WATER FOOTPRINT ANALYSIS OF DELHI TO UNDERSTAND ITS SUSTAINABILITY

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I, Vaibhav, Roll No. 2K17/ENE/16 student of M. Tech (Environmental Engineering), hereby declare that the project Dissertation titled "Water Footprint Analysis of Delhi to understand its sustainability" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title of recognition.

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ABSTRACT

Environmental footprint and sustainability are gaining a lot of emphasis because of the increased burden on environmental resources due to increasing population density, increasing living standards, lower crop productivity in some regions, changes in diet pattern etc particularly in cities. The rate of consumption of environmental resources by human beings is much higher than the regenerative capacity of the environment. Environmental resources are fixed hence its allocation must be such that a consumer, group, region or nation gets sufficient environment resources for its development. Major environmental footprints are water footprint, carbon footprint and ecological footprint which can be used to account for human activities and consumption pattern. Major disadvantage of these footprints is not considering issues associated to sustainability like soil loss, forest loss etc. These issues are considered by sustainability indicators such as environmental sustainability index (ESI) which is a helpful tool giving values to sustainability from 0 to 100 (100 being most sustainable and 0 being least sustainable). In this report, studies have been carried out to find water footprint of Delhi and to estimate its future footprint using water footprint assessment method. Water footprint of Delhi in the year 2011 came out to be 4691 lpcd which is greater than Indian average water footprint of 4095 lpcd. Interestingly around 94% of water footprint of a person in Delhi is due to indirect consumption in the form of goods and services. Since there are no agricultural practices in Delhi, therefore around 91-94% of total water footprint of Delhi is being imported from other regions and only about 6-9% of the total water footprint is being supplied by Delhi Jal Board. Study of ecological and carbon footprint will give idea about the intensity with which citizens of Delhi are using environmental resources while environmental sustainability index will define how sustainable human activities are in Delhi.

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LIST OF ABBREVIATIONS

WF Water Footprint

WFA Water Footprint Assessment

DJB Delhi Jal Board

DDA Delhi Development Authority

WFN Water Footprint Network

FAO Food and Agriculture Organisation

LPCD Litre per capita per day

GPCD Gallon Per Capita Per Day

GHG Greenhouse Gases

LCA Life Cycle Assessment

ESI Environmental Sustainability Index

CHAPTER 1

INTRODUCTION

1.1 Background and Significance

Today, 55% of the world's population lives in urban areas and it is expected to increase to 68% by 2050. Cities are the congested economic hub of any nation, due to increasing urban population density it is likely that many nations will face challenges in meeting the increasing demands of land, energy, environment etc (World Urbanization Prospects).

The environment is considered as a free resource but with excessive pressure on environmental resources due to increasing industrialisation, urbanisation and population density, especially in cities, people and organizations have started realising that environment shouldn't be considered as a free resource because the environment has a limit on its regeneration capacity. Therefore, the allocation of environmental resources for various human activities and development processes without exceeding the regenerative capacity of environment can be a key challenge for policy makers and governments.

To account for human activities and consumption an indicator is needed; footprints are such indicators. Footprints can quantify human activities, trade and consumption of various products in numeric values and hence can be used for comparison and analysis. For example, the carbon footprint of a region can give kg of CO2 produced due to various activities within the boundary of that region. Footprints can be used as a tool in the process of decision and policy making. There are numerous types of footprints but only three footprints from footprint family will be discussed in this report, that are water footprint, ecological footprint and carbon footprint. It is a common perception that environmental resources such as water, air and land are a local phenomenon, but due to increased globalisation and trade practices, products are bought or exchanged among different regions/nations which have hidden or virtual water in it.

The manufacturing of these products requires local environmental resources such as water, land, raw materials etc. Therefore, contrary to common perception, environmental resources like water, land etc. are traded through the trade of goods and services among different regions. An example to conclude how important trade policies, policy making and sustainable thinking can be to reduce pressure on the local environment is that the transfer trend of environmental footprints through trade between China and EU was analysed, which showed that EU countries caused 8.21 times of emission footprint than China's, and China provided 6.25 times of energy footprint, 16.76 times of land footprint and 17.38 times of water footprint for EU countries' final consumption (Tian et al., 2017).

