Water Footprint Assessment of Livestock in Banjar River Watershed

THESIS

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**Jawaharlal Nehru Krishi Vishwa Vidyalaya
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In partial fulfillment of the requirements for the Degree of

MASTER OF TECHNOLOGY
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AGRICULTURAL ENGINEERING
(Soil and Water Engineering)

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CERTIFICATE - I

This is to certify that the thesis entitled **"Water Footprint Assessment of Livestock in Banjar river watershed"** submitted in partial fulfillment of the requirement for the degree of **MASTER OF TECHNOLOGY** in **AGRICULTURAL ENGINEERING (Soil and Water Engineering)** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafide research work carried out by **Mr. Vora Hardikkumar Mansukhbhai** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

All the assistance and help received during the course of the investigation has been acknowledged by him.

Place : Jabalpur
Date : / / 2019

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Place: Jabalpur

Date: (**Vora Hardikkumar Mansukhbhai)**

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LIST OF ABBRIVIATIONS

Symbols		Stands for
%	:	Percent
&	:	And
‘	:	minute
“	:	Second
°	:	degree
°C	:	Celsius
°E	:	East direction
°N	:	North direction
CAE	:	College of Agricultural Engineering
cc	:	cm^3
cm	:	Centimeter
CWU	:	Crop water use
CWU_{blue}	:	Blue crop water use
CWU_{green}	:	Green crop water use
DEM	:	Digital Elevation Model
Eg.	:	Exempli gratia (for example)
ERDAS	:	Earth Resources Data Analysis Systems
ET	:	evapotranspiration
et al.	:	and others
ET_c	:	Crop evapotranspiration
etc.	:	Etcetera (and so on)
ET_o	:	Reference evapotranspiration
FAO	:	Food and Agricultural Organization
Fig.	:	Figure
GIS	:	Geographical information system
Gm^3	:	Giga meter cube
h	:	Hour
H_2O	:	Water

ha	:	hectare
i.e.	:	id est (that is)
JNKVV	:	Jawaharlal Nehru Krishi Vishwa Vidyalaya
K_c	:	Crop coefficient
kg	:	Kilo gram
Kg-f	:	Kilogram-force
KJ	:	Kilo joule
km	:	Kilometer
kPa	:	Kilopascal
K_y	:	Yield response factor
Lit or L	:	Litre
Litres kg^{-1}	:	Litre per kilogram
m	:	Meter
m^3/ton		meter cube per ton
Mix	:	Mixing water requirement
mm	:	Millimeter
Mm^3/ton	:	Million meter cube per ton
MP	:	Madhya Pradesh
MSL	:	Mean Sea Level
NASA	:	National Aeronauticals and Space Administration
NBSS & LUP	:	National Bureau of Soil Survey & Land Use Planning
pixel	:	Picture element
RAW	:	Readily available water
RS	:	Remote Sensing
Rs.	:	Indian rupees
sec or s	:	Second
SRTM	:	Shuttle Radar Topographic Mission
TAW	:	Total available water
TIFF	:	Tagged Information File Format
ton	:	tones

UHT	:	Ultra high temperature
UTM		Universal Transverse Mercator
Vs.	:	Versus
WF	:	Water footprint
WF_{drink}	:	Drinking water footprint
WF_{feed}	:	Feeding water footprint
$WF_{service}$	:	Servicing water requirement
WGS		World Geodetic System
WP	:	Welting Point
Yr	:	Year

CHAPTER – 1

INTRODUCTION

INTRODUCTION

Water is very important natural resource. Due to increasing population the demand of animal products are also increased. In the last few decades the world has seen a significant shift in food consumption patterns towards more animal products such as meat, milk and egg, mainly due to growing economies and rising individual incomes. In developing countries, in particular, consumption of meat, milk and dairy products has been growing the last few decades at 5-6 percent and 3.4-3.8 percent annually respectively (Bruinsma, 2003). Due to increasing demand of milk the utility of livestock will also increase. The essence of global water scarcity is the geographic and temporal mismatch between freshwater demand and availability. Livestock uses one third of the total freshwater used.

Livestock requires large volumes of water for feed production, drinking water and servicing animals. By far the largest water demand of livestock is the water needed to produce animal feed. The fodder crops requires high amount of water. For producing the fodder crops water also polluted. Over 75% of these livestock are of inferior quality, farmers let them loose in the field for free grazing. This has been causing denudation of vegetation and heavy soil erosion. It is very essential to manage the water resource so that the optimum freshwater used enough to supply the demand of the animal product. In India, about 46 per cent of the total milk produced is consumed in liquid form and 47 per cent is converted into traditional products. Only 7 per cent of milk goes into the production of western products.

The first and most comprehensive assessment of the water footprint of farm animals and animal products was carried out by Chapagain and Hoekstra (2003) and later updated by the same authors in their water footprint of nation’s publication (Chapagain and Hoekstra, 2004). The water footprint is a consumption based indicator of water use and refers to all forms of freshwater use (direct and indirect) that contribute to the production of goods and services consumed by the inhabitants of a given geographical region. Water footprint assessment is very useful for equitable, sustainable and efficient use of limited freshwater resources and guidelines for the reduction and offsetting of impacts of water footprint (Aldaya, 2012).

The water footprint of livestock in a geographically delineated area is freshwater consumed by the livestock within the area. It mainly consists of three components namely green, blue and grey water footprint. The green water footprint refers to the consumption of rainwater. The blue water footprint relates to the consumption of surface and groundwater. The previous literature available on water footprint assessment of a geographically delineated area depicted that only mere importance was given to water footprint assessment of agriculture whereas the water footprint assessment of livestock was overlooked. This research work tries to focus on the freshwater used by the livestock within the watershed because heavy amount of water consume by the livestock sector also.

The water footprint is the sustainable tool for efficient use of freshwater resource. It is a comprehensive indicator of fresh water resource appropriation, next to the traditional and restricted measure of water withdrawal. It helps to understand how activities and products related to water scarcity and pollution. Water footprint assessment considered all of the activities influencing to freshwater resources. (Aldaya, 2012).

Banjar river watershed lies near Mandla and Balaghat district of Madhya Pradesh and some area of Chhattisgarh. It has its origin from Malajkhand region, which is close to Madhya Pradesh and Chattisgarh state border. Banjar River is a major tributary of the Narmada River. It contribute water in Narmada River near Bamhani town of Mandla district. Major area of Banjar river watershed covered with forest. In Banjar river watershed, utmost mankind are rural background. The maximum area of watershed is covered with forest. Farmers are small and marginal which entirely contingent on agriculture. Due to uncertainty in agriculture, they nurse animals for their livelihood. Dairy husbandry is one of the most reliable sources of livelihood for small farmers, as the families maintaining 2-3 good quality cows are able to come out of poverty.

The watershed lies in tribal region of Madhya Pradesh. In the Banjar river watershed, the cow, buffalo and goat are nursed mainly. Cow and buffalo are nursed for production of milk and goat is used for meat production. The water footprint assessment of livestock at watershed level was not done previously as well as particular block wise. Previous work done on India level or globally only. This research work is focus on cow, buffalo and goat which are caregiver within the Banjar river watershed.

Keeping the above facts into consideration, the present investigation is undertaken with the following objectives:-

1. To determine drinking water footprint of livestock within Banjar River Watershed
2. To determine servicing water footprint of livestock within Banjar River Watershed
3. To determine feeding water footprint of livestock within Banjar River Watershed

CHAPTER – 2

REVIEW OF LITERATURE

REVIEW OF LITERATURE

This chapter deals with the brief review of work done by several researcher in the country and abroad related to water footprint assessment of livestock within the river basin, administrative unit, etc. It also includes review on freshwater use in dairy barn for drinking and other purposes and water footprint of farm animal product.

2.1 Water footprint of milk and milk products

Drastig *et al.* (2010) analysed water footprint assessment of milk production in Brandenburg (Germany). They calculated the water footprint for agricultural processes and farms. They divided water footprint into green water footprint, blue water footprint and dilution water footprint. The green and blue water demand of a dairy farm plays very important role in the regional water balance. The water used for feeding, milk processing, and servicing of cows over the time period of ten years was assessed in their study. The preliminary results of the calculation of the direct blue water footprint show a decreasing water demand in the dairy production from the year 1999 with 5.98×10^{9} L/year to a water demand of 5.00×10^{9} L/year in the year 2008 in Brandenburg because of decreasing animal numbers and an improved average milk yield per cow. Improved feeding practices and shifted breeding to greater-volume producing Holstein-Friesian cow allow the production of milk in a more water sustainable way. The mean blue water consumption for the production of 1 kg milk in the time period between1999 to 2008 was 3.94 L.

Ridoutt *et al.* (2010) estimated the water footprint of dairy products in Australia. Water footprints are emerging as an important sustainability indicator in the agriculture and food sectors. They mainly developed life cycle assessment based methodology that takes into account local water stress where operations occur and normalized water footprints of milk products from South Gippsland which is one of Australia’s major dairy regions, were 14.4 L/kg of total milk solids in whole milk and 15.8 L/kg of total milk solids in skim milk powder delivered to export destination. These results demonstrate that dairy products can be produced with minimal potential to contribute to fresh water scarcity. Although not all dairy production systems are alike and the variability in water footprints between systems and products should be explored to obtain strategic insights that will enable the dairy sector to minimize its burden on freshwater systems from consumptive water use.

Thomassen and Ledgard (2012) compared the methods of dairy farming using water footprint in New Zealand. They assess the water footprint of New Zealand dairy farming in two contrasting regions of Waikato and Canterbury and illustrate differences in water footprint methods. They evaluate the suitability of indicators derived from each water footprint method. The environmental impacts of fresh water consumption expressed in damage to resources, damage to ecosystem quality, and damage to human health and freshwater ecosystem impacts and freshwater depletion were applied to two average dairy systems in the different regions. Total WF was 945 and 1084 L H_2O/kg fat-and-protein-corrected milk for the average Waikato and Canterbury dairy farm systems, respectively. The Waikato farm system had a higher green WF, whereas the Canterbury farm system had the highest blue WF impact.

Alvarenga *et al.* (2014) estimated the water footprint of milk produced in the southern region of Brazil. They evaluated the blue and green WF of three different milk production systems in the southern region of Brazil. The results showed that milk from confined feedlot, semi-confined feedlot, and pasture-based systems had blue water footprint of 19 litres kg^{-1}, 11 litres kg^{-1}, and 7 litres kg^{-1} ECM. The green water footprint of 1478, 2209, and 1584 litres/kg ECM. They conclude that higher pasture productivities and feed conversion ratio should be sought in all systems, in order to reduce the green water footprint.

Aamoum (2015) estimated water footprint of cow milk production on finnish farm. He found that in Finland, for cattle having mixed fodder like industrial and grazing and the water footprint of 1 kg of milk is 751 Litres green, 25 litres blue and 30 litres grey making a total of 806 Litres. The percentage of the green water footprint found from research was 93%, 3% for the blue and 4% for the grey. Most of the water footprint in this studied case is green water footprint which is rain water, which was mainly used for the production of firewood (25%) and fodder (63%). It was probable that the estimation of the grey water was too generous leading to its portion being significantly bigger than the literature (10% Vs. 4%). However, the grey water footprint of milk production remains relatively small in both cases.

Bach *et al.* (2013) calculated water footprint of milk in Germany. They studied 18 different feeding systems were determined based on the nutrition needed by cows during their full life cycle. The blue water consumption reaches from 3 to 23 litre depending on the analysed system which are used there. The 10,000 litre system tend to have the lowest water consumption due to the smaller amounts of fodder needed by the cows. The water consumption of 1 litre raw milk produced in Germany based on their study was lower compared to the results of the Water Footprint Network. Results show that concentrated feed is important, but not as important as the subsystem itself.

Boonyanuwat and Sirikul (2015) calculated water footprint of milk production in Thailand. The calculation of blue water demand for dairy farming in Thailand in 2013. The water used for feeding, servicing, and milk processing of cows in 1 year was assessed in their study. The resulted that the calculation of the green, blue, and grey water footprint showed as 93.39 %, 6.16 %, and 0.46 % respectively. The total water for 1 kg milk production at farm gate was 366.22 kg. The water footprint of milk processing were 88.05 and 78.03 kg per pack of 200 cc UHT and pasteurized milk respectively. The major part of water footprint in milk production was green water footprint from rain using by forage crop production.

Harika et al. (2015) studied water footprint of milk production in Andhra Pradesh. Food consumption patterns are changing day by day more towards high income elastic milk. It demands more feed grains and in turn more water resources for milk production. This required better quantification and analysis of nexus between water with milk production which is important for livestock security of India. Quantification can be done by Water Footprint concept more significantly. The average water footprint of milk production in Andhra Pradesh for crossbred cow, buffalo and local cow is 10.50, 6.73 and 2.01 m^3/lactating animal, respectively. It is correlated with feed requirements of animal, feeding pattern and water footprint of crops fed during different season. Water consumption for it can be reduced by increasing crop and milk productivities.

Irfan and Mondal (2015) analysed the water footprint of Indian dairy industry. Primary survey has been conducted in Pondicherry Cooperation Milk Supply Society. Daily production of milk is 1.2 lakh L/day. Ground water is used for production. Total water consumed by individual indigenous cow is calculated as 899 L/day. Total water productivity is given by 0.0033. Total water consumed by individual cross bred cow is calculated as 1127.19 L/day.

Pandey and Sirohi (2015) estimated water footprint of milk production in India. They resulted direct water footprint of milk production varied from 9 m^3/ton to 11 m^3/ton in organized sector and from 7.95 m^3/ton to 14.64 m^3/ton in unorganized sector at Karnal. The water use in organized farm was higher than clearly showing a high consumptive water use in unorganized sector. The reason for a high water footprint in unorganized sector is due to use of different feed and fodder mix, especially concentrates. The total water footprints in organized sector varied from around 1200-1600 m^3/ton of milk production and in unorganized sector it varied from 1550-2000 m^3/ton of milk production. The unorganized sector uses those concentrate mix which had high water footprint and coupled with lower milk yield.

