prod} of Wheat

Total water footprint is a comprehensive indicator that can reflect water consumption, types, quantities and degree of fresh water pollution during crop growth periods. In this study total water footprint of crop production comprises green and blue water footprints. Grey water, which is also the part of total water footprint of crop production, is not considered here as the data were not available for the grey water uses. So, the degree of fresh water pollution during growth period of sugarcane is not included. The inter-annual variability of WF_{prod} of wheat in KRB during 2005-2014 as shown in Figure 5.38 showed that WF_{prod} of wheat had slightly fluctuating and decreasing trend of 3.78 (m^3/ton) per year over study period. However, the trend appears to be insignificant as R^2 value is 0.004 which is very less. The percent departure of WF_{prod} showed that it had higher value in 2009. Both the $WF_{prod,green}$ and $WF_{prod,blue}$ components were more in this year as compared to those of other years.

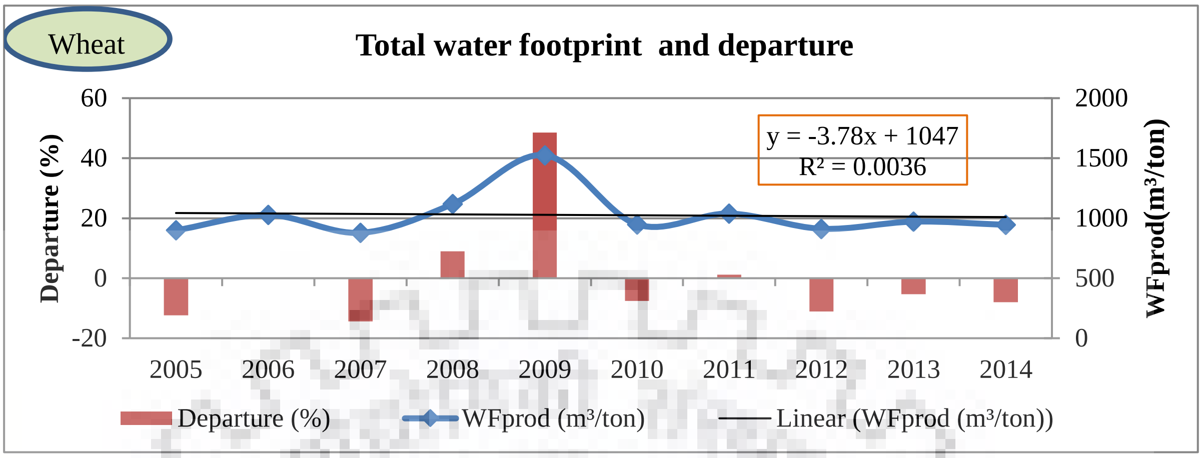

Figure 5.38: Inter-annual variability of total WF_{prod} of Wheat in KRB during 2005-2014

The $WF_{prod,green}$ and $WF_{prod,blue}$ components in relation to total WF_{prod} of wheat between 2005 and 2014 are shown in Figure 5.39. It has been observed that $WF_{prod,green}$ had 100% proportion. It indicates that the wheat crop is rainfed.

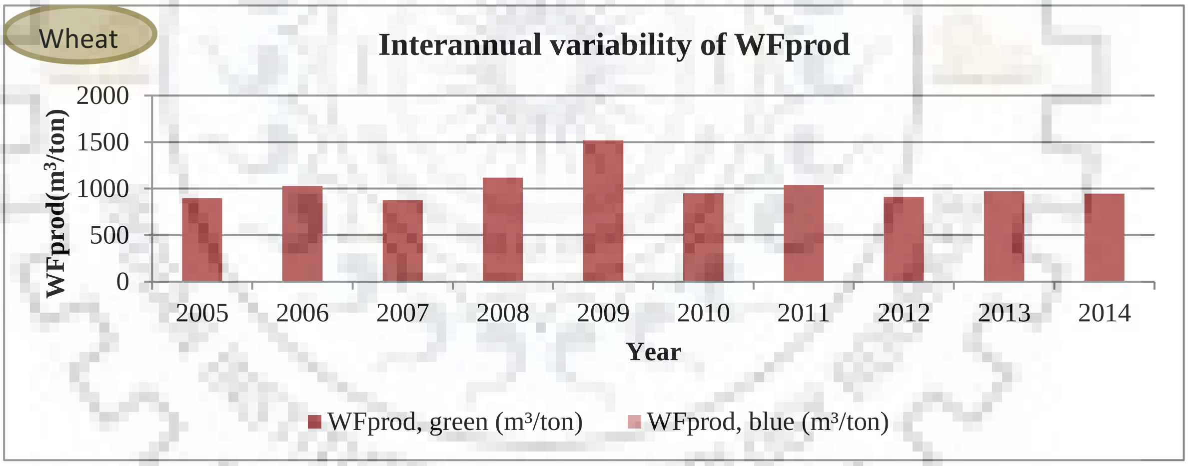

Figure 5.39: $WF_{prod,green}$ and $WF_{prod,blue}$ component in relation to total WF_{prod} of wheat between 2005 and 2014.