Sustainability and its concept was first discussed in the Brundtland Report. This report concludes that changing the approach and concept of human development is necessity of the hour as the ecology of our planet is suffering serious and irreversible damage (Siche et al., 2008). For example, sustainability is being used in product design of industries where the aim is to achieve cleaner production with special consideration for environmental impacts of a product in the whole life cycle (He et al., 2017). This can be achieved by a number of ways such as by increasing the efficiency of the process, changing to less harmful raw material etc.

The footprint family (set of indicators or footprints to account human pressure on the planet has a wide scope of policy applications and research as it can be employed at scales ranging from a single product, a process, a sector, up to individuals, cities, nations, and the whole world. The footprint family helps to understand sustainability in a comprehensive and integrated way. However, several other environmental, social and economic issues are not considered therefore it cannot be considered as a complete measure of sustainability (Galli et al., 2010).

Delhi is the capital city of the India. According to census 2011, it was the second most populous city in India with an estimated population of 11.03 million, and population density of 11297 persons per square kilometers, in comparison to India’s average population density is 382 persons per square kilometers (Census, 2011).

Current water productivity in agriculture in India is lower than that of the global average. With rapid population growth, it seems inevitable for India to become water scarce nation (Falkenmark, 1997). To tackle the situation there are two possible ways, first can be by increasing the crop productivity, second can be by changing consumption pattern. Only increasing the crop productivity or only changing consumption pattern won't be effective in the long run hence both the options should go hand in hand. Water saving can be created by trading a product having higher virtual water content in the water-scare state than in the water-rich state (Chapagain & Hoekstra, 2006).

1.2 Aim and objectives

The current project work is centred on the following objectives:

- To find water footprint of Delhi
- To forecast the water footprint of Delhi for 2021
- To find losses in WF during various processes
- To perform a sensitivity analysis with respect to various consumption products
- To find limitations in existing policy or practice

1.3 Organization of report

This report consists of five chapters. The first chapter includes the background information, objectives and scope of the study. The second chapter consists of the literature available on the environmental footprint. Chapter three discusses the data collected and the methodology used in the study. The fourth chapter summarizes the results obtained from the analysis of data available. The final fifth chapter includes the summary and future scope of work. This report focuses on finding water footprint of Delhi

CHAPTER 2

LITERATURE REVIEW

2.1 FOOTPRINT FAMILY

Footprint family is set of indicators to track pressure created by human activities on the planet. The footprint family comprises of ecological footprint, carbon footprint, water footprint and others. A footprint is an indicator that quantifies how human activities are imposing different types of burdens and impacts on the environment and global sustainability (Paterson et al., 2015). According to global footprint network objective of footprint analysis is to track cities‟ demand on natural resources and to compare this demand with available resources and shedding light on region's constraints or future liabilities (Hoff et al., 2014).

2.1.1 Ecological footprint

It is an accounting tool measuring direct and indirect human demand for the planet's regenerative capacity and comparing it with the bio-capacity available on the planet (Wackernagel et al., 1999). As given by Galli et al., 2012 "the demand for six main types of bio-productive areas, each providing different resources and ecosystem services, is considered: (1) cropland for the provision of plant-based food: (2) grazing land and cropland for the provision of animal-based food and other animal products; (3) fishing grounds (both marine and inland) for the provision of fish-based food products; (4) forest areas for the provision of timber and other forest products; (5) carbon uptake land for the absorption of anthropogenic carbon dioxide emissions; and (6) built-up area representing productivity lost due to the occupation of physical space for shelter and other infrastructure".

For example, using the ecological footprint concept which tracks national economies and resources it was found out that the ecological footprint of India in 1997 was 0.8 ha/cap against 0.5 ha/cap available ecological footprint, hence ecological deficit of 0.3 ha/cap. Ecological deficit means more resources were being utilized than what was available or what could be regenerated within the boundaries of India (Wackernagel et al., 1999).

Human activities are generating wastes such as CO2, at a much higher rate than what biosphere can dispose, as a result, the capacity of the natural ecosystem to provide the necessary life support systems for mankind is likely to decrease in the coming decades. Amount of per-capita biological capacity has fallen because of increasing population growth and this has led to growing ecological deficits all around the world. Units of the ecological footprint are the area of land necessary to regenerate the respective resource flow (Ewing at el., 2012).

