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Assessment of water footprint at regional level: A case study of Prayagraj, Uttar Pradesh, India

Vipin Mishra, DM Denis, SK Srivastava and Himanshu Mishra

Abstract
The aim of this study to quantify the water footprint (WFP) of crop production, animal's products and human population for district Prayagraj U.P, India. Assessment of water used in agricultural for food production is essential to scrutinize the dynamic behaviour of crop production and its water footprint. Water consumption and crop productivity form the basis to calculate the water footprint of a specific crop. Water footprint is essential for the quantified total water consumption of crop production. In the present study Water footprint assessment for selected nine crops namely, Wheat, Paddy, Barley, Jowar, Sugarcane, Potato, Bajra, Oilseed and Pulses have been carried out. The research based on assesses water use in these selected crops grown in the study area. Water footprint of paddy production is maximum (5952.38 m^3/ton) followed by Oilseed (5142.86 m^3/ton), Pulses (4629.63 m^3/ton), Jowar (4591.84 m^3/ton), Bajra (4591.84 m^3/ton), Barley (3214.29 m^3/ton), Wheat (2826.09 m^3/ton), Sugarcane (478.26 m^3/ton) while minimum in Potato (343.14 m^3/ton). In this paper the calculation of water footprint for different types of animal products. The following animal categories *viz.* Cow, Buffalo, Goat, Sheep, Pig and Poultry were also considered. Water footprint of milk production of Cow is maximum (5628 lit/kg) followed by Buffalo (5212.50 lit/kg) while minimum is for Goat (1303 lit/kg). Water footprint for pig meat, goat and sheep meat (mutton) and other meats indicate the large volume of water used for their production. Water footprint of meat from Goat is 13402.29 lit/kg, Sheep 16018.67 lit/kg, Pig 15876 lit/kgand for Chicken 4498.67 lit/kg while water footprint of Egg is 192.80 lit/egg. Water footprint of human is 48.82 m^3/capita/year and it includes water used by the people for their life activities as drinking, servicing, bathing and washing our clothes. On an average, water used per capita is 133.75 lit/day in district Prayagraj. Total water footprint of district Prayagraj is 16565.39 m^3/capita/year sharing 3281.22 m^3/ton of agriculture, 13235.35 m^3/animal/year of animals and 48.81 m^3/human/year of human.

Keywords: Water use, quantify, water footprint, production, Prayagraj

Introduction

Water is a dynamic natural resource that is essential for human, plant and animals for their survival as it required for many needs such as drinking, domestic usage, irrigation, power generation, transportation, Industrial cooling, fishing, mining and fire fighting etc. The total amount of water on the earth is approximately 1.35 billion cubic kilometres out of which about 97.1% has been locked into oceans as saltwater. Ice sheets and glaciers have arrested 2.1%. Only 0.2% is the fresh water present on the earth, which can be used by human for their daily needs, remaining 0.6%, is in underground form. India currently has the world's second largest population with over 1.2 billion people (India Census, 2011). The estimate of the amount of people living in India in the year 2050 is 1.6 billion (United Nations, 2004) and is an increase in population of approximately 50% in the next fifty years. Next to this population growth the total Gross Domestic Product (GDP) per capita in India is also growing rapidly (7.1% in 2005 (World Bank, 2006)). Furthermore, there currently is a net export of agricultural products from India, which has shown an increase in the past decade (FAO, 2006a), which is likely to persist. These developments will lead to a large growth in the total food demand in India in the near future with a proportionate increase in water footprint. Agriculture water uses estimated that 70% of worldwide water is used for irrigation, with 15.35% of irrigation withdrawals being unsustainable. It takes around 2,500 - 3,000 litters of water to produce enough food to satisfy one person's daily dietary need. To produce food for the now over 7 billion people who inhabit the planet today requires the water that would fill a canal ten meters deep, 100 meters wide and 2100 kilometres long. Household estimated that 8% of worldwide water use is for household purposes. Drinking water is water that is of sufficiently high quality so that it can be consumed or used without risk of immediate or long term harm.