Sekyere et al. (2016) determined water footprint of milk produced and processed in South Africa and implications for policy-makers and stakeholders along the dairy value chain. The results show that 1352 m^3 of water is required to produce per tonne of milk with 4% fat and 3.3% protein in South Africa. The water used for producing feed for lactating cows accounted for 86.35% of the total water footprint of milk. The water footprint of feed ration for lactating cows is about 85% more than that of non-lactating cows. Green water footprint accounts for more than 86% of the total water footprint of feed ration for lactating cows. Green and blue water footprints are the highest contributors of the total water footprint milk production in South Africa. Water used feeding for both lactating and non-lactating cows account for about 99% of the total water footprint of milk production in South Africa.

Murphy *et al.* (2017) accounting water footprint of dairy farming in Ireland. They studied different 24 dairy farm and differentiated them. The water footprint of 24 dairy farm was 690 lit/ kg FPCM. In which, 684 is green water footprint and 6 lit/ kg FPCM is blue water footprint. 1% of water used for processing the farm process mainly for drinking. The average stress weighted 0.4 lit/ kg FPCM across farm. The highest water used for grass production with green water from total water used. They concluded that the water footprint used for feeding was higher in proportion from total water footprint.

2.2 Freshwater consumption of animal and animal product

Cardot *et al.* (2008) observed drinking behaviour of lactating dairy cows and prediction of their water intake in France. They monitored water intake of 41 dairy cows managed according to current dairy farm practices was individually and continuously. They also investigate drinking behaviour and determined factors affecting water intake. The cows were housed in a free-stall barn and fed once daily with a corn silage and concentrate-based total mixed ration in which 48% dry matter content and 20.6 kg/day of dry matter intake. Cows were milked twice daily, with a yield of 26.5 kg/day. The daily free water intake was 83.6 L, achieved during 7.3 drinking bouts. The drinking bout water intake was 12.9 lit. Consumption peaks at feeding and milking times.

Hess *et al.* (2012) explained water consumption of British milk. The blue water consumption on 11 dairy farms. They making comparison with recorded usage over a 12-month period. They concluded a comparison of metered water use with that estimated using a commercial water footprint tool and the original Cranfield methodology Average consumption of blue water, derived from a sample of real farm data using water footprint 5.3 per L FPCM and Cranfield models 6.7 per litre fat and protein corrected milk were broadly comparable to the theoretical estimates for British milk production.

Boer *et al.* (2013) assessed environmental impacts associated with freshwater consumption along the life cycle of animal products. Production of 1 kg of fat and protein corrected milk on the model farm in Noord-Brabant required 66 L of consumptive water. About 76% of this water was used for irrigation during roughage cultivation and 15 % for production of concentrates. 8 % water use for drinking and cleaning services. Consumptive water use related to production of purchased diesel, gas, electricity and fertiliser was negligible (i.e. total 1 %). Production of 1 kg of FPCM resulted in an impact on human health of 0.8×10^{-9} disability adjusted life years, on ecosystem quality of 12.9×10^{-3}

m^2year and on resource depletion of 6.7 kJ. The impact of producing this kilogram of FPC Mon resource depletion, for example, was caused mainly by cultivation of concentrate ingredients, and appeared lower than the average impact on resource depletion of production of 1 kg of broccoli in Spain.

Huang *et al.* (2014) clarified water availability footprint of milk and milk products from large scale dairy production systems in Northeast China. The water footprint of milk produced in Heilongjiang was around 11 L H_2O kg fat-protein-corrected milk. This compared to 461 and 0.01 L H_2O kg fat-protein-corrected milk for production in California and New Zealand respectively. The water footprint of milk products produced in Heilongjiang were lower than those imported from California, but higher than those from New Zealand.

Sultana *et al.* (2014) estimated water use in global milk production for different typical farms agricultural systems. They measured green, blue and grey water use of milk production in 72 dairy regions from 48 countries. The global comparison results of water use has shown the average green, blue and grey water use are 1466, 121 and 106 L/kg ECM, respectively. The lowest green and blue water was found in Western Europe and Oceania with an average of 743 and 44 L/kg ECM, respectively. The highest green water was 4549 L/kg ECM was in African small-scale farms. The blue water 304 L/kg ECM was highest in Middle East feedlot farms. The lowest 65 L/kg ECM and the highest 268 L/kg ECM grey water was observed in Oceania and Asia.

Sultana *et al.* (2015) calculated consumptive water use of bovine milk production for 60 dairy regions. They studied consumptive water use of typical milk production systems in 60 dairy regions from 49 countries representing 85% of the world's total milk production. They resulted 739 lit CWU/ kg on Danish farm to 5622 lit CWU /kg on Uganda farm which lowest in Europe and highest in Africa. The feeding is most affected the water footprint of milk 94-99 % of total water footprint. Disaggregated CWU results showed that green water which ranges from 547–3405 L/kg ECM.

Kraub *et al.* (2016) discussed drinking and cleaning water use in cow dairy barn. 38 water meters were installed in a barn with 176 cows and two milking systems automatically and herringbone parlour. The cows in the automatic milking system used 91.1 litre drinking water per cow per day, while those in the herringbone parlour used 54.4 litre per cow per day. The cleaning water demand had a mean of 28.6 litre per cow per day in the automatic milking system, and a mean of 33.8 litre per cow per day in the herringbone milk parlour.

2.3 Water footprint of farm animal and animal product

Mekonnen and Hoekstra (2010) estimated the green, blue and grey water footprint of farm animals and animal products. The total water footprint for global animal production was 2422 Gm^3/yr, in which 87.2 green, 6.2% blue and 6.6% grey water. The largest water footprint for the animal production comes from the feed they consume, which was 98% of the total water footprint. Drinking water, service water and feed mixing water further account only for 1.1%, 0.8% and 0.03% of the total water footprint. The global water footprint of feed production is 2376 Gm^3/yr, of which 1463 Gm^3/yr refers to crops and after grazing. The total water footprint of feed crops amounts to 20% of the water footprint of total crop production in the world, which is 7404 Gm^3/yr. The globally aggregated blue water footprint of feed crop production is 105 Gm^3/yr, which is 12% of the blue water footprint of total crop production in the world. This means that an estimated 12% of the global consumption of groundwater and surface water for irrigation is for feed. The total water footprint of animal production was 2422 Gm^3/yr. They found that beef cattle have the largest contribution 33% to the global water footprint of farm animal production (33%), followed by dairy cattle (19%), pig (19%) and broiler chicken (11%). In the grazing system, over 97% of the water footprint related to feed comes from grazing and fodder crops and the water footprint is dominantly (94%) green. In the mixed and industrial production systems, the green water footprint forms 87% and 82% of the total footprint, respectively. The blue water footprint in the grazing system accounts for 3.6% of the total water footprint and about 33% of this comes from the drinking and service water use. In the industrial system, the blue water footprint accounts for 8% of the total water footprint.

Leenes *et al.* (2011) studied water footprint of poultry, pork and beef in different countries and different production systems. The water footprint of animal product was 2422 Gm^3 globally. It was one third of total water footprint of agriculture. It can decrease by replacing animal products by food products of plant origin or by reducing food waste. The water footprint of meat is in general far greater than the water footprint of plant based sources of equivalent foods. The food related water footprint of a consumer in an industrialized country can be reduced by 36% by shifting from an average meat-based diet to a vegetarian diet. They found that in the UK the water footprint of avoidable food waste amounts to 6% of the total water footprint of a UK citizen.

Mekonnen and Hoekstra (2012) estimated water footprint of farm animal product globally. They considered different countries and different production system. Livestock consume one third of total water footprint for animal production. The water footprint of any animal product is larger than the water footprint of crop products with equivalent nutritional value. The average water footprint per calorie for beef is 20 times larger than for cereals. The water footprint per gram of protein for milk, eggs and chicken meat is 1.5 times larger than for pulses. Low feed conversion efficiency was main reason for higher water footprint as compared to agriculture product.

Thomassen et al. (2014) throw light on water footprint of beef cattle and sheep produced in New Zealand water scarcity and eutrophication impacts. Survey data from Beef and Lamb New Zealand for the year 2009 and 2010 were used to cover a range of beef cattle and sheep farm types throughout New Zealand in which 426 farms averaged in seven farm classes, and water scarcity footprint and EP weighted averages were calculated for beef cattle and sheep. The normalised New Zealand weighted average water scarcity footprint of beef cattle of 0.37 L H_2O-eq/kg LW was lower than the published normalised values for the water scarcity footprint of beef cattle produced in Australia and in the UK. Also, the New Zealand weighted average water scarcity footprint of sheep of 0.26 L H_2O/kg meat was lower than the water scarcity footprint of sheep meat reported for the UK. Blue water losses associated with evapotranspiration from irrigated pasture comprised the greatest proportion of the total water scarcity footprint, despite the small areas of farmland irrigated. The weighted average EP of beef cattle was 51.1 g PO_4/kg LW, and the weighted average EP of sheep was 26.1 g PO_4/kg LW. The New Zealand weighted average EP for beef cattle was lower than the 105 g PO_4/kg LW reported for European Union suckler beef cattle.

2.4 Water footprint of feed and fodder production

Singh *et al.* (2014) estimated water requirement of feed and fodder production for Indian livestock vis a vis livestock water productivity. Water required by livestock in mainly used for feed and fodder production. Water required to produce a kg dry mass of common green fodder, protein and energy feeds varied from 267 to 713.3 litre, 1,000 to 2,000 litre and 690 to 850 litre for sorghum Lucerne, linseed, soybean, maize, grain oat, grain respectively. Total water requirement estimated for livestock population 2003 and 2010 were 16.30 and 16.15 MCM where cattle for both indigenous and crossbred had highest water requirement 10.11 and 9.51 MCM, respectively. To meet the green fodder and concentrate requirement of livestock 151.72, 156.83 and 161.81 and 142.76, 157.67 and 172.04 BCM water required in year 2015, 2020 and 2025, respectively. Livestock water productivity to produce 1 kg milk ranged from 475 to 3,751 litre depending on the animal rearing system as extensive to Intensive system. To produce a kg of meat water requirement ranges from 8215 to 9680 litre depending on the animal species. Livestock water requirement for drinking and washing is very low like 3.6% than for feed and fodder production, while the livestock water productivity varies widely with their rearing system and animal species.

Palhares *et al*. (2017) studied impact of roughage concentration ratio of water footprint of beef feedlots. They used bottom-up approach of water footprint for the beef feedlot production was applied. They included green and blue volumetric water footprint. To explore differences in agricultural performance on sensitivity assessment was done. Total water footprint ranged from 1935 to 9673 $m^3\ kg^{-1}$ of meat. The results are demonstrating the variability in water footprint that can exist from farm to farm for different. Green water represented on average 84.5% and blue water 15.4% of the footprint value. The farms with larger amounts of concentrate in the diet had high footprint values and the differences in feed composition have a significant effect on the water footprint. The average water footprint of the current crop yield was 5814 L kg^{-1} of meat. With a reduction of 25% in the current crop yields, it was 7.416 L kg^{-1}

of meat and with an increase of 25% in the current crop yields, 4677 L kg^{-1} of meat. They resulted show that increasing agricultural productivity has positive impacts on reducing the water footprint.

2.5 Water footprint of administrative level

Zeng *et al.* (2012) assessed water footprint at river basin level for the Heihe River Basin in northwest China. They studied water footprint within the river basin located in China. That research show that the WF was 1768 million m^3 yr^{-1} in the Heihe River Basin over 2004–2006. Agricultural production was the highest water consumer, accounting for 96% of the WF. In which, 92% for crop production and 4% for livestock production water was used. The remaining 4% was for the industrial and domestic sectors. The blue component of water footprint was 811 million m^3 yr^{-1}. This indicated that the blue water proportion of 46 % which is much higher than the world average and China's average. Reason for blue water footprint was dependency on irrigation mainly for crop production. In such a river basin, blue water footprint was still smaller than green water footprint and indicating the importance of green water. They find that blue WF exceeded blue water availability during eight months per year and also on an annual basis.

Zhao *et al.* (2015) assessed water footprint regional level of Leshan city of China in period of 2001 to 2012. The water footprint is calculated by the sum of the water footprints of various sectors like crop production, livestock products, industrial processes, domestic waster, eco-environment, and virtual water trade. They resulted that the water footprints of the various sectors rose by degrees varying from 19% to 55%, which gave rise to an increase of the total water footprint of 43.13% from 2001 to 2012. Crop production and livestock are identified as the major water intensive sectors about 68.97% of the total water footprint. The application of water footprint assessment is expected to provide insight into the improvement of urban water efficiency and thus aid in better water resources management.

Reviewing the previous work done related to water footprint assessment of livestock, the methods for this research work was concluded. The major methodology used for water footprint assessment of livestock in the Banjar river watershed is taken from the Zhao *et al.* (2015), Mekonnen and Hoekstra (2010), Singh *et al.* (2014) and Harika *et al.* (2015).

The previous research was done on global and India level only, watershed or geographically delineated area was not done before. The Banjar river watershed contribute one of the major river basin of Narmada river and Madhya Pradesh also. So that decided to work on the water footprint assessment of livestock in Banjar river watershed.

CHAPTER – 3

MATERIAL AND METHODS

MATERIALS AND METHOD

The study was undertaken to calculate the water footprint of livestock in Banjar river watershed. This chapter describes the steps to evaluate the water footprint of livestock. The details regarding data essential for assessment of water footprint is presented in this chapter.