2.1.2 Carbon footprint

The carbon footprint measures the total amount of GHG (Greenhouse Gas) emissions caused by an activity or is accumulated over the life stage of a product (includes goods and services). It includes activities of individuals, population, government, industry sectors, organisations, companies, processes etc. Carbon footprint of a region is the total amount of carbon produced by all the activities within the boundary of that region it may be due to consumption of product at individual level, household level, by government, through trade etc. If only CO_2 is considered, the unit is kg CO_2 but if other GHGs are considered, CO_2- equivalent is used and the unit becomes kg CO_2-e (Galli et al., 2010).

For example, in 2001 based on emissions embodied in construction, shelter, food, clothing, manufactured products, mobility, service and trade it was found out that India had per capita carbon footprint of 1.8 ton CO_2-e while the USA had per capita carbon footprint of 28.6 ton CO_2-e which signifies drastic difference in the environmental resources use pattern in the developing and developed nations (Pandey et al., 2011).

Methodology used for carbon footprint analysis depends upon the objective of the study and the availability of the data, however life cycle assessment (LCA) approach is being widely used. LCA can be done by two approaches first is top down and second is bottom up In bottom up approach carbon emission from each product and activity is summed up to move up the ladder and find total carbon footprint. Top down approach uses economic input-output model where matrices are solved (Pandey et al., 2011).

2.1.3 Water footprint

Any human activity whether it is the production of crops or raising of animals for meat or dairy products or any other day to day activity such as bathing, drinking water etc., it requires water, hence the volume of water for a particular activity/product is called as its water footprint. For example, if a t-shirt is bought by a person, obviously there is no direct water exchange but indirectly the virtual water being exchanged is around 2700 litres (Ridoutt et al., 2010). In India rice grown in different states shows huge variation in the water footprint required for its production. For example, in Punjab water footprint required to grow 1 kg of rice is 2914 L while the same 1 kg of rice will need 8142 L of water footprint in Madhya Pradesh (Kampman, 2007).

Hence, if Madhya Pradesh is facing drought, instead of growing rice that year we can get rice exported from Punjab (economic viability must also be considered). Therefore, the concept of water footprint and virtual water becomes very important for decision makers and governments.

Water footprint is discussed in detail in the next section.

2.2 WATER FOOTPRINT

It is an indicator of usage of water as it traces the flow of water directly (domestic water use) and indirectly (water required to produce industrial and agricultural products) through consumption of products (Ahams et al., 2017). Indirect water is also referred as embedded or virtual water. It can be also be defined as the total volume (metre cube) of freshwater used for the production of goods and services consumed by an individual, region or nation. (Paterson et al., 2015)

It is important to understand the difference between the water footprint of production (WFprod) and the water footprint of consumption (WFcons). The former is the sum of direct and indirect water use of regional water resource used in the process of production and latter is the sum of direct and indirect water use of regional and foreign water resource through domestic consumption (Vanham and Bidoglio, 2013).

For any region or nation,

$$WFcons = WFprod +/- \text{Virtual Water}$$

2.2.1 Virtual water

As the name suggests, transfer of virtual water is not the actual transfer of water but pseudo water in form of trade (import or export) of industrial and agricultural products. Professor Tony Allan first used the term virtual water for the water used for crop production traded in markets internationally (Allan 1996). After being coined, the term virtual water has gained much of the attention of public officials and policymakers to ensure wise use of limited water resources.

Virtual water has received enormous attention in the recent years through both academia and media.

The concept of virtual water can be used as a water scarcity reducing strategy and it has been suggested that water-scarce countries should import water-intensive products from water-rich countries while using their limited water resources for more essential and basic activities. However only virtual water cannot be used as a criterion for optimal policies formation, it might happen that optimal strategy from virtual water perspective is not consistent with economic trading strategies (D. Wichelns, 2010).