The water footprint is defined as the volume of water needed for the production of the goods and services consumed by the inhabitants of a country. This concept is developed in analogy to the concept of the ecological footprint (Wackernagel & Rees, 1996). Water is also required to produce nearly everything we use and consume, from the food we eat and the clothes we wear to the technological devices that are integral to our modern society. Agriculture is by far the largest global consumer of freshwater. In this sector, a water footprint measures the volume of evapotranspiration or water use of a crop per unit mass of yield. Comparing water footprints of different management practices in agriculture can help evaluate drought tolerance, water use efficiency, the effective use of rainfall, and the significance of irrigation. Many of the risks agriculture faces from climate change are the result of precipitation changes, which makes the water footprint a useful measure to compare resilience of agricultural systems to droughts and dry spells. The water footprint is often reported as three components: green water, blue water, and grey water. Green water is the amount of precipitation and soil moisture that is directly consumed in an activity, such as in growing crops. Blue water is the amount of surface or groundwater that is applied and consumed in an activity, such as in growing crops or manufacturing an industrial good. Grey water is the amount of water needed to assimilate pollutants from a production process back into water bodies at levels that meet governing standards, regardless of whether those standards are actually met (Hoekstra *et al*. 2011). Green water is the rain water temporarily stored in the unsaturated soil, on the soil or on the vegetation. Green water is either productively used for plant transpiration or unproductively evaporated from the soil or from vegetation canopies (Savenije, 2000; Falkenmark and Rockström, 2004). Blue water refers to water in rivers, lakes, wetlands and aquifers, which can be withdrawn for irrigation and other purposes. Green water has generally been given little attention and only just recently green water has been recognized as an important resource that is beneficial for society. Globally, about 60% of all food is produced from rain-fed agriculture, and hence from green water (Cosgrove and Rijsberman, 2000b; Savenije, 2000). Since most of the utilizable water supply in India is used for crop production (Hoekstra & chapagain, 2007), an important criterion for the evaluation of a possible food supply strategn is the pressure on renewable water resources. At the moment there are regions in India that are determined as water scarce, as the water availability per is capita is less than 1000 m^3/yr which is either cased by the lack of natural water resources or a result of over exploitation of ground water resources for irrigation purposes (CGWB, 1989; Bobba *et al*., 1997).

Materials and Methods

Study area characteristics

Prayagraj is located in the southern part of the state, at 25.45°N 81.84°E, and stands at the confluence of the Ganga and Yamuna rivers. Geographical area of Prayagraj is 5482 Sq. Km. the region was known in antiquity as the Vats (initially Kuru) country. Prayagraj stands at a strategic point both geographically and culturally. A part of the Ganga-Yamuna Doab, it is the last point of the Yamuna River, and culturally, the last point of the Indian west. As with the rest of Doab, the soil and water are predominantly alluvial in origin.