CHAPTER 6
SUMMARY AND CONCLUSIONS

The assessment of water footprint at river basin level in Nepal is the first attempt. The spatio-temporal explicit information regarding how water is appropriated for human purposes can be indicated by water footprints. Evaluation and understanding of water footprint of agricultural crop production support production as well as trade decision. The present study presents monsoon variability during 1980-2015 in the Koshi river basin (KRB) and the water footprint of different crop productions during the period 2005-2014 at the same basin. First, irrigation schedule option assuming "optimal" irrigation in CROPWAT version 8.0 model has been used to estimate green and blue evapotranspiration. Then, water footprint calculations are made based on local meteorological station and local crop yield. Following conclusions are drawn from this study:

- About 76% of the total rainfall within the KRB occurs during monsoon that normally starts from June and ends in September. Monsoon average rainfall in the KRB varies from 1425mm (in 2009) to 2044mm (in 1989). There is seven monsoon deficient years and three excess monsoon years during1980-2015.
- Average monsoon rainfall variation in KRB is 8% in seasonal scale. Its variation is higher in June and September. Monsoon variability is more in daily scale (40% to 106%) than that of decadal (19% to 42%) or monthly (13 % to 19%) or seasonal scale. The average annual water footprint of crop production in KRB is 1248m^3/ton with the variation of 9% during the period 2005-2014 and associates average blue water proportion of 0.76% indicating mostly rainfed agriculture.
- Lowest water footprint of crops productions is in the Sunsari (1103 m^3/ton), Dhankuta (1160m^3/ton) and Kavrepalanchok (1160m^3/ton) districts. Highest water footprints of crop production are found for Ramechhap (1478m^3/ton) and Shankhuwasabha (1447m^3/ton) districts.
- Average Water footprint production of rice in the basin is highest (1872m^3/ton) followed by millet (1744m^3/ton), maize (1739m^3/ton) and barley (1569m^3/ton) respectively. Potato has lowest average WF_{prod} followed by sugarcane; 207m^3/ton and 580m^3/ton respectively.
- Co-efficient of variation of water footprint of crop production is lowest for millet (4%) whereas it is highest for sugarcane (33%). Maize and rice have 9% co-efficient of variation in water footprint production.

- About 98% of total water use (Mm^3/year) in crop production KRB during 2005-2014 is due to green water use (received from rainfall) and remaining 2 % is due to blue water use received from irrigation (surface and ground water as sources).
- Potato has highest BWP (22%) and the millet has lowest BWP (0%) among the crops considered in the study. Potato is the main blue water consuming crops that contributors 85% of the total blue water use in KRB. However, contribution of potato production on total water footprint of KRB is 7%. Maize, rice and millet have major contribution on total water use of crops production in KRB; 46%, 31% and 10% respectively. Water footprint productions of most of the crops in the year 2009 (the monsoon rainfall deficient year) are higher than that of other year resulting from higher evapotranspiration. Blue water use in that year is also highest among others year.
- After the year 2010, there is large improvement in the reduction of total water footprint of sugarcane production due to introduction of higher yielding/diseases resistant variety of sugarcane.
- The average water footprint of crop production of the year 2005-2014 represents the situation of water footprint of crop production of that period in basin level. This water footprint of crop production accounts only the green and blue component of water footprint of the crop and does not include grey component. In this study data for grey water is not available and hence it is excluded for crop production. Total water footprint of the crop production in the basin gives only the idea of water requirement of different types of crops at field and does not represent the irrigation diversion requirement.
- Marginal blue water (2%) used in crop production indicates more use of rainfall and less use of surface and ground water for crop production. Use of rainfall in the KRB can be further maximized in both irrigated and rainfed agricultural land by adopting suitable planting time, improving soil characteristics and vegetation cover that improves effectiveness of rainfall.
- Both green water and blue water footprint (m^3/ton) within the basin can be decreased substantially by increasing green and blue water productivity (ton/m^3). In irrigated and rainfed agriculture, green water footprint reduction can be done by increasing green water productivity or by increasing total production from rainfed agriculture. In irrigated agriculture, blue water footprint can be minimized by decreasing ratio of blue/green water footprint.