3.1 Study area

The present study is carried out in Banjar river watershed. The watershed lies in Balaghat and Mandla districts of Madhya Pradesh and Kabirdham and Rajnandgaon district of Chhattisgarh. It is geographically located in between 21°41’ N and 23° 29’ N latitudes and 80°22’ E and 81°00’ E longitudes. The watershed covers total geographical area of 2460.84 km^2 up to the gauging point. The general elevation of the watershed varied from 442 m to 905 m. Climate of the area is tropical with moderate winter and severe summers and it generally received rainfall from southwest monsoon.

However due to high general elevation and abundance of forests, summer temperature does not rise as much as in other areas of the state. The normal annual rainfall of the Banjar river watershed ranges from 1000 to 1400 mm in different parts of watershed. The soils of the study area is characterized by black grey, red and yellow colors, often mixed with red and black alluvium and ferruginous red gravel or lateritic soils. In broad sense, these soils are called black soils**.** The topsoil is mostly loamy with subsoil as sandy clay loam except in alluvial deposits that had relatively fine texture of clay. The soil is found shallow in barren areas with fine platy structure surface soil and compressed blocky structure subsurface soil. The location of the study area and its synoptic view is displayed in Fig. 3.1 and Fig 3.2 respectively.

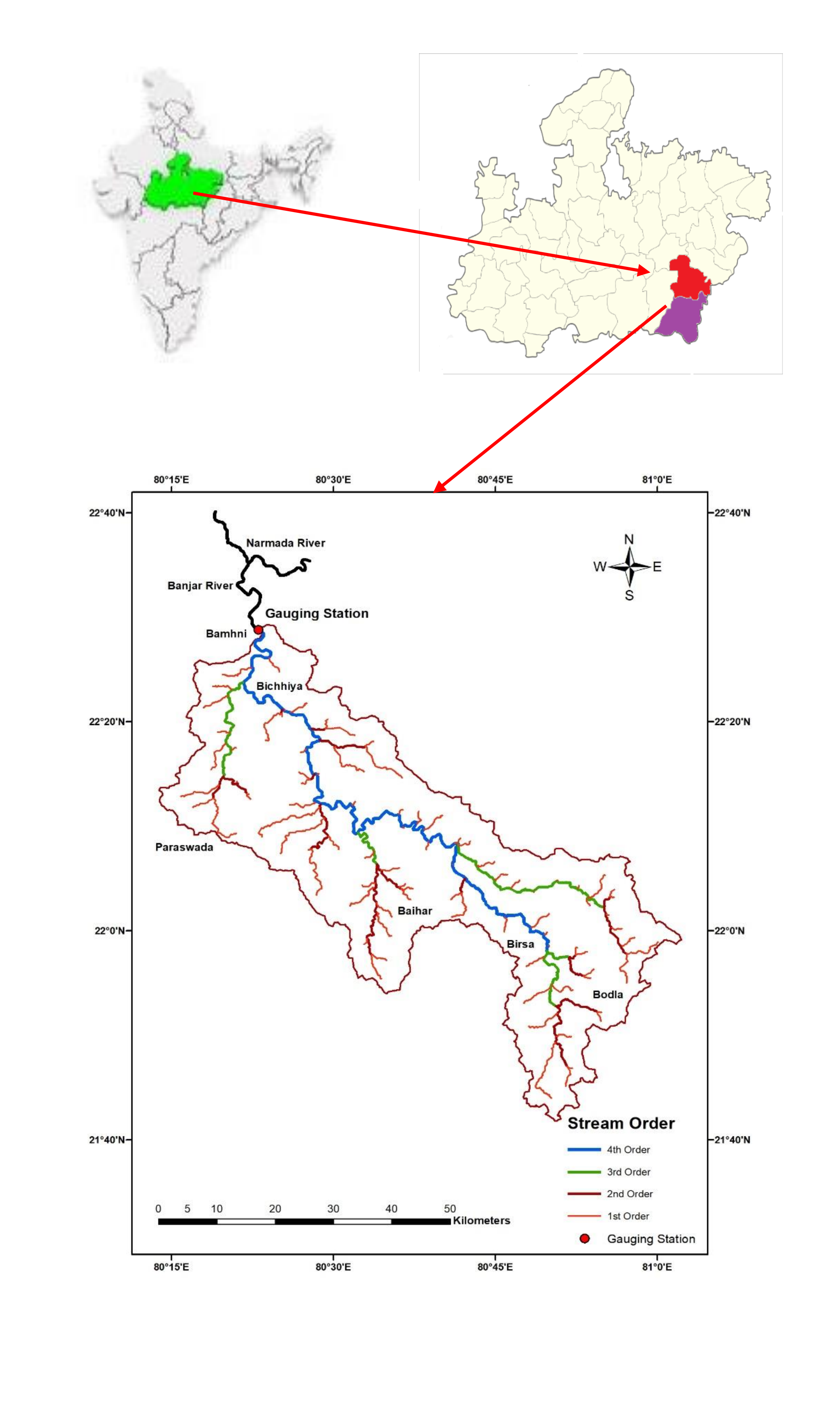

Fig 3.1 Location map of the study area

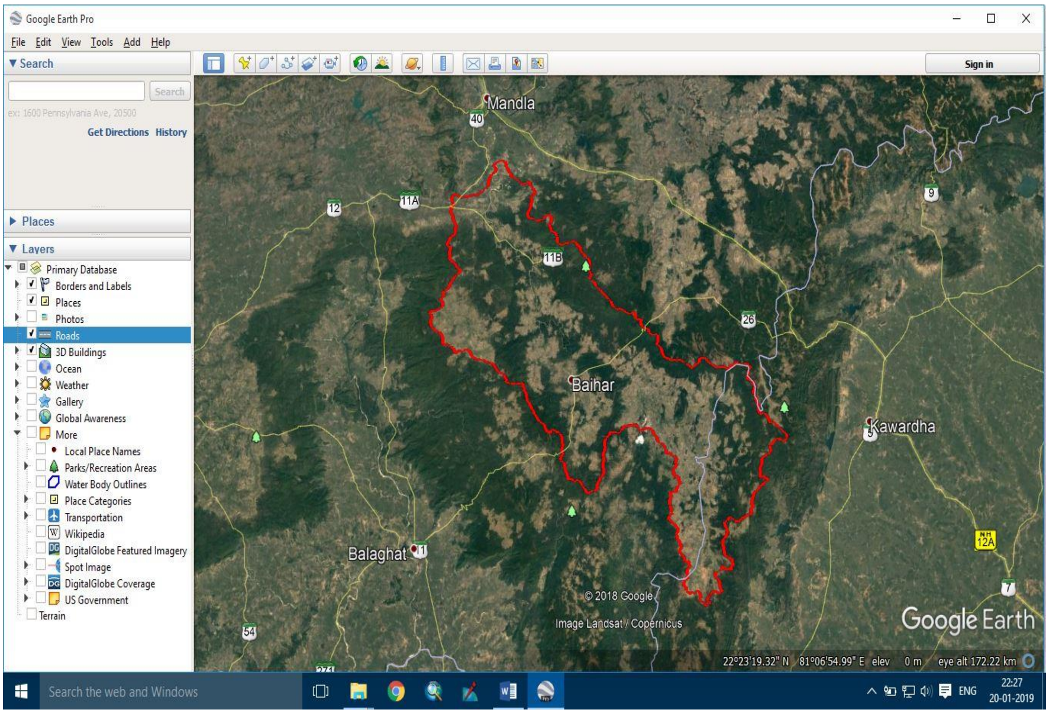

Fig 3.2 Synoptic view of the study area

3.2 Watershed delineation

A watershed may be defined as a geographical area contributing single outlet runoff to a single outlet. From the past few years, the management of water resources at a watershed level has proved itself to be the most ideal unit for the management of water and land resources.

Water can be easily stored and managed at a watershed level. Before watersheds can be managed, it is necessary to delineate their boundaries and this is done in Arc Map using the hydrologic analysis tools. These tools are available in ArcGIS 9.3, after enabling the Spatial Analyst extension. The Hydrology toolbox is present in Arc Toolbox under Spatial Analysis.

3.2.1 Digital Elevation Model (DEM)

Digital Elevation Model (DEM) is a digital file consisting of terrain elevation for ground positions at regularly spaced intervals. In other words, Digital Elevation Model are digital representatives of cartographic information. DEM data is required for delineation of watershed, determination of watershed area, identification of blocks of different districts covered in the watershed area and for the preparation of soil map, drainage map, spatial variability maps of different attainable quantities etc.

The DEM of the study area is obtained from Consultative Group on International Agricultural Research (CGIAR) – Consortium for Spatial Information (CSI) – Shuttle Radar Topographic Mission (SRTM) [URL: srtm.csi.cgiar.org/srtmdata]. The data obtained is in Tagged Information File Format (TIFF) and is having a ground resolution of 90m. The general elevation of the watershed is identified using the clip option of Raster processing under the data management tool section of Arc toolbox of ArcGIS 9.3 software.

3.2.2 Creating a depression less DEM

As the first step, the elevation value is modified by filling the sinks in the grid. This is done to avoid the problem of discontinuous flow when water is trapped in a cell, which is surrounded by cells with higher elevation. This is done by using the Fill tool under Hydrology section found under Spatial Analyst Tool Function in ArcGIS 9.3.

3.2.3 Creating a runoff flow direction grid

Runoff flow direction of Banjar river watershed is generated from the Fill grid. The Flow direction tool takes a terrain surface and identifies the down-slope direction for each cell. This grid showed the surface water flow direction from one cell to one of the eight neighbouring cells. This is done by using the Flow direction tool under Hydrology section found under Spatial Analyst Tool Function in ArcGIS 9.3. The runoff flow direction in Banjar river watershed is shown in Fig 3.3.

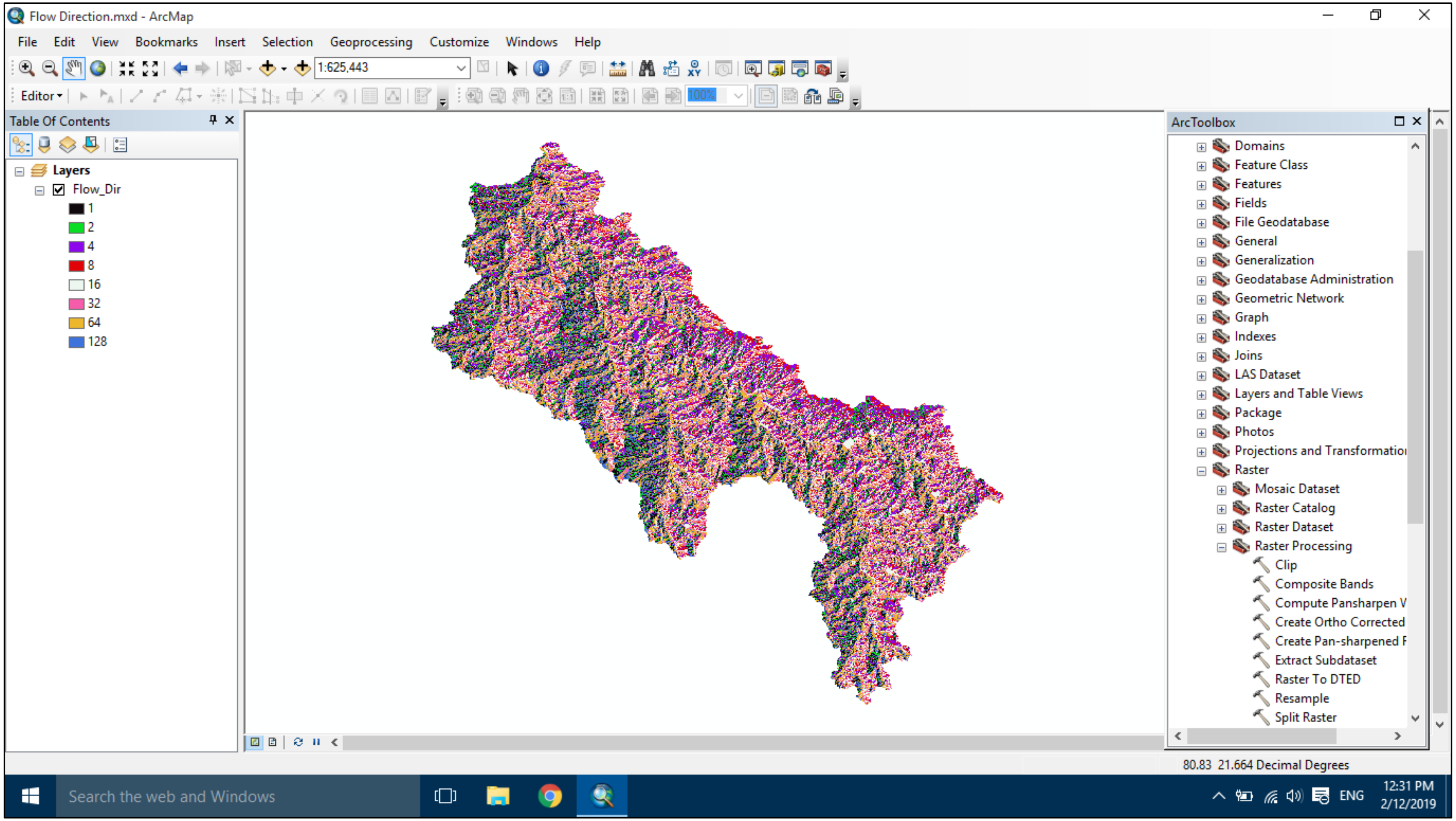

Fig. 3.3 Runoff flow direction in Banjar river watershed

3.2.4 Creating a runoff flow accumulation grid

Based on the runoff flow direction, Flow accumulation is calculated. Flow accumulation tool identified how much surface flow accumulated in each cell; cells with high accumulation values are usually stream or river channels. It also identified local topographic highs (areas of zero flow accumulation) such as mountain peaks and ridgelines. This is done by using the Flow accumulation tool under Hydrology option of Spatial Analyst Tool Function in ArcGIS 9.3. The runoff flow accumulation in Banjar river watershed is presented in Fig 3.4.