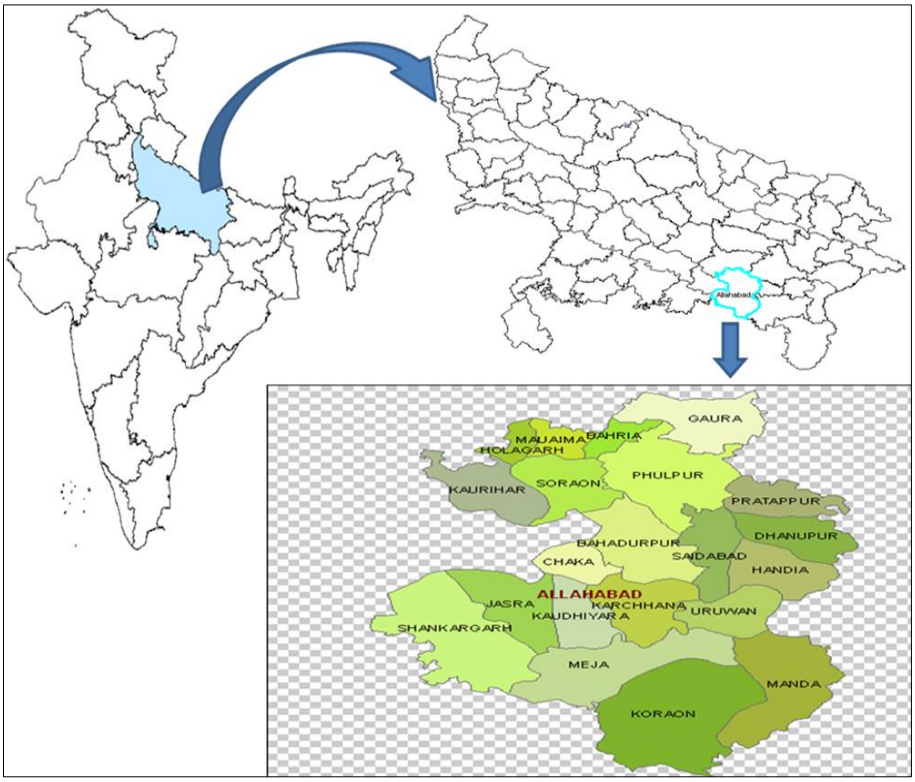


Fig 1: The study area in relation to its orientation in U.P. State and India

Water footprint

The water footprint is defined as the volume of water needed for the production of the goods and services consumed by the inhabitants of a country. This concept is developed in analogy to the concept of the ecological footprint (Wackernagel & Rees, 1996). The water footprint can be divided into an internal and an external water footprint. The internal component covers the use of domestic water resources and the external component covers the use of water resources elsewhere.

Component of the water footprint

The water footprint has three components: Green water footprint, Blue water footprint and Grey water footprint.

A) **Green water footprint:** Green water footprint is water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plant. It is particularly relevant for agricultural, horticultural and forestry products.

B) **Blue water footprint:** Blue water footprint is water that has been sourced from surface or groundwater resources and is either evaporated, incorporated into a product or taken from one body of water and returned at a different time. Irrigated agriculture, industry and domestic water use can each have a blue water footprint.

C) **Grey water footprint:** Grey water footprint is the amount of fresh water required to assimilate pollutants to meet specific water quality standards. The grey water footprint considers point–source pollution discharged to a freshwater resource directly through a pipe or indirectly through runoff or leaching from the soil, impervious surface.