Since the 1990s, several researchers have estimated the flow of virtual water between different countries by calculating the water used to produce crops which are then traded (Chapagain & Hoekstra, 2004). This helped people understand how trade can help water-deficit nations in becoming water sufficient without actual transfer of water. India has a large amount of water resources but still, India faces water scarcity, by increasing crop productivity and existing trade patterns among different states, India can become water self-sufficient (Hoekstra & Mekonnen, 2012).

2.2.2 Classification of water footprint

There are two classifications of water footprint:

Classification 1: Water footprint is classified as direct and indirect to distinguish between the natures of the water footprint.

- Direct water footprint
- Indirect water footprint

Classification 2: Water footprint is divided as blue water, green water and grey water to account for various water sources and water quality levels.

- Blue water footprint
- Grey water footprint
- Green water footprint

2.2.2.1 Direct and indirect water footprint

The direct water footprint refers to the water consumption and pollution that is related to water supplied directly to any consumer.

The indirect water footprint refers to the water consumption and pollution of water that is caused by the production of the goods and services used by the consumer. It refers to the water that was used to produce the food, paper, clothes, energy, raw material etc (Hoekstra et al., 2009).

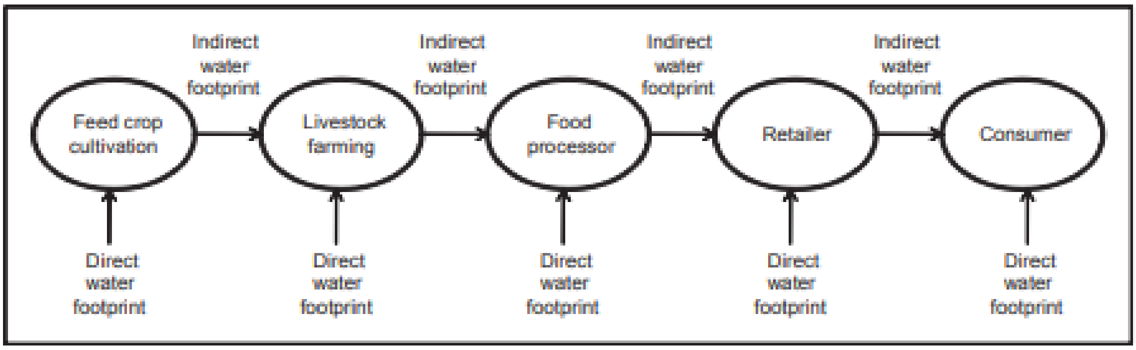

Figure 2.1 The direct and indirect water footprint of an animal product in each stage of the supply chain (Source: Hoekstra et al., 2009)

2.2.2.2 Blue, green and grey water footprint

The **Blue** water footprint refers to the water taken up from groundwater and surface water resources during the production of a commodity.

The **Green** water footprint is an indicator of the precipitated water that does not run off or recharge the groundwater but gets stored as moisture in the soil and ultimately taken up by plants for their growth or gets evaporated.

The **Grey** water footprint is the water required to dilute the water, coming out from a production line of a product, according to water quality standards (Hoekstra et al., 2009).

2.2.3 Definitions

Water footprints of products:

The water footprint of a product (WFp) is defined by Hoekstra et al., 2009 as "the total volume of fresh water (m3) that is used directly or indirectly to produce the products which can be agricultural, industrial or service sector". It is estimated by considering water consumption and pollution in all steps of the production chain. .

$$WFp = WFp_{,,dir} + WFp_{,indir} = WFp_{,,green} + WFp_{,blue} + WFp_{,grey}$$

Water footprints of consumers:

The water footprint of a consumer (WFcons) is defined by Hoekstra et al., 2009 as the "total volume of freshwater consumed and polluted for the production of the goods and services used by the consumer. The water footprint of a group of consumers is equal to the sum of the water footprints of the individual consumers".

$$WF_{cons} = WF_{cons,dir} + WF_{cons,indir} = WF_{cons,green} + WF_{cons,blue} + WF_{cons,grey}$$

Water footprint of a business:

The water footprint of a business is defined by Hoekstra et al., 2009 as "the total volume of freshwater that is used in all the activities directly or indirectly to run and support a business".

Water footprint of a nation:

The water footprint of a nation is defined by Hoekstra et al., 2009 as "the total freshwater volume utilised, consumed or polluted within the boundary of the nation".