3.2.5 Creating outlet (pour) points

A new point file is created in Arc Catalog and then pour points are added by zooming in on the flow accumulation grid and placing points in areas of high flow accumulation. Pour points are added as close to the centre of cells as possible. Everything upstream from each point will define a single watershed. The points are converted to a grid first, which verifies that the pour point locations are in the high-flow pathway.

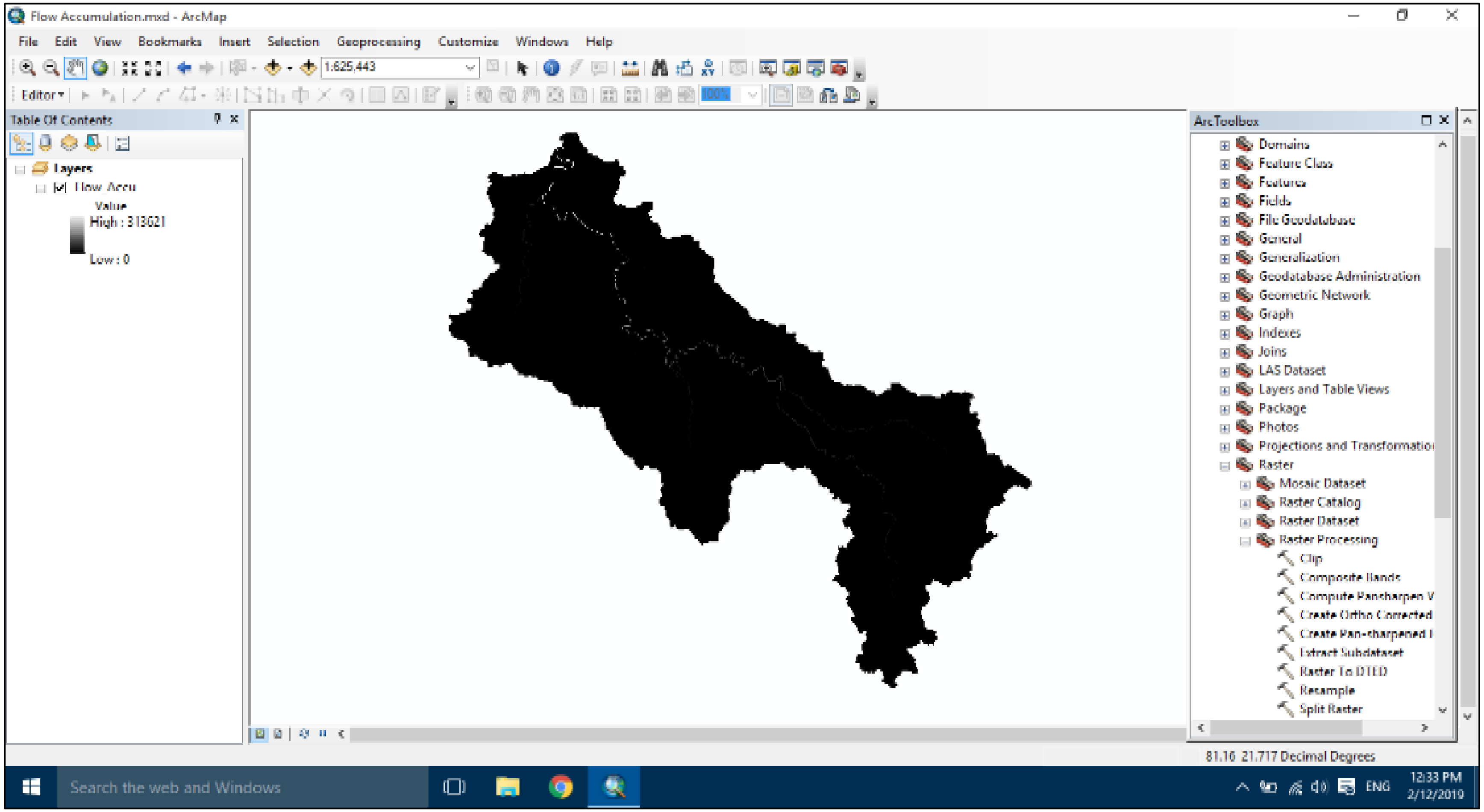

Fig. 3.4 Runoff flow accumulation in Banjar river watershed

3.2.6 Delineating watershed

Finally, the watershed is delineated by double clicking on watershed tool under spatial analyst tool function in ArcGIS 9.3 and it is depicted in Fig. 3.5

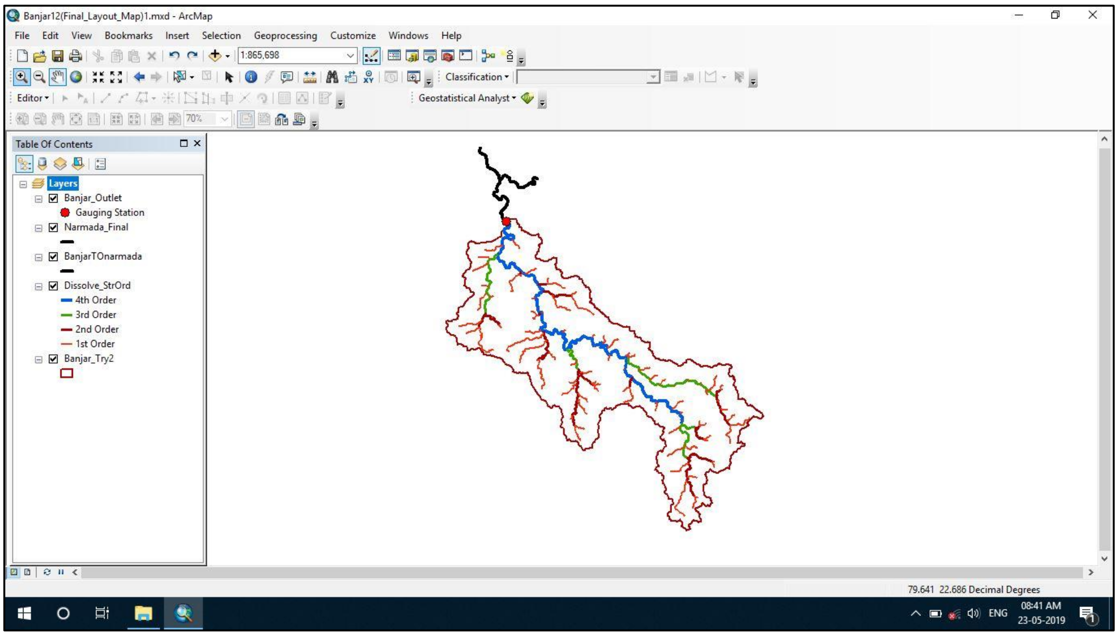

Fig. 3.5 Delineation of watershed by snap pour point method

3.3 Water footprint of livestock

Water footprint of livestock refers to the fresh water used by livestock in Banjar river watershed. The water footprint of livestock is further subdivided in two part as direct water footprint and indirect water footprint based on the type of use. The direct water footprint includes drinking and servicing water footprint. The indirect water footprint includes mixing water footprint and feeding water footprint. On the basis of source of water used for the feed for livestock the water footprint is further subdivided into three components as green, blue and grey water footprint.

The green water footprint of crops refers to the residual profile stored soil moisture or precipitation utilized for production of crop, good or service, either evaporated, evapo-transpired and incorporated into product. Blue water footprint refers to the amount of surface or ground water used for crop production over complete growing period.

The livestock census of 2012 is taken into consideration for calculating the population of livestock in Banjar river watershed. Cows, buffaloes, goats, poultry, pigs, horses, etc. animals are generally reared in Banjar river watershed but due to lack of availability of data on feeding and water consumption patterns, this study is mainly executed to study and assess the water footprint of livestock in Banjar river watershed.

3.4 Questionnaire based field survey of Banjar river watershed

The survey is done near the outlet of the Banjar river watershed and relevant data are obtained which is further used in calculation of water footprint of livestock. During the survey the questions are asked to the farmers (Fig. 3.6) about drinking, servicing water use patterns. The feeding pattern of livestock in the watershed is also observed by the questionnaire based field survey. The information collected during the questionnaire based field survey of Banjar river watershed are name of the farmer, name of block in which the farmer resides, number of animals owned and cherished by the farmer, breed of the animal, type of environment in which animal lives. A complete information of consumption patterns of feed and water by the livestock in Banjar river watershed is thoroughly observed. The Fig. 3.7 shows the dry and green fodder stored by the farmers which is used as a feed material for the livestock. The fig 3.8 depicts the feed consumption pattern of goat. The Fig. 3.10 and 3.11 shows the water used for bathing as well as well for maintaining the barn. Information collected during the survey has been tabulated in Appendix 1.1, Appendix 1.2 and Appendix 1.3.

The second observation is done at dairy farm of Department of Livestock Production and Management, Nanaji Deshmukh Veterinary Science University, Jabalpur. The direct and indirect water requirement of cow, buffalo and goat in organised farm are observed and estimated.

Fig. 3.6 Farmer's Survey in Banjar river watershed

Fig. 3.7 Dry fodder given as a feed to the livestock

Fig. 3.8 Green fodder given as a feed to the livestock

Fig. 3.9 Feeding of green fodder by Goats

Fig 3.10 Bathing of Buffaloes

Fig. 3.11 Cleaning of Dairy Barn

3.5 Determination of drinking water footprint

The total geographical area of blocks of the districts in which the watershed lies and the area of each block covered in the watershed s used determining the percentage area of block covered in the watershed. The table 3.1 shows the proportionate percentage area of each block lying in the watershed to the total area of the block.

Table 3.1 Percentage of area covered by block in Banjar river watershed

Block	Total geographical area of block (ha)	Area covered within the Banjar river watershed (ha)	Percentage of area covered within the Banjar river watershed (%)
Baihar	190640	62667	32.87
Bichhiya	145180	32274	22.23
Birsa	110397	34223	31.00
Bodla	137715	35128	25.50
Chhuikhadan	134991	7941	5.90
Mandla	94476	1327	1.40
Nainpur	85373	14243	16.68
Paraswada	132970	62533	47.02

Livestock population of various development blocks have been adopted from Livestock Census (2012) and tabulated in Table 3.2. It has been considered in proportion to percentage area of block covered in the watershed. The population of livestock is presented in Table 3.3

.

Table 3.2 Development block wise livestock population

Block	Cow	Buffalo	Goat
Baiher	100285	27228	31750
Bichchiya	56710	10030	9773
Birsa	109899	29838	34597
Bodla	166491	32938	29752
Chhuikhadan	129138	16728	17526
Mandla	31535	5631	5487
Nainpur	40786	7283	7096
Paraswada	96317	26150	30321

Table 3.3 Block wise population of cow, buffalo and goat within the Banjar river watershed

Block	Percentage of area covered (%)	Cow	Buffalo	Goat
Baihar	32.87	32964	8950	10436
Bichhiya	2.23	12607	2230	2173
Birsa	31.00	34069	9250	10725
Bodla	25.50	42455	8399	7587
Chhuikhadan	5.90	7619	987	1034
Mandla	1.40	441	79	77
Nainpur	16.68	6803	1215	1184
Paraswada	47.02	45288	12296	14257

3.5.1 Daily drinking water requirement

Daily drinking water requirement of livestock is collected through farmer's interview in Banjar river watershed. During the field survey the volume of water used for drinking is estimated by volume of water used in terms of number of buckets and number of times the bucket is used for giving water to the livestock. The estimation of this component is executed in the field survey however it is difficult to find the exact value of water used for drinking by the livestock.

On the basis of inquiry in the field visit about the daily drinking water requirement, the drinking water requirement of cow, buffalo and goat are 26.2 lit/day, 55 lit/day and 5.23 lit/day respectively. The complete information about the field survey is depicted in Appendix 1.1, Appendix 1.2 and Appendix 1.3. It is found that water requirement of livestock is 1-2 gallon of water per 100 pound of its body weight (Singh *et al.* 2014).

The drinking water footprint from drinking water requirement is calculated using following equation (Zhao *et. al*, 2015):

$$WF_{drink} = \int \frac{Qd\ dt}{W}$$

Where,

WF_{drink} = Drinking water footprint m^3/ton

Q_d = Daily drinking water consumed by the animal, m^3/d;

W = Average live weight of the animal at the end of its lifespan, tonne

3.5.2 Average Live Weight of Animal at the End of the Lifespan

In Banjar river watershed, most of the area lies in tribal region. Livestock population in Banjar river watershed has not been categorised as marked breed. Therefore, information on characteristics of cow, buffalo and goat found in Banjar river watershed is not available. The average live weight of animals taken by local observed data. The average live weight of the animals has been finalised in consultation with officials of District Animal Husbandry Hospital, Mandla. The average live weight of animal considered in this study is shown in Table 3.4.

Table 3.4 Average Live Weight of Animal at the End of the Lifespan

Animal	Weight (kg)
Cow	240
Buffalo	350
Goat	40

3.6 Determination of servicing water footprint

Data for servicing water requirement is collected through questionnaire based field survey in Banjar river watershed. Servicing water footprint included freshwater used for bathing and cleaning of livestock in watershed. The calculation of the servicing water footprint is quite hard due to the reason that water consumption patterns of livestock varies with season, place animal. The regular bathing of cow is generally not preferred in the watershed. They used to bath once a week or ten days. The bathing pattern of buffalo is such that they used to make bath daily. Goats are very sensitive with water and hence they are not bathed in the watershed.