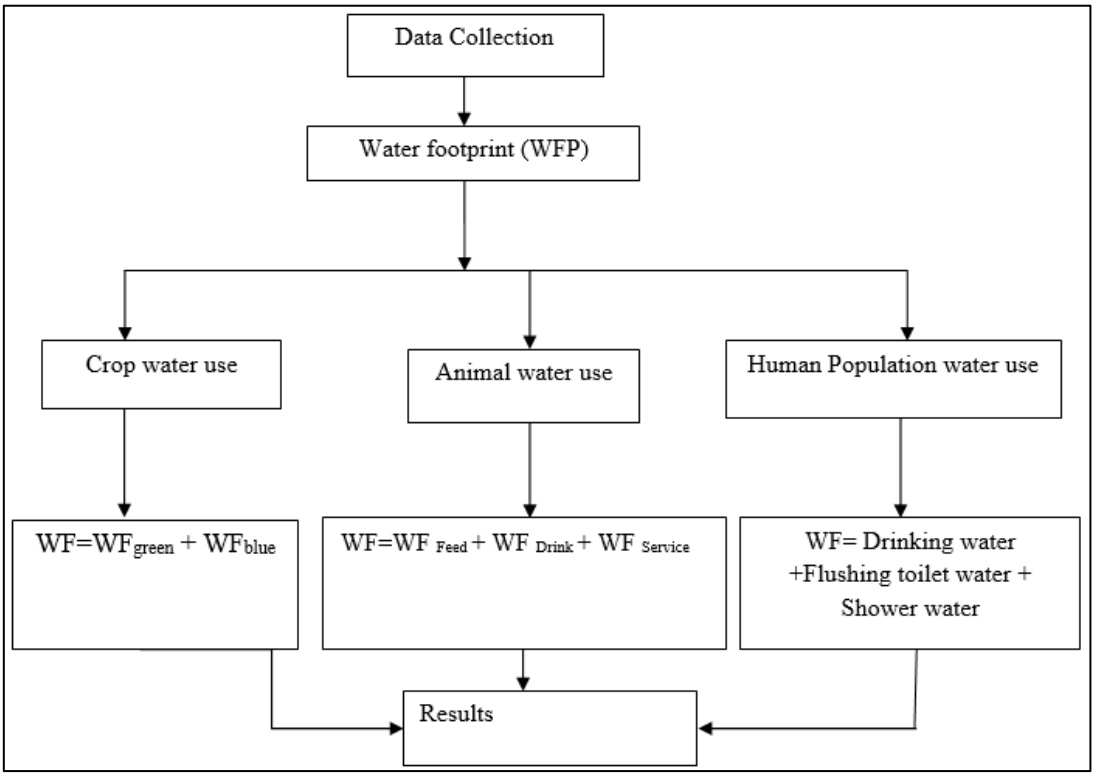


Fig 2: Flow chart of methodology for water footprint

Crop water requirement

The calculation of the water content of a crop starts with the calculation of the volume of water that is required for the crop growth. Crop water requirement (CWR, m^3/ha) is defined as the volume of water that is required to compensate the water loss of a crop through evapotranspiration under growth conditions with no constraint by water shortage (Allen *et al*., 1998). The CWR is calculated by accumulating the data on the crop evapotranspiration under optimal conditions ($ET_{c,\ opt}$, mm/day) over the complete growing period.

$$CWR[c,s] = 10 * \sum_{t=0}^{lp} \mathrm{ETc, opt, [c, s, t]}$$

Where,

CWR = Crop water requirement (m^3/ha)

$ET_{c,\ opt}$ = crop evapotranspiration under optimal conditions (mm/day)

Independent variable c denotes crop, s state, t time steps of 10 days. The factor 10 is included to convert mm into m^3/ha and the summation is done in time steps of 10 days over the full growing period (lp). It is worth noticing that in this calculation each month is taken to be equal to 3 time steps of 10 days, which means that all months are assumed to consist of exactly 30 days.

The ET_c, opt is calculated as follows:

$ET_{c,opt}[c,s]=K_c[c]*ET_o[s]$

Where,

Kc = Crop coefficient

ET_o = Reference evapotranspiration (mm/day).

ET_o is defined as the evapotranspiration rate from a

Hypothetical grass reference crop with specific characteristics, which has an abundance of water. Soil factors cannot form a constraint for the ET_o rate. This means that ET_o only expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider a difference in crop characteristics and soil factors. Therefore ET_o is computed with climatic data. K_c determines how $ET_{c,opt}$ from a certain crop field relates to ET_o from the reference surface. The major factors that determine K_c are crop variety, climate and crop growth stage. Crop growing period is divided into four growth stages: the initial stage, the crop development stage, the mid-season stage and the late season stage (Allen *et al*, 1998). The initial stage is the period

from the planting date to approximately 10% ground cover. The crop development stage is the period from 10% ground cover to effective full cover.

Green crop water use

Green crop water use is the volume of the total rainfall that is actually used for evapotranspiration by the crop fieldand is calculated by accumulating the data on evapotranspiration under rain fed conditions over the complete growing period.

$$CWU_{green}[c,s] = 10 * \sum_{t=1}^{lp} ETc, rw[c,s,t]$$

Where,

CWU_{green} =green crop water use (m^3/ha)

$ET_{c,rw}$= Crop evapotranspiration under rain fed conditions (mm/day)

Blue crop water use

Blue crop water use is the volume of irrigation water that is actually supplied to the crop field and is calculated by accumulating the data on the actual crop evapotranspiration of irrigation water over the complete growing period.

$$CWUblue[c,s] = 10 * \sum_{t=1}^{lp} ETc, iw[c,s,t]$$

Where,

CWU_{blue}= Blue crop water use (m^3/ha)

ETc,iw = Crop evapotranspiration of irrigation water (mm/day)

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

Animal's water use

Water requirement of livestock varies significantly among animal species. The animal's size and growth stage will have a strong influence on daily water intake. Providing enough quality water is essential for good livestock husbandry. Livestock water use is water associated with livestock watering, feedlots, dairy operations, and other on-farm needs. Livestock includes dairy cows and heifers, beef cattle and calves, sheep and lambs, goats, hogs and pigs, horses, and poultry. Other livestock water uses include cooling of facilities for the animals and animal products such as milk, dairy sanitation and wash down of facilities, animal waste-disposal systems, and incidental water losses (Chapagain and Hoekstra 2003, 2004).