- Water footprint of a crop can be reduced by increasing productivity for which improved agriculture production technology and improved irrigation water management is essential.
- Crop having lower water footprint of production at a location is recommended for intensifying and crops which consume more water for its production can have high economic value of exporting or consumption; can be intensified providing blue water or irrigation.

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APPENDICES

Appendix-1: Sample Calculation

Output from CROPWAT 8- Considering Station 1206 and Potato Crop (year 2009)

1. Irrigation Schedule Option-Output-Medium Soil

a) Rainfed scenario (irr=0)

ET_{green} *(irr=0) =*ET_{tot} *(irr=0) =Eta*

ET_{blue} *(irr=0) = 0*

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	mm/day	%	mm	mm	mm	mm	l/s/ha
1-Dec	1	Init	0	1	0.8	1	0	0.8	0	0	0
3-Apr	124	End	4.4	1	2	40	0	69.8	0	0	0
4-Apr	125	End	4.4	1	1.6	39	0	67	0	0	0
5-Apr	126	End	0	1	2.3	40	0	69.4	0	0	0
6-Apr	127	End	0	1	2.2	41	0	71.6	0	0	0
7-Apr	128	End	0	1	2.7	43	0	74.3	0	0	0
8-Apr	129	End	0	1	2.5	44	0	76.7	0	0	0
9-Apr	End	End	0	1	2.3	44					
Sum over the crop period					**188.1**						

b) Irrigated scenario (irr=1)

ET_{green} *(irr=1) =* ET_{green} *(irr=0)*

ET_{blue} *(irr=1) =* ET_{tot} *(irr=1)-* ET_{green} *(irr=0)*

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	mm/day	%	mm	mm	mm	mm	l/s/ha
1-Dec	1	Init	0	1	0.8	1	0	0.8	0	0	0
2-Dec	2	Init	0	1	0.8	2	0	1.5	0	0	0
3-Dec	3	Init	0	1	0.7	2	0	2.3	0	0	0
5-Apr	126	End	0	1	2.3	2	0	4	0	0	0
6-Apr	127	End	0	1	2.2	4	0	6.2	0	0	0
7-Apr	128	End	0	1	2.7	5	0	8.9	0	0	0
8-Apr	129	End	0	1	2.5	7	0	11.4	0	0	0
9-Apr	End	End	0	1	2.3	7					
Sum over the crop period					**256.3**						

Eta=actual evapotranspiration in different scenario represents total evapotranspiration in respective scenario (i.e. ET_{tot}*)*

Appendix-2: Irrigation Schedule option -component ET_g and ET_b for potato production at station 1206

CROPWAT Option	Crop	ET_g (mm/period)	ET_b (mm/period)	ET (mm/period)	CWU_g (m^3/ha)	CWU_b (m^3/ha)	CWU (m^3/ha)
Medium	Potato	188.1	68.2	256.3	1881	682	2563

Here, ET_g = green water evapotranspiration, ET_b = blue water evapotranspiration, ET = total water evapotranspiration, CWU_g =green crop water use, CWU_b = blue crop water use, CWU = total crop water use.

Appendix-3: Water Footprint Estimation Procedure at Koshi River Basin (year 2009)

CROPWAT Option (Irrigation Schedule)-Soil (Medium)-Crop(Potato)

Representative Station	District Portion under Station polygon	Harvested area (ha)	Production (ton)	ET_g (mm/period)	ET_b (mm/period)	ET (mm/period)	CWU_g (m^3/ha)	CWU_b (m^3/ha)	CWU (m^3/ha)	Y* (ton/ha)	$WF_{prod,green}$ (m^3/ton)	$WF_{prod,green}$ (m^3/ton)	WF_{prod} (m^3/ton)
1206	Bhojpur	4	38	188.1	68.2	256.3	1881	682	2563	10.70	176	64	240
1301	Bhojpur	346	3699	197.4	67.4	264.8	1974	674	2648	10.70	184	63	247
1303	Bhojpur	985	10539	183.7	72.4	256.1	1837	724	2561	10.70	172	68	239
1304	Bhojpur	1549	16579	184.3	131.0	315.3	1843	1310	3153	10.70	172	122	295
1311	Bhojpur	116	1245	173.6	128.9	302.5	1736	1289	3025	10.70	162	120	283
	Bhojpur	**3000**	**32100**	**185.2**	**104.3**	**289.5**	**1852**	**1043**	**2894.8**	**10.70**	**173**	**97**	**271**
1303	Dhankuta	72	1190	183.7	72.4	256.1	1837	724	2561	16.50	111	44	155
1304	Dhankuta	773	12750	184.3	131.0	315.3	1843	1310	3153	16.50	112	79	191