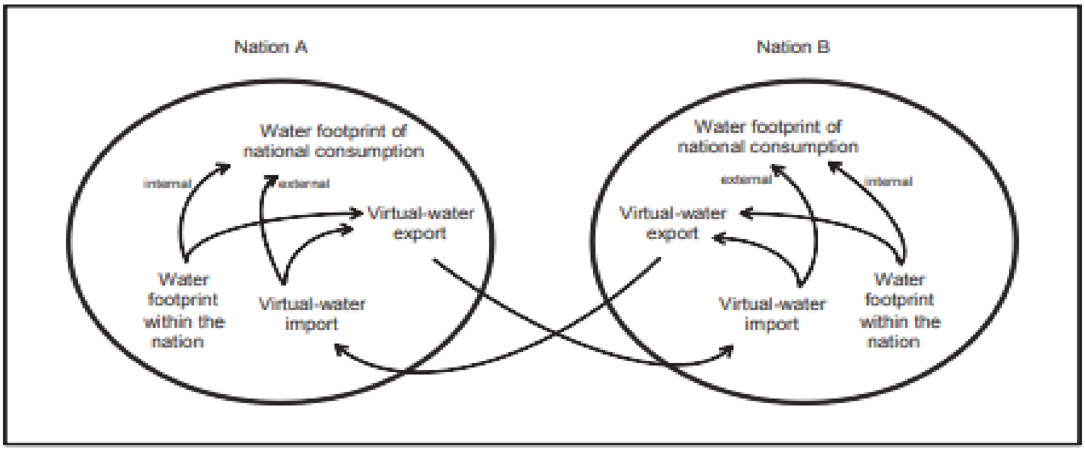

Figure 2.2 Virtual water trade example between two trading nations (Source: Hoekstra et al., 2009)

2.2.4 Methodologies for water footprint analysis

In this paper, three main methodologies are identified which are as follows

1. Water footprint Assessment (WFA)

2. Environmental Extended Input Output (EEIO)

3. Life Cycle Assessment (LCA)

1. Water footprint Assessment (WFA):

This method developed by water footprint network (WFN), which uses the database called WaterStat and CROPWAT. It is a bottom-up approach and used at the product or commodity level. This method will be discussed in detail in the later sections of the report.

2. Environmental Extended Input Output (EEIO):

This method is top down approach which evaluates the interdependencies between various sectors by tracking the flow of money along the supply chain. Amount of virtual water can be determined in the units of water volume per dollar of commodity value for a trade network. Input-output (IO) tables which give the amount of consumptive water used by each sector in the cases where trade data is available multi-regional input-output (MRIO) method is usually employed.

3. Life Cycle Assessment (LCA):

LCA is a cradle to grave approach used to identify the environmental impact of a product or process throughout its lifetime. Recently LCA has been used to evaluate freshwater used across production sectors and it standardised the quantification of impact on water resources.

LCA is more useful to find water footprint of an individual product and commodity. It would be time consuming and uneconomical process to use LCA for a region where we have to incorporate various products. (Paterson et al., 2015)

Table 2.1 Different methodologies to find water footprint

Source	**Name of the Method used**	**Methodology**	**Results**
Leeuwen et al., 2012	Blue City Index	-A number of indicators were used for sustainability assessment of urban areas. It is divided into 8 categories: (1) water security, (2) water quality, (3) drinking water, (4) sanitation, (5) infrastructure, (6)	Rotterdam (Netherlands) score for WF = 0.7 because WF was twice the global average

		climate robustness, (7)biodiversity and attractiveness and (8) governance -Scale of 0 (a very poor performance) to 10 (an excellent performance which requires no further attention)	
L. Feng et al., 2017	Input-Output Analysis (IOA) and Structural Decomposition Analysis (SDA)	- IOA - Leontief inverse matrix method -SDA - adopted to analyse the WF contributed by different sectors and the pattern has changed over the years through matrices solution	The WF recorded an overall decrease of 1.4 x10^7 m3 and WF = 831 m3/yr in Zhangye for the period of 2001-2011
Oel et al., 2009	Water Footprint Assessment (WFA)-	- -Bottom-up approach	Netherlands is 2300m3/year/person for the period 1996–2005
K. Feng et al., 2010	Environmental input-output analysis (EIOA)	Leontief inverse matrix method	WF of UK=1,438 m3 per person in 2006
Zhang et al., 2011	Input-Output Analysis (IOA)	Leontief inverse matrix method	The total water footprint of Beijing in 2002= 4498.4x10$_6$ m3/year = 229.36 m3/yr/capita