3.6.1 Daily servicing water requirement

On the basis of analysis, the daily servicing water requirement of cow, buffalo and goat are 9.3 lit/day, 21.77 lit/day and zero respectively which is shown in Appendix 1.1, Appendix 1.2 and Appendix 1.3.

The water footprint from servicing water requirement is calculated by following equation (Zhao *et. al*, 2015):

$$\mathrm{WF_{service}} = \int \frac{\mathrm{Qs\ dt}}{\mathrm{W}}$$

Where,

$WF_{service}$ = Servicing water footprint m^3/ton

Q_s = the daily service water requirement of the animal, m^3/d

W = average live weight of the animal at the end of its lifespan, tonne

3.7 Determination of feeding water requirement

The calculation of feeding water footprint comprises of calculation of water use by feed and fodder crops (dry and green). For feed and fodder production crop water use may be satisfied from irrigation and effective rainfall. For fodder production the leaching of fertilizer is negligible and hence, the grey component is not adopted for the study. For feeding, grazing of livestock in Banjar river watershed is generally preferred however such datasets are unavailable due to uncertainty consumption patterns of feed.

It can be measured as the sum of the water requirement of the prepared feed mix and the virtual water of various feed ingredients contained.

The quantity of water used for mixing the feeding material and also the quantity of feeding material feed daily are collected through questionnaire based survey in Banjar river watershed. It is depicted in Appendix 1.1, Appendix 1.2 and Appendix 1.3.

3.7.1 Daily feeding requirement

The questionnaire based field survey concluded that the daily feeding requirement of cow, buffalo and goat is 7 kg/day, 9 kg/day and 5 kg/day respectively for dry feed (wheat straw and rice straw). The daily feeding requirement of cow, buffalo and goat is 8.21 kg/day, 17.7 kg/day and 5.15 kg/day respectively for green feed (barseem, maize and sorghum).

The water used for mixing the concentrate feed for cow and buffalo is 2.21 lit/day and 2 lit/day respectively. It is shown in Appendix 1.1, Appendix 1.2 and Appendix 1.3.

3.7.2 Feeding water footprint

The type of feeding material generally used as dry fodder comprises of wheat straw and paddy straw. The green and blue water footprints of different crops are calculated using the methodology described in Hoekstra and Chapagain (2009). In Banjar river watershed the standard of living of the farmers residing in the watershed is not good. Farmers mainly uses crop residue as a feeding material to livestock (cows, buffalo and goat). However, *Barseem*, maize and sorghum are also used as a green feeding material for cows, buffalo and goat.

The feeding water footprint from feeding water requirement calculated by following equation (Zhao *et al.,* 2015)

$$\mathrm{WF_{feed}} = \frac{\int \sum_{i=1}^{n} \mathrm{WF_i} \times \mathrm{C_i}}{\mathrm{W}}$$

Where,

WF_i = Water footprint of the ith feed crop, m^3/t

C_i = Quantity of feed crop consumed by the animal daily, t/d

W = Average live weight of the animal at the end of its lifespan, tonne

3.7.2.1 Calculation of crop water requirement

The water requirement of a crop is the total quantity of water required from its sowing time to harvest. The crop water requirement of crops varies from palace to place and it also depends on the climate, type of soil, method of cultivation, rainfall etc. The total water required for crop growth is not uniformly distributed during its crop period. The influence of the climate on crop water needs can be calculated by the reference crop evapotranspiration (ET_0). The ET_0 is usually expressed in millimetres per unit of time, e.g. mm/day, mm/month, or mm/season. The relationship between the reference crop evapotranspiration and the crop actually grown is given by the crop factor, K_C, as shown in the following formula:

$$ET_C = ET_0 \times K_C$$

The values of crop coefficients are generally adopted from FAO paper number 56 (Allen *et al.,* 1998). It should be kept in mind that the influence of variations in the total growing period on the crop water requirement is very important. ET_0 is calculated using Penman-Monteith method and crop water requirement is calculated using CROPWAT 8.0 software (Allen et al, 1998).

The crop water requirement is calculated using CROPWAT software which is developed by Land and Water Development Division of FAO that uses the FAO Penman-Monteith model to calculate reference evapotranspiration (ET_0), crop water requirement and crop irrigation requirement (Herbha *et al.,* 2017). CROPWAT requires meteorological data for estimation of reference evapotranspiration. After entering climate data with latitude, longitude and elevation, the reference evapotranspiration is estimated.

In CROPWAT the calculation of crop water requirements is carried out in time steps of 10 days. For the calculation of crop water requirement, the crop coefficient approach is used.

3.7.2.2 Meteorological parameters

The meteorological parameters such as maximum temperature, minimum temperature, precipitation, relative humidity, wind speed and sunshine hours for the year 2017 and 2018 for all 8 development blocks are obtained from NASA climatic data service which is accessible from https://power.larc.nasa.gov/data-access-viewer.

3.7.2.3 Collection of crop data

Crop data includes crop coefficient, planting date, crop development stages (days), rooting depth, critical depletion fraction, yield response fraction and crop height (Mehta *et al.* 2015)) (Mehta and Pandey 2016). These data are adopted from FAO irrigation and drainage paper no. 56 (Allen et al, 1998) and presented in Table 3.5, Table 3.6 and Table 3.7.

Table 3.5 Values of Crop coefficients (K_C) for the initial, middle and end stage of crops

	Crop coefficient (K_C)		
	Initial	**Middle**	**End**
Jowar (Sorghum)	0.30	1.10	0.55
Maize	0.30	1.20	0.35
Barseem (Egyptian Clover)	0.3	1.10	1.05
Rice	1.05	1.20	0.75
Wheat	0.50	1.24	0.42

Table 3.6 Length of Crop development stages of different crops

Crop	**Length of Crop development stages**				
	Initial	**Development**	**Mid-season**	**Late-season**	**Total**
Sorghum	20	35	40	30	125
Maize	20	35	40	30	125
Barseem	10	15	75	35	135
Rice	30	30	80	40	180
Wheat	15	25	50	30	120

Table 3.7 Rooting depth, Critical depletion factor, Yield response function and Crop height of different crops

Crop	Rooting depth (m)	Critical depletion factor (fraction)	Yield response function (factor)	Crop height (m)
Sorghum	1.75	0.55	1.15	1.60
Maize	1.50	0.55	1.40	2.00
Barseem	0.9	0.50	1.2	0.6
Rice	0.75	0.20	1.15	1.00
Wheat	1.40	0.60	0.60	1.00

3.7.2.4 Collection of soil data

Soil data is required for giving input in the form of predefined values for a given soil type to various models for estimation of evapotranspiration and yield of crops. FAO CROPWAT model is used in the study for the estimation of evapotranspiration. The predefined values (total available soil moisture, maximum rain infiltration rate, maximum rooting depth, initial soil moisture depletion, initial available soil moisture) of a soil type is input to the FAO CROPWAT model in the section of soil data (Mehta *et al*, 2015) (Mehta and Pandey 2016). It is depicted in Table 3.8.

Table 3.8 Soil data for wheat, rice, maize, *barseem* and sorghum

General Soil Data	Clay	Clay Loam
Total available soil moisture (FC - WP)	150 mm/meter	160 mm/meter
Maximum rain infiltration rate	30 mm/day	30 mm/day
Maximum rooting depth	900 centimetres	900 centimetres
Initial soil moisture depletion (as % TAW)	50 %	0 %
Initial available soil moisture	75 mm/meter	160 mm/meter

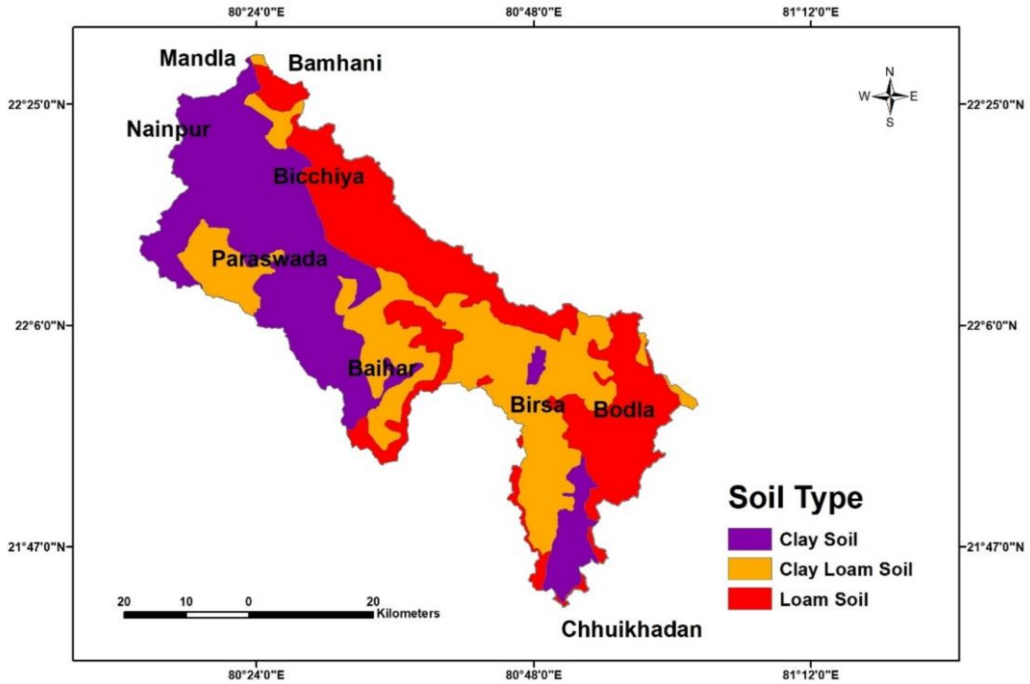

Fig. 3.12 Soils in Banjar river watershed

3.7.2.5 Spatially distribution map

The spatial distribution maps are developed using IDW (Inverse Distance Weighted Technique) tool in ArcToolbox option of Arc GIS. This tool is used to study the spatial distribution of residue crops over the entire watershed.

3.7.2.6 AquaCrop

Biomass of crop residue, which is being used as dry fodder to livestock has been estimated using AquaCrop Software. AquaCrop is extended version of CROPWAT, designed to simulate biomass and yield responses of field crops to various degrees of water availability. Its application encompasses rain fed as well as supplementary, deficit and full irrigation. It is based on a water-driven growth engine that uses biomass water use efficiency as key growth parameter (Harika *et. al*, 2015).

After calculating residue yield the water footprint of feeding crop is calculated. The water footprint of crops is generally divided into two components as green water footprint and blue water footprint.

3.7.2.7 Green water footprint (WF_{green})

The green water refers to the residual profile stored soil moisture or precipitation (in so far as it doesn't become runoff) utilize for production of crop, good or service, either evaporated, evapo-transpired and incorporated into product. The precipitation on land that doesn't runoff or recharge groundwater but stored in the soil and utilise as crop evaporation or transpiration is called green water footprint. This part of water (precipitation) transpires or evaporates through the plant. Sometimes, no rainfall received during the monsoon season but residual stored soil moisture taken as green water. The green crop water use (CWU_{green}, m^3/ha) is estimated using the following formula (Hoekstra and Chapagain, 2009):

$$CWU_{green} = 10 \times \sum_{t=1}^{lgp} [\mathrm{Min}\ (ET_C, P_{eff})]$$

Where

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

P_{eff} = Effective rainfall (mm/day)

ET_c = Crop evapotranspiration

$$WF_{green} = \frac{CWU_{green}}{Y}$$

Where,

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

Y = Crop yield (tons/ha)

3.7.2.8 Blue water footprint (WF_{blue})

Blue water refers to the amount of surface or ground water consumed by plant for production of particular crop, agro-based goods or service or evaporated, evapo-transpired or incorporated into product. The blue water requirement is the irrigation requirement in the crop production which is equal to the crop water requirement minus the effective precipitation and residual profile stored moisture (if no rainfall or irrigation). The blue crop water use (CWU_{blue}, m^3/ha) is determined using the following formula

$$CWU_{blue} = 10 \times \sum_{t=1}^{lgp} Max\,(ET_C - P_{eff}, 0)$$

Where

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

P_{eff} = Effective rainfall (mm/day)

ET_c = Crop evapotranspiration (mm/day).

$$WF_{blue} = \frac{CWU_{blue}}{Y}$$

Where,

WF_{blue} = Blue water footprint

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

Y= Crop yield (ton/ha)

The factor 10 is multiplied to convert mm to m^3/ha. The summation is done over the length of growing period in a time series of 10 days.

3.7.2.9 Water footprint

The total water footprint refers to the summation of green and blue component of water footprint. Total water footprint includes direct and indirect water used by crop during the production. The green and blue component of water footprint (WF_{green}, m^3/ton) and (WF_{blue}, m^3/ton) of a crop is calculated using the following formulas.

$$WF = \sum_{b=1}^{N} WF_{green} + \sum_{b=1}^{N} WF_{blue}$$

3.7.3 Mixing water footprint

A small amount of water used for mixing the concentrate feeding material which are used for improve quantity and quality of milk. During the survey it is found they make mixture of *bhusa, khali chuni, salt, daliya,* etc. is used as a feed. The feeding material such as soybean cake, mustard cake, wheat bran, de oiled rice bran, etc. are also used as a concentrate feed product but is not generally not given as feed in large quantities due to high cost of such feed materials. The feed concentrate is generally given to the cow. The amount of water used to produce concentrates has been ignored in this study. The mixing water footprint of livestock within the Banjar river watershed calculated using following formula (Zhao et al., 2015).

$$\mathrm{WF_{mixing}} = \frac{\int \mathrm{Q_{mixing}}}{\mathrm{W}}$$

Where,

WF_{mixing} = Mixing water footprint

Q_{mixing} = Water demand of mixing the feed, m^3/t

W = Average live weight of the animal at the end of its lifespan, tonne

3.7.4 Total water foot print

Total water foot print of livestock in Banjar river watershed has been calculated by summing up the direct and indirect water foot print for all the livestock of the watershed.