1307	Dhankuta	909	14992	178.3	213.7	392	1783	2137	3920	16.50	108	130	238
1311	Dhankuta	269	4432	173.6	128.9	302.5	1736	1289	3025	16.50	105	78	183
1314	Dhankuta	3	49	177	82.0	259	1770	820	2590	16.50	107	50	157
	Dhankuta	**2025**	**33412**	**180.16**	**165.7**	**345.83**	**1801.57**	**1657**	**3458.2**	**16.50**	**109.19**	**100**	**209.6**
1027	Dolakha	16	176	181.1	78.8	259.9	1811	788	2599	10.78	168	73	241
1103	Dolakha	2486	26796	205.3	126.4	331.7	2053	1264	3317	10.78	190	117	308
1107	Dolakha	3	32	202.9	261.8	464.7	2029	2618	4647	10.78	188	243	431
	Dolakha	**2505**	**27004**	**205.14**	**126.3**	**331.39**	**2051.39**	**1263**	**3313.9**	**10.78**	**190.30**	**117**	**307.4**
1024	Kabhrepalanchok	3624	67051	200.8	175.1	375.9	2008	1751	3759	18.50	109	95	203
1027	Kabhrepalanchok	3047	56369	181.1	78.8	259.9	1811	788	2599	18.50	98	43	140
1107	Kabhrepalanchok	251	4647	202.9	261.8	464.7	2029	2618	4647	18.50	110	142	251
	Kabhrepalanchok	**6922**	**128066**	**192.21**	**135.9**	**328.06**	**1922.05**	**1359**	**3280.6**	**18.50**	**103.89**	**73**	**177.3**
1206	Khotang	3270	50607	188.1	68.2	256.3	1881	682	2563	15.47	122	44	166
1213	Khotang	1623	25108	167.2	123.8	291	1672	1238	2910	15.47	108	80	188
1301	Khotang	49	755	197.4	67.4	264.8	1974	674	2648	15.47	128	44	171
1303	Khotang	172	2654	183.7	72.4	256.1	1837	724	2561	15.47	119	47	166
1304	Khotang	618	9560	184.3	131.0	315.3	1843	1310	3153	15.47	119	85	204
1311	Khotang	69	1065	173.6	128.9	302.5	1736	1289	3025	15.47	112	83	195
	Khotang	**5800**	**89750**	**181.62**	**91.3**	**272.91**	**1816.24**	**913**	**2729.0**	**15.47**	**117.37**	**59**	**176.3**
1103	Okhaldhunga	219	2357	205.3	126.4	331.7	2053	1264	3317	10.75	191	118	308
1107	Okhaldhunga	42	456	202.9	261.8	464.7	2029	2618	4647	10.75	189	243	432
1206	Okhaldhunga	2643	28425	188.1	68.2	256.3	1881	682	2563	10.75	175	63	238