2.3City and its water footprint

Cities are the heart of global economic activities because of high population density and extensive networks for exchange and trade. Transfer means exchanges within a nation while trade means exchange outside national boundaries. More than half of the world's population lives in cities and it is expected to grow up to two third by 2050, therefore creating a stress on water resources and environment of a city. Some studies were done at city level such as Leeuwen et al., 2012 has defined a number of indicators for sustainability assessment of urban areas. It is divided into 8 categories: (1) water security (2) water quality (3) drinking water, (4) sanitation, (5) infrastructure, (6) climate robustness, (7)biodiversity and attractiveness and (8) governance scale of 0 (a very poor performance needing further attention by managers and politicians) to 10 (an excellent performance which requires no further attention) it was found that score of Rotterdam (Netherlands) for WF = 0.7 because WF came out to be 2300m3/year/person which is twice the global average in year 2006.

Water footprint for Beijing City was calculated in Zhang et al., 2011 using inter regional input output method where data was collected from various sources such as National Bureau of Statistic of China, Beijing Municipal Water Conservation Office, Beijing Water Authority etc. Leontief inverse matrix was formed and solved. It was found out that total water footprint of Beijing in 2002 was $4498.4x10^{6}m^{3}$/year or $229.36m^{3}$/yr/capita. Above both the methods used for the cities but were completely different, other methodologies are: bottom up approach, hybrid approach, input output top down approach etc. Hence it can be concluded that the approach used primarily depends upon their data available and objective of the study. There was no literature available for water footprint of Indian cities; however water footprint of India has been calculated in many research papers.

Much research has been done at a national or country level which might help in developing international policy or national policy but it would do a little help to local government bodies in policy formation. Research at national level is unable to deal with the local and regional issues and in countries like India where there is huge spatiotemporal and geographic variability, international policies and sometimes even national policies might not make any sense in some regions. Hence it becomes clear that cities must be targeted in order to achieve the goal of sustainable development and address problems like climate change, increasing air pollution, increasing water pollution and biodiversity and environmental loss.

However, there are no defined indicators for a city worldwide for comparison and analysis, hence different indicators and common standards for cities are needed to be defined worldwide so that the results can be compared irrespective of the uniqueness of a city (Kampman, 2007).

According to the Master Plan of Delhi-2021 prepared by Delhi Development Authority, the population of Delhi will be 23 million (by linear projection) in 2021 and proposed water requirement with the norm of 80 Gallon Per Capita Per Day (GPCD), out of which 50 GPCD is for domestic requirement and 30 GPCD for non-domestic purposes hence the pressure on environmental resources are only going to increase and without proper planning, Delhi will definitely face much more problems than ever.

2.4 Sustainability and water footprint

With globalisation and ease of transportation trade of commodities as food and as products is growing rapidly hence water is flowing rapidly. Therefore for sustainability, it is important that trade policies are made keeping in mind the water-scarce and food-insecure regions. Example: in EU in the past decade net food imports from countries outside of Europe has doubled (Hoff et al., 2013). The rate of growth of resource demand in cities is increasing faster than the national averages because of rapid economic development and change in lifestyle and diet.

The fast depletion of water resources can lead to:

- Groundwater depletion
- Fresh water pollution
- Loss of biodiversity

(Ahams et al., 2017)

A sustainable society "meets the needs of the present generation without compromising the ability of future generations to meet their own needs, in which each human being has the opportunity to develop itself in freedom, within a well-balanced society and in harmony with its surroundings" (UN 1987). Sustainability indicator such as environmental sustainability index (ESI) is a helpful tool which gives value to sustainability from 0 to 100 (100 being most sustainable and 0 being least sustainable).Life cycle thinking (LCT) is being widely used but for large scale study, it becomes too complex to work. Mori & Christodoulou, 2012 developed a new index for sustainability called City Sustainability Index (CSI) which can analyse the sustainability of a city and can be used to compare sustainability of different cities so as to understand two things-

1) Global impacts of cities or external impacts also called as leakages,
2) Whether it is socially, environmentally and economically sustainable also called as triple bottom line of sustainability.