CHAPTER – 4

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The result of the study are presented and discussed in this chapter. It generally deals with the variation of water footprint of livestock at a watershed level.

4.1 Preparation of drainage map of the study area

The DEM generated from Consultative Group on International Agricultural Research (CGIAR) – Consortium for Spatial Information (CSI) – Shuttle Radar Topographic Mission (SRTM) is used for delineation of the Banjar River watershed boundary and preparation of drainage map. The downloaded map has been verified by process of ground truth as described by Warwade et al. (2013). The watershed map of the study area is shown in Fig. 4.1 and its outlet in Fig. 4.2.

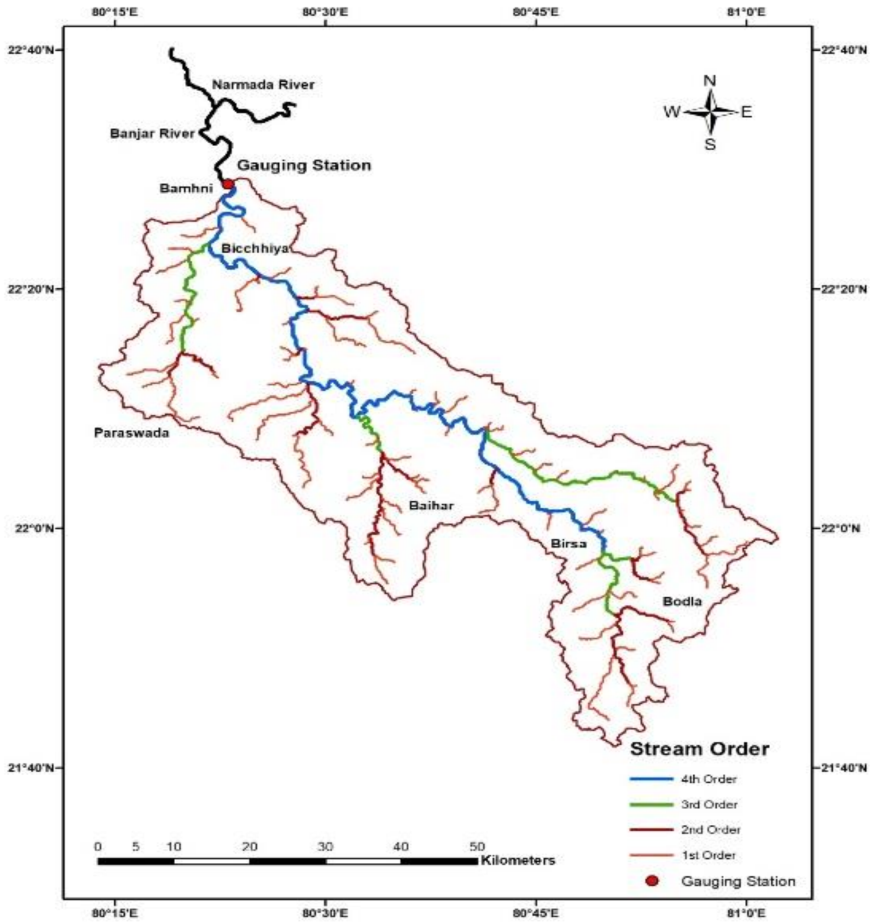

Fig 4.1 Drainage Map of Study Area

Fig. 4.2 Outlet of Banjar river watershed

Fig. 4.3 Gauging station of study area

The rain gauge depicted in Fig. 4.3 is float gauge recorder. In this recorder, stilling well is balanced by counter weight of the pulley. Displacement in float due to rising and lowering of water surface elevation causes angular displacement in pulley. Mechanical linkages convert angular displacement to linear displacement. It is recorded over a drum driven by clockwork. It is also recorded for a day, week, fortnight and provide continues plot of stage vs. time.

4.2 Identification of blocks covered within the Banjar river watershed

After delineating the watershed the shape file of watershed made. There are eight blocks covered within the Banjar river watershed namely Baihar, Bichhiya, Birsa, Bodla, Chhuikhadan, Mandla, Nainpur and Paraswada. In which Bicchiya, Mandla, and Nainpur are blocks of Mandla district, Baihar, Birsa and Paraswada are blocks of Balaghat; Chuuikhadan block is part of Rajnandgaon district, and Bodla is part of Kabirdham district. The percent of area of Baihar, Bichhiya, Birsa, Bodla, Chhuikhadan, Mandla, Nainpur and Paraswada blocks within the Banjar river watershed is 32.87%, 2.23%, 31%, 25.5%, 5.9%, 1.4%, 16.68% and 47.02% respectively of their total geographical area of development block. Various development blocks included in the Banjar river watershed is shown in Fig.4.4.

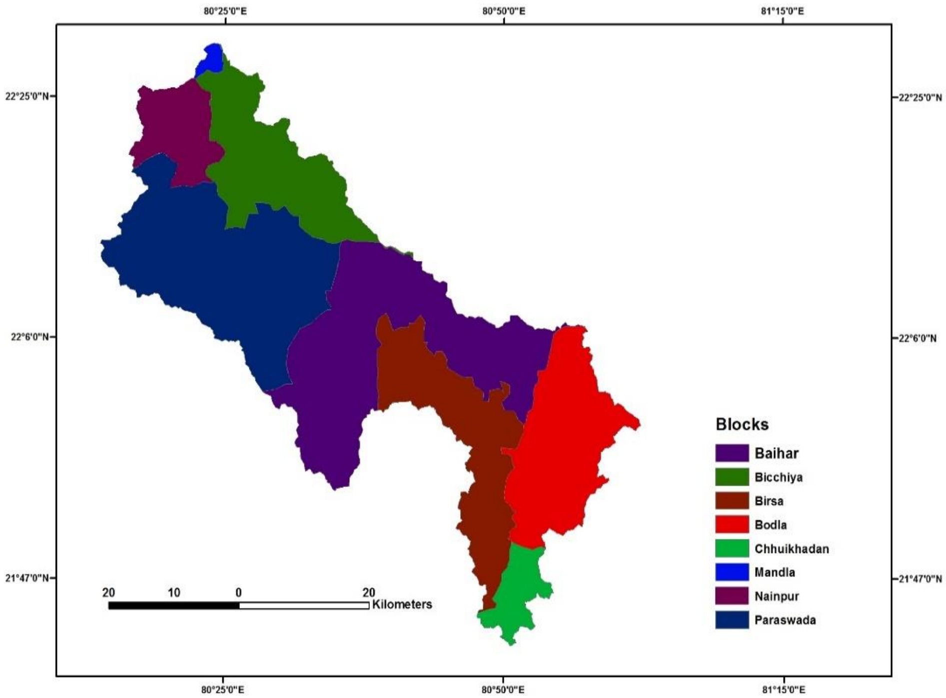

Fig 4.4 Blocks covered in the Banjar river watershed

4.3 Drinking water footprint

The data regarding drinking water required by livestock is obtained by the questionnaire based field survey of the owners of livestock residing in Banjar river watershed and is further discussed in the upcoming sections.

4.3.1 Drinking water footprint of cow

The data collected during the questionnaire based field survey concluded that the average drinking water requirement of a cow is 26.2 lit/day. The average body weight of a cow is 0.24 ton. Annual drinking water requirement is estimated as 9.49 m^3 per cow per year which is 39.54 m^3/ton/year. Considering the population of cows in various blocks within watershed, drinking water footprint of cows in Banjar river watershed have been worked out and presented Table 4.1. The Total drinking water footprint of cow within the Banjar river watershed is 1.730 MCM per year.

Table 4.1 Block wise drinking water footprint of cow

Block	Population	Drinking Water footprint MCM/year
Baihar	32964	0.313
Bichhiya	12607	0.120
Birsa	34069	0.323
Bodla	42455	0.403
Chhuikhadan	7619	0.072
Mandla	441	0.004
Nainpur	6803	0.065
Paraswada	45288	0.430
Total	182246	1.730

4.4.2 Drinking water footprint of buffalo

As per information obtained through field survey, average drinking water requirement of buffalo is 55.8 lit/day/buffalo. On annual basis, it is 20.367 m^3 per year per buffalo. On an average a buffalo in the watershed weighs 0.35 ton. Thus water footprint of buffalo is 58.19 m^3/ton/yr. The block wise drinking water footprint of buffalo is presented in Table 4.2. The Total drinking water footprint of buffalo in Banjar river watershed is 0.883 MCM per year.

Table 4.2 Block wise drinking water footprint of buffalo

Block	Population	Drinking water footprint MCM/year
Baihar	8950	0.182
Bichhiya	2230	0.045
Birsa	9250	0.188
Bodla	8399	0.171
Chhuikhadan	987	0.020
Mandla	79	0.002
Nainpur	1215	0.025
Paraswada	12296	0.250
Total	43406	0.883

4.4.3 Drinking water footprint of goat

The data collected during the questionnaire based field survey concluded that the average drinking water requirement of goat is 5.23 lit/day/goat. The average body weight of a goat is 0.04 ton. Annual drinking water requirement is estimated as 1.825 m^3 per goat per year which is 45.63 m^3/ton/year. The block wise drinking water footprint of goat is presented in Table 4.3. Total drinking water foot print for livestock in Banjar river watershed is 2.70 MCM per year.

Table 4.3 Block wise drinking water footprint of goat

Block	Population	Drinking water footprint MCM/year
Baihar	10436	0.019
Bichhiya	2173	0.004
Birsa	10725	0.020
Bodla	7587	0.014
Chhuikhadan	1034	0.002
Mandla	77	0.000
Nainpur	1184	0.002
Paraswada	14257	0.026
Total	47473	0.087

4.5 Servicing water footprint

For organised and unorganised farm the servicing water requirement are different. Servicing water used in organised farm are higher than the water used in unorganised farm. Servicing water footprint included freshwater used for bathing and cleaning of livestock in Banjar river watershed.

4.5.1 Servicing water footprint of cow

As per information obtained through field survey, average servicing water requirement of cow is 9.3 lit/day/cow. On annual basis it is 3.39 m^3 per year per cow. On an average a weight of cow in the watershed is 0.240 ton. Thus water footprint of cow is 14.14 m^3/ton/yr. The lower value of servicing is a consequence as a cow did not require water for bathing daily. In summer, they bath once or twice a week or ten days. The amount of water is used only for cleaning of farm. Block wise servicing water footprint of cow is shown in Table 4.4.

Table 4.4 Block wise servicing water footprint of cow

Block	Population	Servicing water foot print MCM/year
Baihar	32964	0.112
Bichhiya	12607	0.043
Birsa	34607	0.117
Bodla	42455	0.144
Chhuikhadan	7619	0.026
Mandla	441	0.001
Nainpur	6803	0.023
Paraswada	45288	0.154
Total	182784	0.620

4.5.2 Servicing water footprint of buffalo

The data collected during the questionnaire based field survey concluded that the average servicing water requirement of a buffalo is 21.7 lit/day. The average body weight of a buffalo is 0.350 ton. Annual servicing water requirement is estimated to be 7.96 m^3 per buffalo per year which is 22.73 m^3/ton/year. This value of servicing is due to the reason that buffalo required more water for bathing and cleaning. The Block wise servicing water footprint of buffalo is shown in Table 4.5.

Table 4.5 Block wise servicing water footprint of buffalo

Block	Population	Servicing water foot print MCM/year
Baihar	8950	0.071
Bichhiya	2230	0.018
Birsa	9250	0.074
Bodla	8399	0.067
Chhuikhadan	987	0.008
Mandla	79	0.001
Nainpur	1215	0.010
Paraswada	12296	0.098
Total	43406	0.347

4.5.3 Servicing water footprint of goat

Servicing water requirement of goat is very less. The lower value of servicing is due to the goat did not require water for bathing. They are very sensitive with water.

Total servicing water footprint of livestock in the Banjar river watershed is 0.967 MCM per year.

4.6 Direct water footprint of livestock

Direct water footprint is calculated by the freshwater used directly by the livestock (cow, buffalo and goat). It incorporated drinking water footprint and servicing water footprint. Servicing water footprint included freshwater used for bathing the livestock and cleaning the dairy farm which kept the animals. The direct water footprint of livestock is depicted in Table 4.6.

Table 4.6 Block wise direct water footprint of livestock

Block	Cow	Buffalo	Goat	Direct WF of livestock (MCM /year)
Baihar	0.425	0.182	0.0190	0.6260
Bichhiya	0.162	0.045	0.0040	0.2110
Birsa	0.446	0.188	0.0196	0.6536
Bodla	0.547	0.171	0.0138	0.7318
Chhuikhadan	0.098	0.020	0.0019	0.1199
Mandla	0.006	0.002	0.0001	0.0081
Nainpur	0.088	0.025	0.0022	0.1152
Paraswada	0.584	0.250	0.0260	0.8600
Total	2.356	0.883	0.0866	3.3280

4.7 Feeding water footprint

Feeding water footprint is the summation of the total volume of water used for producing the fodder crop. Feeding water footprint is contributed maximum amount of water footprint in assessment of water footprint of livestock.

4.7.1 Water footprint of fodder

The calculation of water footprint of different fodder crops described in Appendix 2 to Appendix 6. The water footprint of wheat straw, rice straw, maize, *barseem* and sorghum are described below. These five fodder crops are mainly used for feeding purpose of the livestock (cow, buffalo and goat) in stall feeding within the Banjar river watershed.