	Okhaldhunga	**2905**	**31238**	**189.61**	**75.4**	**265.03**	**1896.14**	**754**	**2650.3**	**10.75**	**176.33**	**70**	**246.4**
1307	Panchthar	119	1366	178.3	213.7	392	1783	2137	3920	11.44	156	187	343
1314	Panchthar	576	6587	177	82.0	259	1770	820	2590	11.44	155	72	226
1405	Panchthar	59	679	191.7	119.3	311	1917	1193	3110	11.44	168	104	272
1407	Panchthar	113	1289	163.7	163.0	326.7	1637	1630	3267	11.44	143	142	286
1419	Panchthar	1853	21196	196.9	198.3	395.2	1969	1983	3952	11.44	172	173	345
	Panchthar	**2720**	**31117**	**190.38**	**171.2**	**361.55**	**1903.82**	**1712**	**3615.5**	**11.44**	**166.42**	**150**	**316.0**
1027	Ramechhap	148	1422	181.1	78.8	259.9	1811	788	2599	9.63	188	82	270
1103	Ramechhap	1565	15065	205.3	126.4	331.7	2053	1264	3317	9.63	213	131	345
1107	Ramechhap	1325	12753	202.9	261.8	464.7	2029	2618	4647	9.63	211	272	483
1206	Ramechhap	2	19	188.1	68.2	256.3	1881	682	2563	9.63	195	71	266
	Ramechhap	**3040**	**29260**	**203.07**	**183.1**	**386.13**	**2030.66**	**1831**	**3861.2**	**9.63**	**210.98**	**190**	**401.1**
1301	Sankhuwasabha	2432	25084	197.4	67.4	264.8	1974	674	2648	10.31	191	65	257
1303	Sankhuwasabha	619	6383	183.7	72.4	256.1	1837	724	2561	10.31	178	70	248
1304	Sankhuwasabha	0	0	184.3	131.0	315.3	1843	1310	3153	10.31	179	127	306
1314	Sankhuwasabha	21	216	177	82.0	259	1770	820	2590	10.31	172	80	251
1405	Sankhuwasabha	3	29	191.7	119.3	311	1917	1193	3110	10.31	186	116	302
	Sankhuwasabha	**3075**	**31712**	**194.50**	**68.6**	**263.05**	**1944.98**	**686**	**2630.5**	**10.31**	**188.60**	**66**	**255.0**
1107	Sindhuli	287	2455	202.9	261.8	464.7	2029	2618	4647	8.56	237	306	543
1206	Sindhuli	102	876	188.1	68.2	256.3	1881	682	2563	8.56	220	80	299
1213	Sindhuli	2	16	167.2	123.8	291	1672	1238	2910	8.56	195	145	340
	Sindhuli	**391**	**3346**	**198.86**	**210.5**	**409.35**	**1988.58**	**2105**	**4093.4**	**8.56**	**232.34**	**246**	**478.2**

1001	Sindhupalchok	1061	12732	199.8	111.8	311.6	1998	1118	3116	12.00	167	93	260
1027	Sindhupalchok	3499	41989	181.1	78.8	259.9	1811	788	2599	12.00	151	66	217
1103	Sindhupalchok	340	4079	205.3	126.4	331.7	2053	1264	3317	12.00	171	105	276
	Sindhupalchok	**4900**	**58800**	**186.83**	**89.2**	**276.08**	**1868.28**	**892**	**2760.7**	**12.00**	**155.69**	**74**	**230.0**
1103	Solukhumbu	3560	52549	205.3	126.4	331.7	2053	1264	3317	14.76	139	86	225
1206	Solukhumbu	3491	51530	188.1	68.2	256.3	1881	682	2563	14.76	127	46	174
1301	Solukhumbu	3090	45602	197.4	67.4	264.8	1974	674	2648	14.76	134	46	179
	Solukhumbu	**10141**	**149681**	**196.97**	**88.4**	**285.36**	**1969.72**	**884**	**2853.6**	**14.76**	**133.45**	**60**	**193.3**
1311	Sunsari	82	1220	173.6	128.9	302.5	1736	1289	3025	14.79	117	87	205
	Sunsari	**82**	**1220**	**173.60**	**128.9**	**302.50**	**1736.00**	**1289**	**3025.0**	**14.79**	**117.38**	**87**	**204.5**
1301	Taplejung	160	1839	197.4	67.4	264.8	1974	674	2648	11.46	172	59	231
1303	Taplejung	24	270	183.7	72.4	256.1	1837	724	2561	11.46	160	63	223
1405	Taplejung	3371	38631	191.7	119.3	311	1917	1193	3110	11.46	167	104	271
1419	Taplejung	60	686	196.9	198.3	395.2	1969	1983	3952	11.46	172	173	345
	Taplejung	**3615**	**41426**	**191.99**	**118.0**	**309.99**	**1919.87**	**1180**	**3099.8**	**11.46**	**167.54**	**103**	**270.5**
1304	Terhathum	19	190	184.3	131.0	315.3	1843	1310	3153	10.04	184	130	314
1307	Terhathum	214	2150	178.3	213.7	392	1783	2137	3920	10.04	178	213	390
1314	Terhathum	1849	18565	177	82.0	259	1770	820	2590	10.04	176	82	258
1405	Terhathum	259	2602	191.7	119.3	311	1917	1193	3110	10.04	191	119	310
1419	Terhathum	379	3802	196.9	198.3	395.2	1969	1983	3952	10.04	196	198	394
	Terhathum	**2720**	**27309**	**181.32**	**112.5**	**293.78**	**1813.24**	**1125**	**2937.8**	**10.04**	**180.60**	**112**	**292.6**
1206	Udayapur	19	185	188.1	68.2	256.3	1881	682	2563	9.93	189	69	258