The water footprint of an animal is expressed as:

$$WF\ (acs) = WF_{feed}\ (acs) + WF_{drink}(acs) + WF_{service}(acs)$$

Where,

WF_{feed}[a, c, s] = Feed water consumption

WF_{drink}[a,c,s] = Drinking water consumption

WF_{serv}[a,c,s] = Service water consumption

Represent the water footprint of an animal for animal category a in country c in production systems s.

The water footprint of an animal related to thefeed consumed consists of two parts: the waterfootprint of the various feed ingredients and thewater that is used to mix the feed:

$$WF_{feed}\ (acs) = \frac{\sum_{p=1}^{n}(feed[a,c,s,p] \times WFprod[p] + WFmixing\ [a,c,s]}{Pop\ [a,c,s]}$$

Where,

Feed [a,c,s,p] = Annual amount of feed ingredient p consumed by animal category a in country c and production system s (ton/y).

WF prod [p] = Water footprint of feed ingredient p (m^3/ton).

WF mixing [a,c,s] = Volume of water consumed for mixing the feed for animal category a in country c and production system s (m^3/y/animal).

Pop [a,c,s] = Number of animals per year or the number of milk or egg producing animals in a year for animal category a in country c and production system s.

$$WF_{prod}[P] = \frac{P[p] \times WFprod[p] + \sum_{ne}(Ti[ne,p] \times WFprod\ [ne,p])}{P[p] + \sum_{ne} Ti[ne,p]}$$

Where,

P[p] = Production quantity of feed product p in a country (ton/y).

Ti[ne,p] = Imported quantity of feed product p from exporting nation ne (ton/y).

WFprod[p] = Water footprint of feed product p when produced in the nation considered (m^3/ton).

WFprod[ne,p] = Water footprint of feed product p as in the exporting nation ne (m^3/ton).

Human population (domestic) water use

Domestic water requirement is based on different living standard, in urban areas requirement of water is more from the rural areas such as gardening, swimming pool, water sprinkling on lawn areas etc. but in rural areas lack of these kinds of the activity. Household estimated that 8% of worldwide water use is for household purposes. Domestic water use is water used for indoor and outdoor household purposes such as drinking, preparing food, bathing, washing clothes and dishes, brushing teeth, watering the yard and garden, and even washing the dog.

$$WF_{(human)} = WF_{(drinking)} + WF_{(civil)} + WF_{(bathing/clothing)}$$

Where,

$WF_{(human)}$ = Water footprint of human population

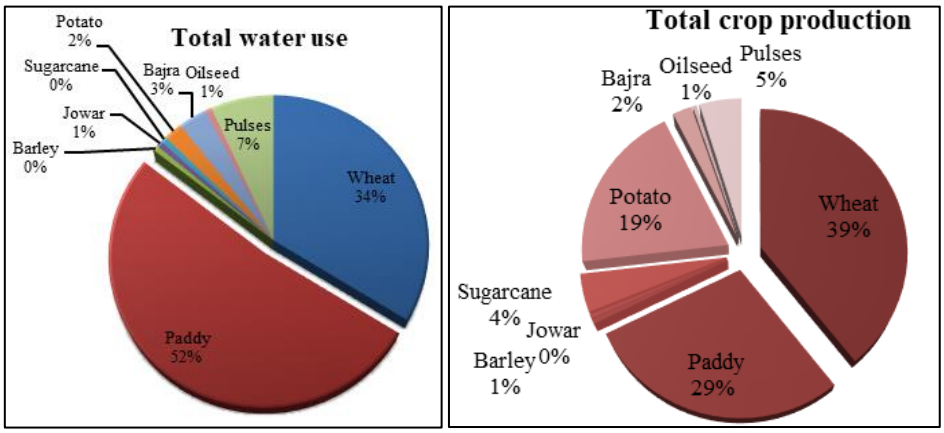
$WF_{(drinking)}$= Drinking water consumption

$WF_{(civil)}$= Civil water consumption

$WF_{(bathing/clothing)}$ = Bathing and clothing water consumption

Results and Discussion

Water requirement of the crops depend mainly on the nature and stage of growth of the crop and environmental conditions. Different crops have different water-use requirements under the same weather conditions. The WF of milk and meat is determined by the water consumption in each process step within the supply chain of the final product. From the perspective of water consumption the most important processes are growing the feed, drinking by the animals and water use on the livestock farm and at the slaughter house for cleaning. In the supply chain of an animal product there are many more processes than growing feed, drinking by the animal and cleaning the farm with water.