The scope of a water footprint sustainability assessment primarily depends on the goal of the researcher whether the water footprint of a region is to be reduced or of an individual product or process. Water footprint sustainability assessment helps to make a comparison of the human water footprint with what the earth can sustainably support (Hoekstra et al., 2009). It is a useful tool for policy making and to enhance performance in the fields such as environment, process and society. However, as footprints do not measure people‟s quality of life, the other imperative for sustainability, need to be complemented by social indicators to cover progress toward sustainability comprehensively (Singh et al., 2009).

2.5 Limitations of water footprint assessment

Some limitations are enumerated below while using water footprint:

- Different indicators and common standards for cities are needed to be defined worldwide so that the results can be compared irrespective of the uniqueness of a city (Kampman, 2007).
- There is a lack of data for cities.
- Limitation of water footprint is that it represents the volume of water used without any estimation of the environmental impact created (Čuček et al., 2012).
- Using virtual water in policy making requires a thorough understanding of the impacts and interactions of trade on the local economic, cultural and environmental conditions (Horlemann and Neubert, 2007).
- The virtual water content of crops and crop products is calculated considering the countries‟ average climate data. In India, there is a huge variation of climate from region to region. Therefore the actual water content locally can be much greater or much smaller than the estimated value (Kumar and Jain, 2007).

CHAPTER 3

METHODOLOGY AND CALCULATIONS

3.1 Water footprint

As discussed in the above section there are three main methodologies which can be adopted to find water footprint of a region which are water footprint assessment (WFA), environmental extended input-output (EEIO) and life cycle assessment(LCA) (Paterson et al., 2015).

According to the availability of data for Delhi, the most suitable method was water footprint assessment. WFA is a bottom-up approach where we tried to find out water footprint used for direct consumption and for the production of each product being used by the consumers within Delhi. Advantage of using a bottom-up approach is it reduces the propagation of error, which is a big drawback in a top-down approach, small errors in estimates can translate into relatively large errors. The consumption of various products and their respective virtual water content are multiplied to find the water footprint of various goods being consumed. The summation of the footprint of individual products gives the total water footprint within the geographical boundaries of a region (here Delhi) as given by equations below.

The aim of the methodology used here is to use available data and no modelling or experimentation to find water coefficient of a product was done. Also, a major advantage of WFA is the availability of a huge database called WaterStat.

$$WF_{region} = WF_{Delhi} = WF_{Direct} + WF_{Indirect}$$

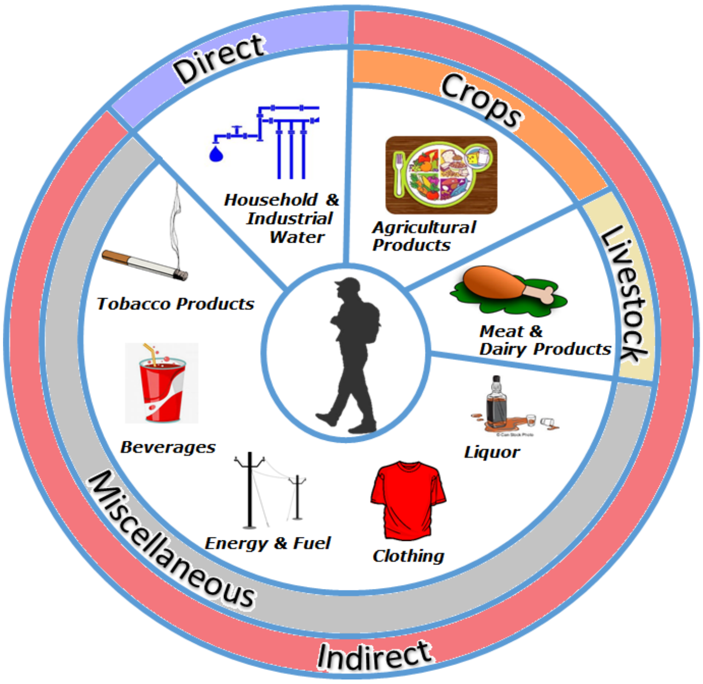

Figure 3.1 Products considered in this study

3.1.1 Direct water footprint

3.1.1.1 Methodology

= Direct WF = Water being supplied by DJB (Municipal Corporation of Greater Delhi) to households and industries in Delhi.