1213	Udayapur	169	1674	167.2	123.8	291	1672	1238	2910	9.93	168	125	293
1311	Udayapur	33	329	173.6	128.9	302.5	1736	1289	3025	9.93	175	130	305
	Udayapur	**220**	**2188**	**170**	**120**	**290**	**1699**	**1199**	**2898**	**10**	**171**	**121**	**292**
		54062	**717630**										

Here, ET_g *= green water evapotranspiration,* ET_b *= blue water evapotranspiration, ET = total water evapotranspiration,* CWU_g *=green crop water use,* CWU_b *= blue crop water use, CWU = total crop water use, Y* = yield of the crop,* $\mathrm{WF}_{prod,green}$ *= green water footprint of a crop production,* $\mathrm{WF}_{prod,blue}$ *= blue water footprint of a crop production and* WF_{prod} *= total water footprint of a crop production.*

Appendix -4: $WF_{prod,blue}$ (m^3/ton) and $WF_{prod,blue}$ (m^3/ton) for Potato in districts and KRB (year 2009)

Districts	Harvested area (ha)	Production (ton)	ET_g (mm/period)	ET_b (mm/period)	ET (mm/period)	CWU_g (m^3/ha)	CWU_b (m^3/ha)	CWU (m^3/ha)	Y* (ton/ha)	$WF_{prod,green}$ (m^3/ton)	$WF_{prod,blue}$ (m^3/ton)	WF_{prod} (m^3/ton)
BHOJPUR	3000	32100	185.2	104.3	289	1852	1043	2895	11	173	97	271
DHANKUTA	2025	33412	180.2	165.7	346	1802	1657	3458	16	109	100	210
DOLAKHA	2505	27004	205.1	126.3	331	2051	1263	3314	11	190	117	307
KABHREPALANCHOK	6922	128066	192.2	135.9	328	1922	1359	3281	19	104	73	177
KHOTANG	5800	89750	181.6	91.3	273	1816	913	2729	15	117	59	176
OKHALDHUNGA	2905	31238	189.6	75.4	265	1896	754	2650	11	176	70	246
PANCHTHAR	2720	31117	190.4	171.2	362	1904	1712	3616	11	166	150	316
RAMECHHAP	3040	29260	203.1	183.1	386	2031	1831	3861	10	211	190	401
SANKHUWASABHA	3075	31712	194.5	68.6	263	1945	686	2631	10	189	66	255
SINDHULI	391	3346	198.9	210.5	409	1989	2105	4093	9	232	246	478
SINDHUPALCHOK	4900	58800	186.8	89.2	276	1868	892	2761	12	156	74	230
SOLUKHUMBU	10141	149681	197.0	88.4	285	1970	884	2854	15	133	60	193
SUNSARI	82	1220	173.6	128.9	303	1736	1289	3025	15	117	87	205
TAPLEJUNG	3615	41426	192.0	118.0	310	1920	1180	3100	11	168	103	271
TERHATHUM	2720	27309	181.3	112.5	294	1813	1125	2938	10	181	112	293
UDAYAPUR	220	2188	169.9	119.9	290	1699	1199	2898	10	171	121	292
KOSHI RIVER BASIN	**54062**	**717630**	**191**	**112**	**303**	**1911**	**1123**	**3034**	**13**	**151**	**89**	**240**

Appendix -5: **Water footprint of potato production (Mm^3/year) in districts and KRB in the year 2009**

Districts within Koshi River Basin	**Harvested Area (ha)**	**Production (ton/year)**	**Y* (ton/ha)**	$WF_{prod,green}$ **(Mm^3/year)**	$WF_{prod,blue}$ **(Mm^3/year)**	WF_{prod} **(Mm^3/year)**
BHOJPUR	3000	32100	10.70	6	3	9
DHANKUTA	2025	33412	16.50	4	3	7
DOLAKHA	2505	27004	10.78	5	3	8
KABHREPALANCHOK	6922	128066	18.50	13	9	23
KHOTANG	5800	89750	15.47	11	5	16
OKHALDHUNGA	2905	31238	10.75	6	2	8
PANCHTHAR	2720	31117	11.44	5	5	10
RAMECHHAP	3040	29260	9.63	6	6	12
SANKHUWASABHA	3075	31712	10.31	6	2	8
SINDHULI	391	3346	8.56	1	1	2
SINDHUPALCHOK	4900	58800	12.00	9	4	14
SOLUKHUMBU	10141	149681	14.76	20	9	29
SUNSARI	82	1220	14.79	0	0	0
TAPLEJUNG	3615	41426	11.46	7	4	11
TERHATHUM	2720	27309	10.04	5	3	8
UDAYAPUR	220	2188	9.93	0	0	1
KOSHI RIVER BASIN	**54062**	**717630**	**13**	**103**	**61**	**164**