(**Source:** Comprehensive-District agriculture plan Prayagraj)

Fig 3: Total water use and total crop production

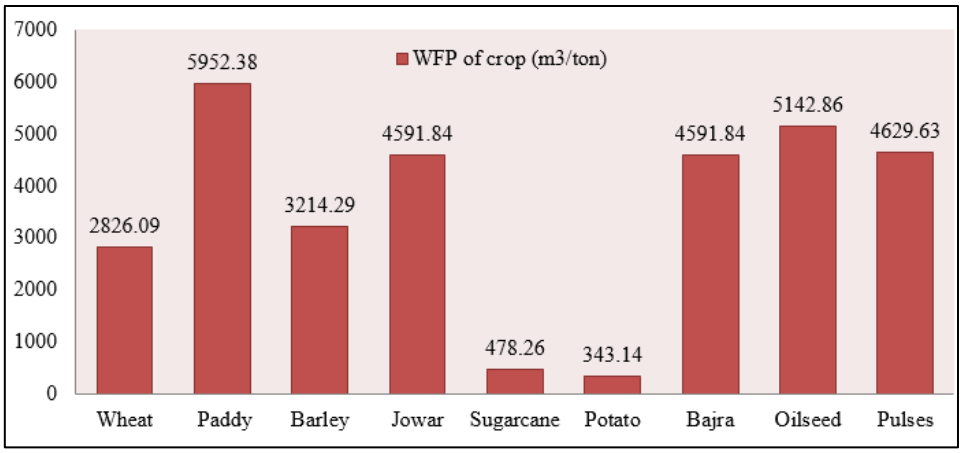
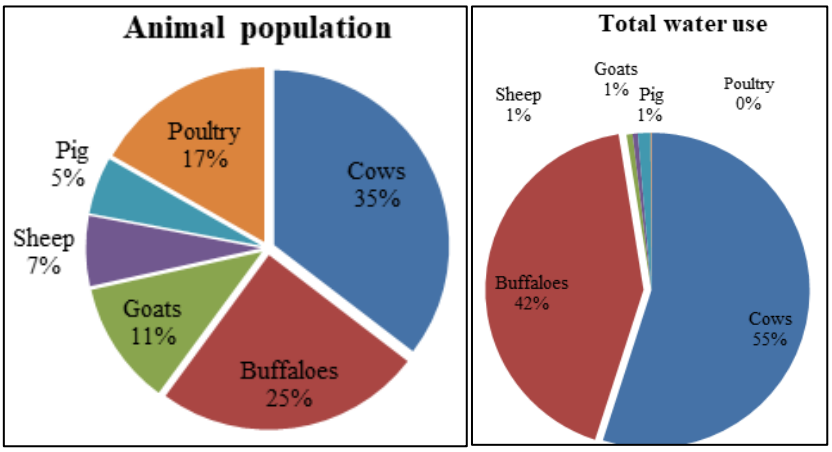


Fig 4: Water footprint of different crop in district Prayagraj

Data presented in figure 3 shows that the total cropped area is 491222.08 hectare and total water use in the district for all crops is 403.65 million cubic meters and the total crop production is 1.23 million tons. Data presented in figure 4 shows that maximum water footprint 5952.38 m^3/ton is of Paddy followed by oilseed 5142.86 m^3/ton, pulses 4629.62 m^3/ton, Jowar and Bajra 4591.85m^3/ton, Barley 3214.29m^3/ton, Wheat 2826.09m^3/ton, Sugarcane 478.26m^3/ton while minimum of Potato crop 343.14m^3/ton. Total water footprint of crops is 3281.22 m^3/ton in district Prayagraj. The variation in water footprint for different crops is mainly due to variation in water used and cropped area.