4.7.1.2 Water footprint of wheat straw

The spatially distribution map of water footprint of wheat straw is drawn so as to study the spatial variation of water footprint of wheat straw. The water footprint of wheat straw varied from 900-1900 m^3/ton. The calculation of water footprint of wheat straw shown in Appendix-2. For calculating block wise water footprint of the wheat straw the average value would be taken. The block wise water footprint of wheat straw in the Banjar river watershed is depicted in Fig. 4.5. The water footprint is very much high in I lower lying areas of the watershed and it is low in higher elevation areas.

The water footprint of wheat straw is maximum in Mandla block followed by Nainpur and Bicchiya because of the lower residue yield of wheat straw in Mandla block. The minimum in Bodla and Chhuikhadan block followed by Baihar and Birsa block because of higher yield of the wheat straw in Bodla and Chhuikhadan block. The block wise water footprint of wheat straw in the Banjar river watershed is depicted in Table 4.7.

Table 4.7 Block wise water footprint of wheat straw

Block	Water footprint of wheat straw MCM per year
Baihar	1071.25
Bichhiya	1443.10
Birsa	1071.25
Bodla	990.50
Chhuikhadan	990.50
Mandla	1798.50
Nainpur	1475.50
Paraswada	1314.00

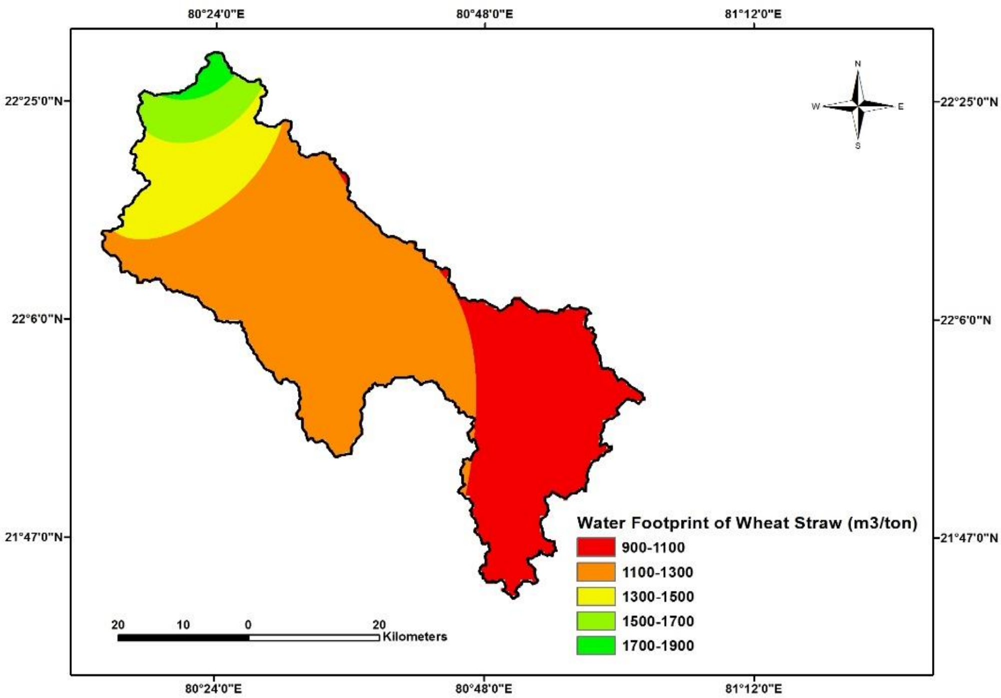

Fig 4.5 Variation in water footprint of wheat straw in Banjar River watershed

4.7.1.3 Water footprint of rice straw

The calculation of water footprint of rice straw shown in Appendix-3. The spatially distribution map of water footprint of rice straw drawn using ArcToolbox in Arc GIS software. The water footprint of rice straw varies from 1500-2500 m^3/ton. The water footprint of rice within the Banjar river watershed is shown in Fig. 4.6.

The water footprint of rice straw is maximum in Mandla block followed by Birsa and Nainpur because of the lower residue yield of rice straw in Mandla block. The minimum in Bodla and Chhuikhadan block followed by Baihar and Paraswada block because of higher yield of the rice straw in Bodla and Chhuikhadan block. The block wise water footprint of rice straw in the Banjar river watershed is depicted in Table 4.8.

Table 4.8 Block wise water footprint of rice straw

Block	Water footprint of rice straw MCM per year
Baihar	2002.90
Bichhiya	1941.75
Birsa	2136.50
Bodla	1969.50
Chhuikhadan	1969.50
Mandla	2386.75
Nainpur	2053.00
Paraswada	2020.00

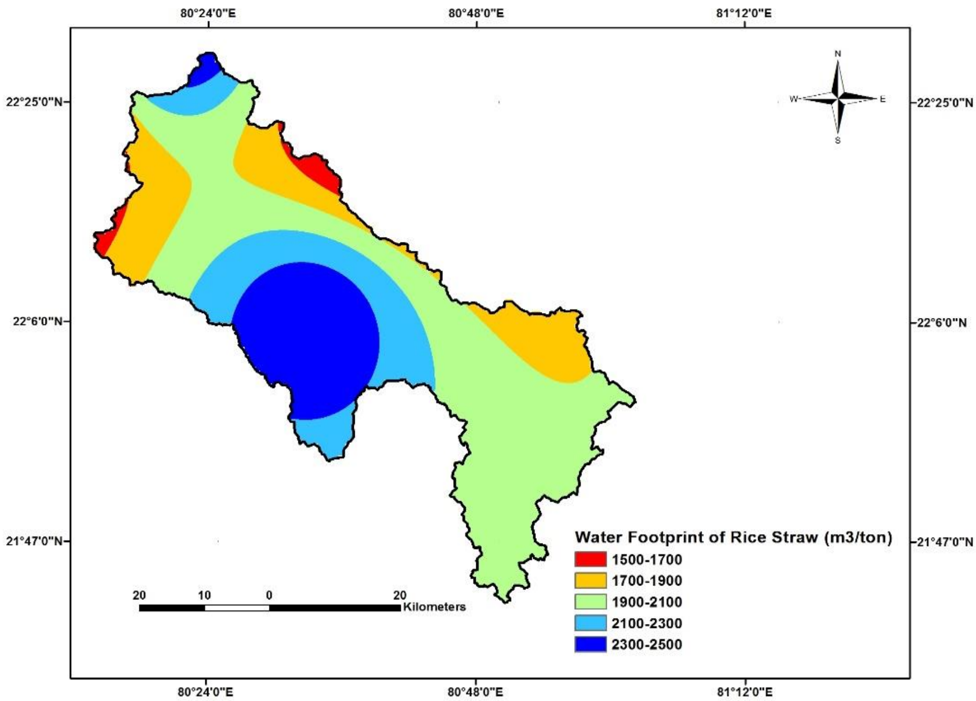

Fig 4.6 Variation in water footprint of rice straw in Banjar river watershed

4.7.1.4 Water footprint of maize

The calculation of water footprint of maize shown in appendix 4. The spatially variable map of water footprint of maize drawn using ArcToolbox in Arc GIS software. The water footprint of maize varies from 4500-7000 m^3/ton. The water footprint of maize within the Banjar river watershed is shown in Fig. 4.7.

The water footprint of maize is maximum in Mandla block followed by Nainpur and Bicchiya because of the lower crop yield of maize in Mandla, Nainpur and Bichhiya block. The minimum in Birsa and Baihar block followed by Baihar and Paraswada block because of higher yield maize in Bodla and Chhuikhadan block. The block wise water footprint of maize in the Banjar river watershed is depicted in Table 4.9.

Table 4.9 Block wise water footprint of maize

Block	Water footprint of maize MCM per year
Baihar	4857
Bichhiya	5907
Birsa	4857
Bodla	5067
Chhuikhadan	5067
Mandla	6747
Nainpur	6327
Paraswada	5277

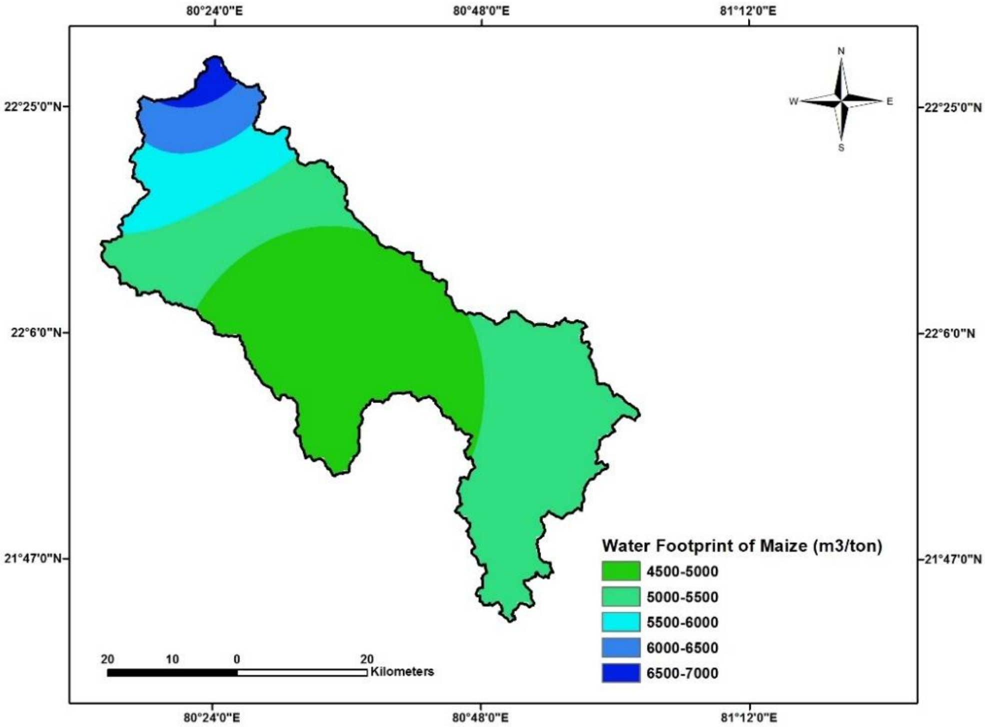

Fig 4.7 Variation in water footprint of maize in Banjar river watershed

4.7.1.5 Water footprint of Barseem

The calculation of water footprint of *barseem* shown in appendix 4. The spatially variable map of water footprint of *barseem* drawn using ArcToolbox in Arc GIS software. The water footprint of *barseem* varies from 200-800 m^3/ton. The water footprint of *barseem* within the Banjar river watershed is presented in Table 4.10 and shown in Fig. 4.8.

The water footprint of *barseem* is maximum in Nainpur block followed by Bichhiya and Paraswada with 670 MCM per year, 558.5 MCM per year and 391 MCM per year respectively. The Minimum water footprint is in Birsa block with 280 MCM per year.

Table 4.10 Block wise water footprint of barseem

Block	Water footprint of barseem MCM per year
Baihar	224.5
Bichhiya	558.5
Birsa	280.0
Bodla	335.5
Chhuikhadan	335.5
Mandla	781.5
Nainpur	670.0
Paraswada	391.0

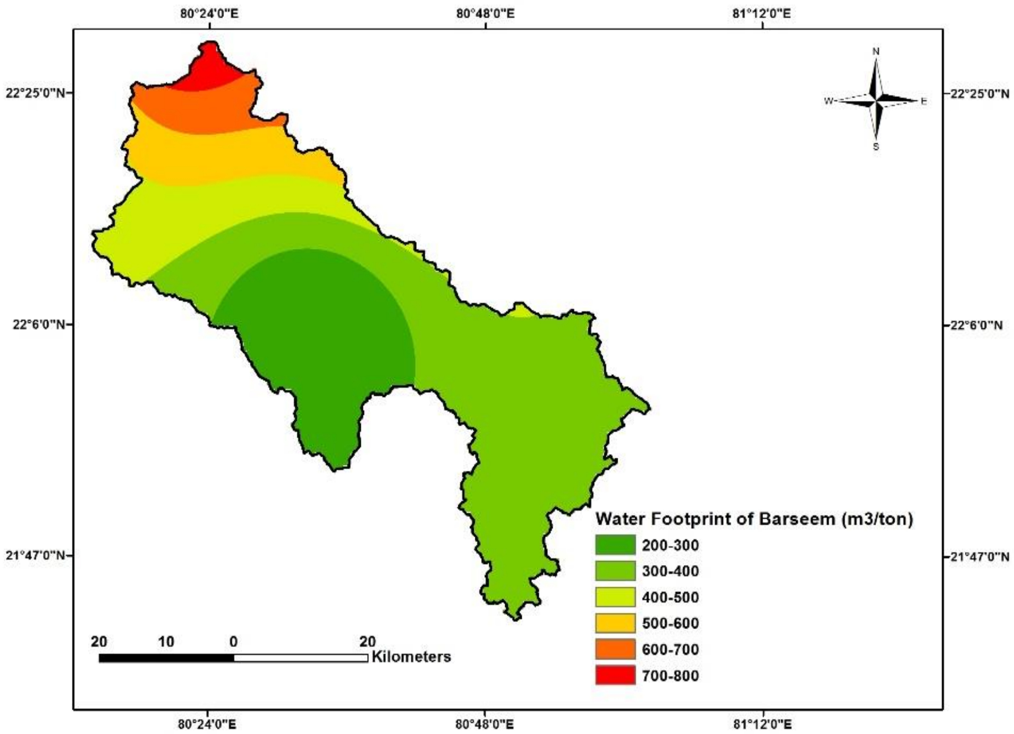

Fig 4.8 Variation in water footprint of *barseem* in the Banjar River Watershed

4.7.1.6 Water footprint of sorghum

The calculation of water footprint of sorghum shown in appendix 5. The spatially variable map of water footprint of sorghum drawn using ArcToolbox in Arc GIS software. The water footprint of sorghum varies from

1050-1550 m^3/ton. The water footprint of sorghum within the Banjar river watershed is presented in Table 4.11 shown in Fig. 4.9.