Appendix-6: Water footprint estimation of potato production in KRB during 2005-2014

year	Harvested area (ha,000)	Production (ton,000)	ET_g (mm/period)	ET_b (mm/period)	ET (mm/period)	Y* (ton/ha)	$WF_{prod,green}$ (m^3/ton)	$WF_{prod,blue}$ (m^3/ton)	WF_{prod} (m^3/ton)
2005	37151	452559	213.71	28.51	242.22	12.18	180.20	24.21	204.41
2006	37388	456979	191.02	65.09	256.10	12.22	159.78	54.37	214.15
2007	38488	448282	194.30	33.58	227.88	11.65	173.16	30.12	203.28
2008	50539	629278	192.85	34.56	227.41	12.45	159.67	29.24	188.91
2009	54062	717630	191.11	112.31	303.43	13.27	150.84	89.00	239.83
2010	54078	721347	184.94	72.90	257.84	13.34	144.89	56.91	201.80
2011	57065	757757	195.80	55.29	251.09	13.28	152.40	43.54	195.94
2012	55816	706398	183.62	63.63	247.25	12.66	151.56	53.80	205.36
2013	55816	706398	212.38	39.95	252.33	12.66	175.80	33.69	209.49
2014	53441	669146	192.24	54.36	246.60	12.52	159.68	46.89	206.56
Avg. 10 years	**49384**	**626577**	**195.20**	**56.02**	**251.22**	**12.62**	**160.80**	**46.18**	**206.98**
SD	8271.28	124667.20	10.15	24.89	21.14	0.55	11.86	19.05	13.48
CV	**16.75**	**19.90**	**5.20**	**44.43**	**8.42**	**4.35**	**7.38**	**41.25**	**6.51**

Appendix -7: Effective rain during growing period of potato crop (2005-2014)

Crop period	Eff rain (mm/dec) during Potato production									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Dec	0	0	0	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	0	1.6	8.1
Dec	0	0	0	9.4	0	6.3	0	0	0	0
Jan	0	0	0	0	0	0	0	37.4	0	0
Jan	16.9	0	0	5.1	0	0	0.9	5.5	0	0
Jan	21.2	0	0	6.6	0	0	0	0	0	0
Feb	7.9	0	21.5	0	0	28	0	40.1	25.2	0
Feb	1.2	2.2	41.4	0	0	0	43.5	0	31.5	31.9
Feb	0	0	11.5	0	7	0.7	0	0	0	0
Mar	2.1	3.2	10.4	7.9	8.6	0	0.5	0	7.5	19.7
Mar	47.5	42.7	20.1	11.8	7.9	0.7	2.3	0.2	7.6	15.6
Mar	11.3	0	4.9	1.7	38.9	18.4	5.6	32.6	10.4	16.6
Apr	9	18.6	7.8	20.1	27.7	0	0	0	0	0.5
Sum	**117.1**	**66.7**	**117.6**	**62.6**	**90.1**	**54.1**	**52.8**	**115.8**	**83.8**	**92.4**

Appendix - 8: Effective rain (mm/dec) in KRB during 2005-2014

Crop period	Eff rain (mm/dec)									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Dec	0.00	0.00	2.21	0.34	0.00	0.00	0.31	1.37	0.00	0.00
Dec	0.00	9.90	0.02	0.72	0.00	0.00	0.00	2.94	4.95	11.42
Dec	1.93	0.45	1.30	6.32	5.91	0.14	0.00	0.00	0.97	0.00
Jan	4.03	0.16	0.02	0.01	0.03	0.03	4.04	7.87	1.22	0.00
Jan	6.75	0.30	0.02	3.67	0.00	1.18	3.81	1.80	6.13	1.26
Jan	23.45	0.12	0.00	6.94	0.68	0.03	1.29	0.86	0.00	0.00
Feb	6.68	0.57	24.64	2.10	0.43	12.64	1.38	11.81	2.15	0.87
Feb	0.84	1.75	40.40	3.07	2.18	2.20	24.23	3.44	31.03	12.64
Feb	2.30	1.87	18.32	1.79	1.95	3.72	1.98	1.66	6.24	2.96
Mar	4.32	0.59	15.82	16.69	0.82	5.87	1.46	1.44	16.35	8.38
Mar	27.54	28.74	5.70	12.88	3.83	4.01	1.80	1.55	14.25	10.73
Mar	20.41	4.05	12.01	20.79	33.91	21.85	12.58	2.63	14.89	24.69
Apr	14.57	32.17	25.80	29.92	39.43	3.07	23.61	45.94	5.46	11.13
Apr	5.68	42.03	23.79	25.41	34.87	31.18	33.55	15.68	38.19	9.00
Apr	39.53	24.86	34.72	23.89	16.00	28.05	27.47	12.77	36.58	14.01