(**Source:** Comprehensive-District agriculture plan Prayagraj)

Fig 5: Animal population and total water use

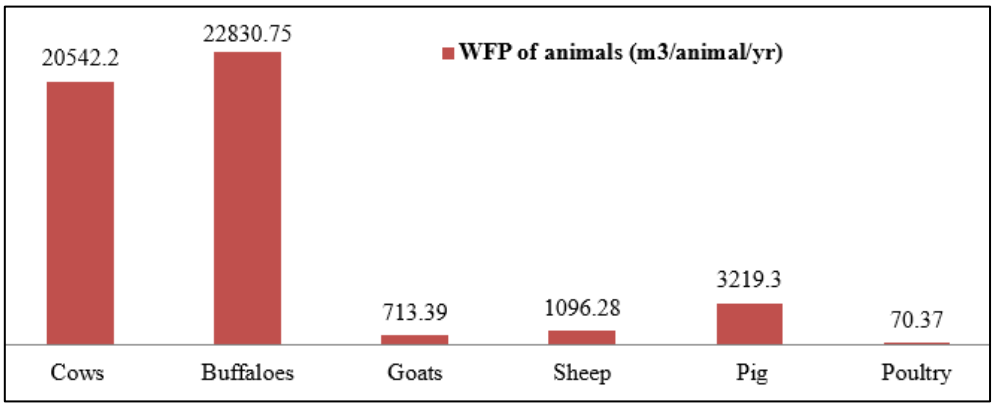


Fig 6: Water footprint of animals in district Prayagraj

Data presented in Figure 5 shows that total animal population is 1.79 million and total water use 23729.21 million cubic meters per year in the district. Data presented in Figure 6 shows that water footprint of Buffaloes is 22830.75 m^3/animal/yr followed by Cow 20542.20 m^3/animal/yr, Pig 3219.30 m^3/animal/yr while minimum Water footprint of Poultry 70.37 m^3/poultry/yr. Total water footprint of district Prayagraj for animals is 13235.35 m^3/animal/yr. The variation in water use is mainly due to variation in their population.

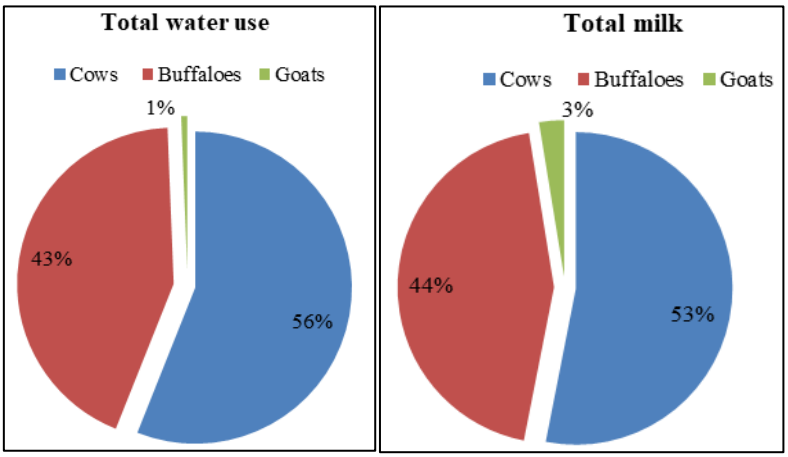


Fig 7: total water use and tatal milk production

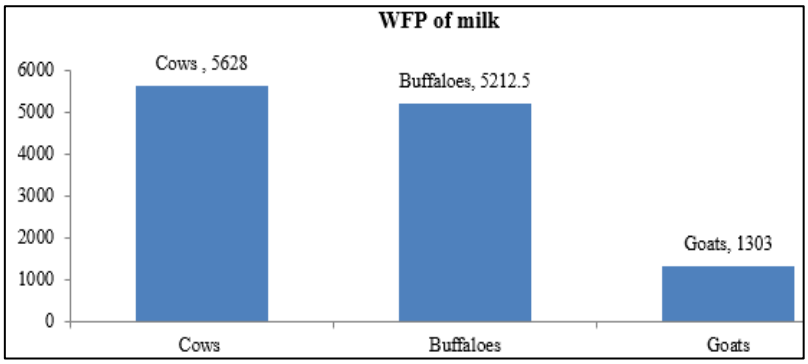


Fig 8: Water footprint of milk Products in district Prayagraj

Data presented in figure 7 shows that total water used for milk production is 23729.21 million cubic meters per year and milk production is 4365091.39 ton per year in the district. Data presented in figure 8 shows that water footprint of milk product for Cow is 5628 lit/kg followed by Buffalo5212.50 lit/kg while minimum for Goat milk 1303 lit/kg.