The water footprint of sorghum is maximum in Paraswada and Baihar followed by Birsa block of Banjar river watershed and minimum in Mandla block followed by Bicchiya, Chhuikhadan and Nainpur.

Table 4.11 Block wise water footprint of sorghum

Block	Water footprint of sorghum MCM per year
Baihar	1313.5
Bichhiya	1198.0
Birsa	1275.0
Bodla	1159.5
Chhuikhadan	1198.0
Mandla	1159.5
Nainpur	1198.0
Paraswada	1313.5

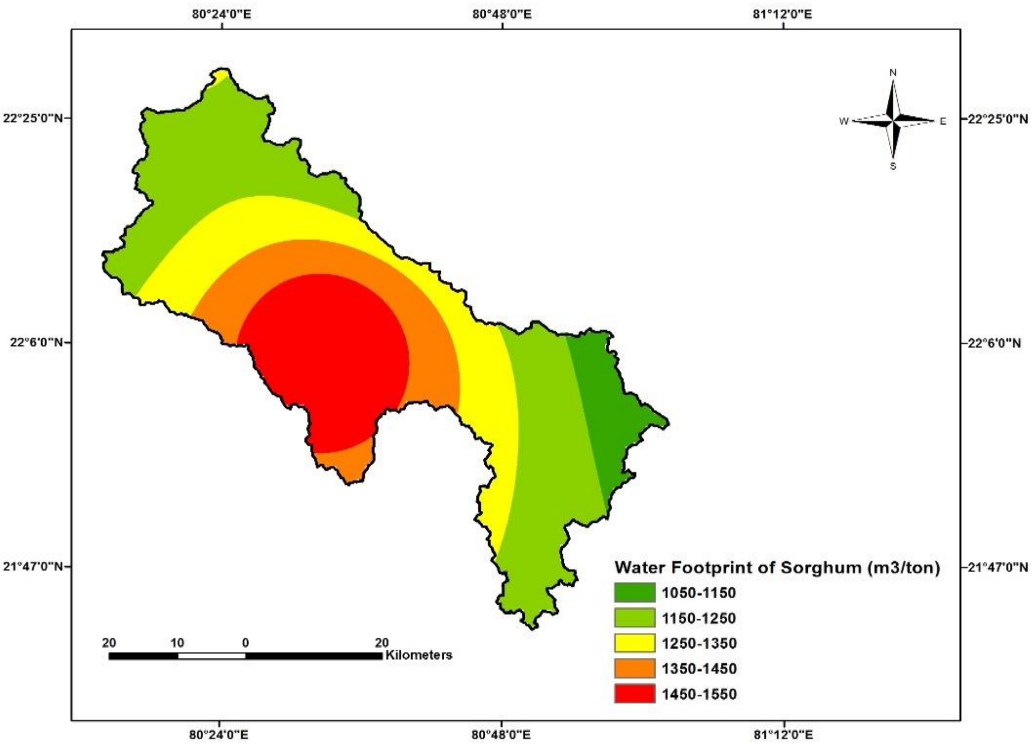

Fig 4.9 Variation in water footprint of sorghum within the Banjar river watershed

4.7.2 Feeding water footprint of livestock

Feeding water footprint of livestock is comprised as freshwater used by livestock in Banjar river watershed. Feeding water footprint of cow, buffalo and goat is discussed in detail below.

4.7.2.1 Feeding water footprint of cow

During the questionnaire based field survey of Banjar river watershed and the observations taken from the Nanaji Deshmukh Veterinary Science University, Jabalpur it is calculated that the average weight of dry and green fodder fed to the cow is 7 kg/day and 8.2 kg/day. Than it multiplied with the water footprint of particular crop. The dry and green water footprint of fodder crop separately calculated than summing up them. The block wise calculation of dry and green fodder crop depicted in appendix 2(a). Block wise feeding water footprint of cow is described in Table 4.12.

Table 4.12 Block wise feeding water footprint of cow

Block	Population	Feeding Water footprint MCM per year
Baihar	32964	3.78
Bichhiya	12607	1.46
Birsa	34607	5.15
Bodla	42455	5.58
Chhuikhadan	7619	0.88
Mandla	441	0.06
Nainpur	6803	0.97
Paraswada	45288	5.29
Total	182784	23.16

4.7.2.2 Feeding water footprint of buffalo

During the questionnaire based field survey of Banjar river watershed and the observations taken from the Nanaji Deshmukh Veterinary Science University, Jabalpur it is calculated that the average weight of dry and green fodder fed to the buffalo is 9 kg/day and 17.7 kg/day. Than it multiplied with the water footprint of particular crop. The block wise calculation of dry and green fodder crop depicted in appendix 2(b). Block wise feeding water footprint of buffalo is depicted in Table 4.13.

Table 4.13 Block wise feeding water footprint of buffalo

Block	Population	Feeding water footprint MCM per year
Baihar	8950	7.737
Bichhiya	2230	2.965
Birsa	9250	10.695
Bodla	8399	11.595
Chhuikhadan	987	1.810
Mandla	79	0.113
Nainpur	1215	1.998
Paraswada	12296	10.821
Total	43406	47.734

4.7.2.3 Feeding water footprint of goat

During the questionnaire based field survey of Banjar river watershed and the observations taken from the Nanaji Deshmukh Veterinary Science University, Jabalpur it is calculated that the average weight of dry and green fodder fed to the goat is 5 kg/day and 5.15 kg/day. Than it multiplied with the water footprint of particular crop. Goats are generally feed by grazing within the Banjar river watershed. Block wise feeding water footprint goat is described in Table 4.14.

Table 4.14 Block wise Feeding water footprint of goat

Block	Population	Feeding WF MCM per year
Baihar	10436	0.79
Bichhiya	2173	0.17
Birsa	10725	1.04
Bodla	7587	0.65
Chhuikhadan	1034	0.08
Mandla	77	0.01
Nainpur	1184	0.11
Paraswada	14257	1.09
Total	47473	3.94

4.7.3 Mixing water footprint

A small amount of water is used for mixing of the concentrate in feeding material. Concentrates are feed to supplement the nutrient requirement and enhance the quantity and quality of milk.

4.7.3.1 Mixing water footprint of cow

As per information obtained through field survey, average mixing water requirement of cow is 2.21 lit/day/cow. On annual basis it is 0.81 m^3 per year per cow. On an average a cow in the watershed area weighs 0.240 ton. Thus water footprint of cow is 0.148 MCM/yr. The mixing water footprint of cow within the Banjar river watershed is sown in Table 4.15.

Table 4.15 Block wise mixing water footprint of cow in Banjar river watershed

Block	Population	Mixing Water Footprint MCM per year
Baihar	32964	0.027
Bichhiya	12607	0.010
Birsa	34607	0.028
Bodla	42455	0.034
Chhuikhadan	7619	0.006
Mandla	441	0.000
Nainpur	6803	0.006
Paraswada	45288	0.037
Total	182784	0.148

4.7.3.2 Mixing water footprint of buffalo

The data collected during the questionnaire based field survey concluded that the average mixing water requirement of a buffalo is 2.2 lit/day. The average body weight of buffalo is 0.350 ton. Annual mixing water requirement is estimated as 0.74 m^3 per buffalo per year which is 0.032 MCM/year. The block wise mixing water footprint of buffalo is described in Table 4.16.

Table 4.16 Block wise mixing water footprint of buffalo in Banjar river watershed

Block	Population	Mixing Water Footprint MCM per year
Baihar	8950	0.007
Bichhiya	2230	0.002
Birsa	9250	0.007
Bodla	8399	0.006
Chhuikhadan	987	0.001
Mandla	79	0.000
Nainpur	1215	0.001
Paraswada	12296	0.009
Total	43406	0.032

4.7.4 Indirect water footprint of livestock

Indirect water footprint is the freshwater used by the livestock (cow, buffalo and goat) not directly in form of water but indirectly used by the livestock (cow, buffalo and goat). Indirect water footprint is the summation of the volume of water used for mixing of feeding material and the volume of water used for producing the fodder crop as well as grazing. Indirect water footprint also calculated block wise. Indirect water footprint of livestock (cow, buffalo and goat) are narrated below in Table 4.17.

Table 4.17 Block wise indirect water footprint of livestock

Block	Cow	Buffalo	Goat	Indirect WF of livestock MCM per year
Baihar	3.78	7.737	0.79	12.30
Bichhiya	1.46	2.965	0.17	4.59
Birsa	5.15	10.695	1.04	16.89
Bodla	5.58	11.595	0.65	17.82
Chhuikhadan	0.88	1.810	0.08	2.77
Mandla	0.06	0.113	0.01	0.18
Nainpur	0.97	1.998	0.11	3.08
Paraswada	5.29	10.821	1.09	17.20
Total	23.15	47.734	3.94	74.83

4.8 Water footprint of Livestock in Banjar river watershed

The summation of direct and indirect water footprint of livestock resulted total water footprint of livestock. It is estimated 78.15 MCM/year. The block wise water footprint of livestock narrated below in Table 4.18.

Table 4.18 Block wise water footprint of livestock within the Banjar river watershed

Block	WF_{cow}	$WF_{buffalo}$	WF_{goat}	WF livestock MCM/year
Baihar	4.20	7.92	0.80	12.93
Bichhiya	1.62	3.01	0.17	4.80
Birsa	5.60	10.88	1.06	17.55
Bodla	6.12	11.77	0.67	18.55
Chhuikhadan	0.98	1.83	0.08	2.89
Mandla	0.06	0.11	0.01	0.18
Nainpur	1.05	2.02	0.11	3.19
Paraswada	5.87	11.07	1.12	18.06
Total	25.51	48.62	4.02	78.15

The area of watershed is 2506 km^2 and the average annual rainfall over the watershed is 1.2 m. Using these data we can determine the total available water which when calculated gave the value of 1402 MCM as total available water. The total water footprint of livestock in Banjar river watershed is 78.150 MCM/yr. Thus we can conclude that there is a lot of scope to intensify the water footprint of livestock.

CHAPTER – 5

SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR FURTHER WORK

5.1 Summary

Water is very important natural resource. Livestock requires large volumes of water for feed production, drinking water and servicing animals. It is very essential to manage the water resource so that the optimum freshwater used enough to supply the demand of the animal product. The water footprint is a consumption based indicator of water use and refers to all forms of freshwater use (direct and indirect) that contribute to the production of goods and services consumed by the inhabitants of a given geographical region.

The present study is conducted to assess water footprint of livestock in Banjar river watershed which falls in the part of Upper Narmada Basin. The watershed lies in the Balaghat and Mandla districts of Madhya Pradesh. It is geographically located in between 20°41’ N and 23°29’ N latitudes and 80°22’ E and 81°00 E longitudes. The watershed covers total geographical area of 2460.84 km^2 up to the gauging point. The general elevation of the watershed varied from 442 m to 905 m. Climate of the area is tropical with moderate winter and severe summers and it generally received rainfall from southwest monsoon.

Considering all the above discussed points, detailed study of the Banjar river watershed is planned with the following specific objectives:

1. To determine drinking water footprint of livestock within Banjar River Watershed
2. To determine feeding water footprint of livestock within Banjar River Watershed
3. To determine servicing water footprint of livestock within Banjar River Watershed

Initially the watershed is delineated using ArcGIS 9.3 software and the block lying in watershed is identified. The blocks lying in the watershed are Baihar, Bicchiya, Birsa, Bodla, Chhuikhudan, Mandla, Nainpur and Paraswada. The proportionate value of the area of blocks taken into consideration for the calculation of the population of livestock. The field survey done in Banjar river watershed for observation of drinking, servicing and feeding habits of livestock within the watershed. Using the methodology given by Zhao *et al.* (2015) the water footprint of livestock is estimated. The crop water requirement of fodder crops are calculated using CROPWAT 8.0 software. The water footprint of fodder crop estimated using the methodology given by Hoekstra *et al* (2009). Following salient features are observed during the study

- The water footprint of cow is in 25.51 MCM/year Banjar river watershed
- The water footprint of buffalo is 48.62 MCM/year in Banjar river watershed
- The water footprint of goat is 4.02 MCM/year in Banjar river watershed.
- The total water footprint of livestock in Banjar river watershed is 78.15 MCM/year.
- The drinking water footprint of livestock in the Banjar river watershed is 2.700 MCM/year.
- The servicing water footprint of livestock within the Banjar river watershed is 0.965 MCM/year.
- The feeding water footprint of livestock within the Banjar river watershed is 74.830 MCM/year.
- The water footprint of livestock in the Banjar river watershed is 78.150 MCM/year.

5.2 Conclusions

From the study carried out on assessment of water footprint of the livestock (cow buffalo and goat) in the Banjar river watershed, following conclusions can be drawn.

- The drinking water footprint of livestock in the Banjar river watershed is 2.700 MCM/year.
- The servicing water footprint of livestock within the Banjar river watershed is 0.965 MCM/year.
- The feeding water footprint of livestock within the Banjar river watershed is 74.830 MCM/year.
- The water footprint of livestock in the Banjar river watershed is 78.150 MCM/year.

The area of watershed is 2506 km^2 and the average annual rainfall over the watershed is 1.2 m. Using these data we can determine the total available water which when calculated gave the value of 1402 MCM as total available water (considering 40 % runoff). The total water footprint of livestock in Banjar river watershed is 78.150 MCM/yr. Thus we can conclude that there is a lot of scope to intensify the water footprint of livestock.

5.3 Suggestions for further work

The water footprint of milk production in the watershed can also be determined in Banjar river watershed and also a comparative study on the water footprint of milk production for the unorganised and organised farms can be executed.

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