May	44.10	35.51	34.55	37.87	28.70	39.48	36.72	29.39	14.16	41.28
May	26.67	44.14	39.70	40.31	42.26	25.90	47.89	25.23	27.43	12.78
May	27.53	50.52	34.07	35.53	52.62	45.44	43.34	46.52	48.30	49.11
Jun	30.17	58.67	49.32	56.48	38.56	32.91	37.97	38.13	56.37	39.78
Jun	53.30	36.77	62.31	55.61	28.77	42.74	51.47	44.23	47.08	49.37
Jun	57.04	58.52	54.60	61.00	52.07	51.67	57.96	58.67	56.05	58.65
Jul	56.59	52.17	48.03	55.62	60.13	54.87	51.15	51.43	61.14	41.98
Jul	58.13	58.96	59.48	58.65	45.73	60.55	59.95	61.48	50.30	64.00
Jul	55.33	54.43	64.01	57.12	59.76	62.30	57.34	54.88	57.54	56.93
Aug	57.93	57.70	45.33	60.61	50.05	54.03	56.52	56.52	57.51	54.27
Aug	61.42	49.50	57.01	59.91	62.59	58.86	56.37	52.87	55.69	59.82
Aug	56.22	57.72	56.03	63.54	56.09	60.79	57.92	59.43	49.90	55.43
Sep	51.16	47.98	66.22	48.59	45.13	61.45	48.91	50.51	56.14	51.03
Sep	28.22	54.12	49.81	46.61	26.97	58.08	47.94	58.22	38.83	52.47
Sep	37.81	52.77	42.12	43.97	30.66	39.02	54.83	29.31	35.07	41.85
Oct	42.72	25.17	29.72	38.90	40.25	15.54	19.54	14.49	22.46	8.47
Oct	8.59	20.52	31.80	4.86	7.86	35.34	2.97	9.60	48.56	33.68
Oct	24.61	11.95	9.35	9.36	0.00	10.60	11.94	7.38	16.63	6.45
Nov	0.24	3.64	9.84	6.98	0.00	1.38	14.80	6.27	4.12	0.00
Nov	0.99	7.83	5.10	1.87	1.70	12.14	7.93	9.97	0.00	0.00
Nov	0.78	2.08	0.91	1.18	0.00	0.61	0.13	0.00	0.00	0.00
Sum	**937.57**	**988.21**	**1054.08**	**999.12**	**869.93**	**937.70**	**961.09**	**876.30**	**981.69**	**884.47**

Appendix - 9: Climate during the growth period of potato during 2005-2014

Year	Harvested area (ha,000)	Avg. Temp(°C)	Humidity (%)	Wind (m/sec)	Sun (hours)	Rad(MJ/m²/day)	ET_O (mm/day)
2005	37151	14.45	73.78	2.58	7.15	15.93	2.32
2006	37388	15.15	73.62	2.79	7.55	16.40	2.39
2007	38488	13.71	78.76	2.59	6.85	15.55	2.26
2008	50539	13.96	65.97	3.29	7.21	16.08	2.21
2009	54062	15.31	73.42	2.12	7.37	16.23	2.73
2010	54078	15.22	72.99	2.65	7.67	16.59	2.43
2011	57065	14.02	74.73	2.31	7.49	16.37	2.35
2012	55816	14.28	72.54	2.91	7.49	16.39	2.35
2013	55816	14.39	71.49	2.78	7.43	16.26	2.33
2014	53441	15.01	73.98	2.55	7.39	16.24	2.38
Avg. 10 years	**49384**	**14.55**	**73.13**	**2.66**	**7.36**	**16.20**	**2.37**
SD	8271.28	0.58	3.16	0.32	0.24	0.29	0.14
CV	16.75	3.99	4.32	12.09	3.22	1.81	5.85