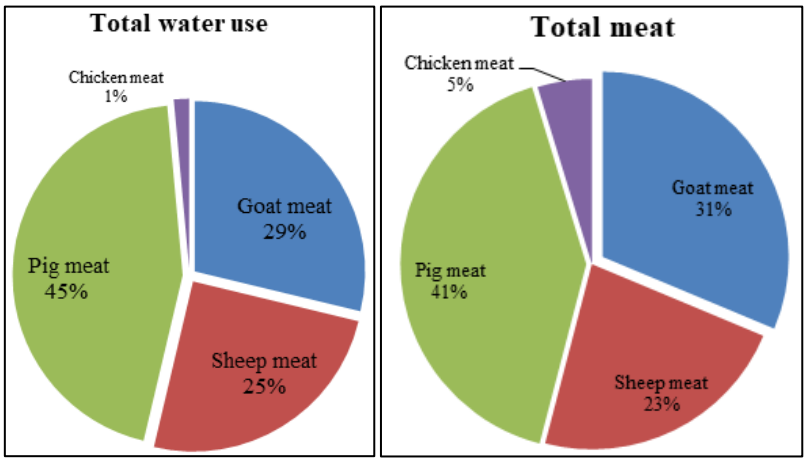


Fig 9: Water footprint of meat Products in district Prayagraj

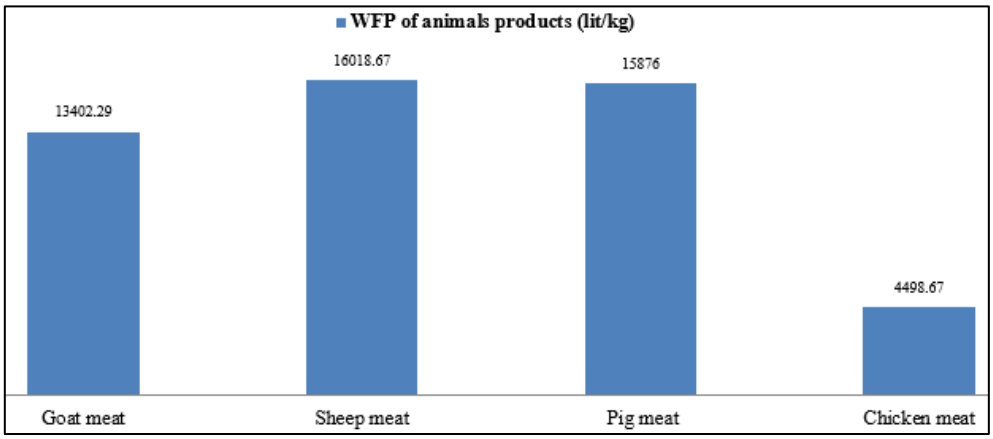


Fig 10: Water footprint of meat Products in district Prayagraj

Data presented in figure 9 shows that total meat production is 311904.60 tons per year. Data presented in figure 10 shows that maximum water footprint of Sheep meat is 16018.67 lit/kg followed by Pig meat 15876 lit/kg, Goat meat 13402.29 lit/kg while minimum of Chicken meat is 4498.67 lit/kg. Total water used for poultry is 21142352564 litres per year and the total no. of egg per year is 109659505.Water footprint of egg is 192.8 lit/egg.

Water Footprint of Human population

The total human population of 20 blocks in district Prayagraj is 4502781(Data of human population, Source: Statistical bulletin of Prayagraj district) and total water used 219820139.94 m^3/yr by human. Water footprint of human is the water used by the people for their life activities as Drinking, Servicing, Bathing and washing our clothes etc and is 48.82 (m^3/capita/year).On an average, water used by per person is 133.75 (lit/day) in district Prayagraj.

Conclusions

The findings of the present study concludes that the water footprint acts as an indicator of water use in relation to the consumption by people, animal products and agriculture as well goods and services by the inhabitants of the area. Total water use in district Prayagraj is 76.67 million cubic meter per day and 27985.48 million cubic meters per year. Total water footprint of district Prayagraj is 16565.39 m^3/capita/year which includes 3281.22 m^3/ton for agriculture, 13235.35 m^3/animal/year for animals and 48.81 m^3/human/year for human**.**

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