Mathematically,

$$\mathbf{WF_{Direct} = \Sigma\ ^{n}_{i=1}\ DW_i}$$

where,

= Direct water through i[th] source

i = 1, 2….n

3.1.1.2 Inventory

Scenario in 2015

Table 3.1 Water supply source of Delhi

Source	**Yield (MGD)**
Ganga River	330
Yamuna River	207
Bhakhra Storage	218
Ground Water	80
Total Supplied (MGD)	835
Total Demand (MGD)	1020
Deficit (MGD)	**185**

(Source: Economic Survey of Delhi, 2015)

As per Yamuna Water Sharing Agreement signed in 1994, among the Northern Region States of Himachal Pradesh, Haryana, Uttar Pradesh, Rajasthan and Delhi, 0.724 BCM Yamuna water was allocated to Delhi. Uttrakhand was part of the Uttar Pradesh at that time. This share is divided into 3 blocks period of the year i.e. July to October, November to February and March to June. Delhi may get its full share of 0.724 BCM (808 Cusecs consumptive) only after construction of 3 new reservoirs in the upper Yamuna Basin Area. These 3 new proposed reservoirs are : Renuka Dam on River Giri, a tributary of Yamuna in Sirmaur District of Himachal Pradesh, Kishau Dam on river Tons, also a tributary of Yamuna river in Uttrakhand and Lakhwar-Vyasi Dam on river Yamuna near Lakhwar village in District Dehradun of Uttrakhand.

Govt. of Delhi paid an amount of 215 Cr. to the HP Govt. for land acquisition for Renuka Reservoir. The DPR of the project has already been prepared and approved. Earlier entire cost of the construction of Renuka Reservoir was to be financed by Delhi Govt. Now Renuka Reservoir project has been declared as a national project and as such the Govt. of India will finance the cost of its construction.

MPD-2021 projected water demand as 1840 MGD @ 80GPCD for projected population of 230 lakhs in Delhi by 2021. DJB projected water demand as 1380 MGD @ 60GPCD. The DDA norms of 80 GPCD include 50 GPCD for domestic requirement and 30 GPCD for non-domestic purposes. The domestic water requirement of 50 GPCD comprises of 30 GPCD for potable needs and 20 GPCD for non-potable water. Thus going by the DJB norms of 60 GPCD, the water supply requirement for the present population of Delhi in 2011 will be 1020 MGD. Taking into account the present water supply capacity of 855 MGD there is a shortfall of 165 MGD at present. Assuming the same population growth, as recorded in 2011 Census, to continue for the next decade, the projected population of Delhi by the end of the 12th Five Year Plan i.e. by March 2017 may be around 190 lakhs. Going by **DJB norms of 60 GPCD**, the water supply requirement in March 2017 for the projected population of **190 lakhs** may be around **1140MGD.**

The present status of non-revenue water of around 54% in Delhi may not be allowed to continue both from the citizen's point of view as well as DJB's point of view. With such high level of non-revenue water, DJB may not find enough resources to meet the cost of water and sewerage infrastructure required for growing population of the NCT of Delhi.

Table 3.2 Projected water deficit of Delhi in MGD

Year	2001	2011	2017	2021 (Projected)	2041 (Projected)
Population (Lakhs)	138	167	190	230	258

Demand	828	1020	1140	1840 (DDA @80GPCD) 1380 (DJB @60GPCD)	2064(DDA) 1584(DJB)
Supply	805	855	925	925 1200(if Renuka Project completed)	1712
Deficit	23	165	215	455*	352*

(Source: Delhi Statistical Abstract, Delhi Statistical Handbook, Department of Economics & Statistics, Govt. of NCT of Delhi.)

About 30-50 per cent of the raw water discharged from Tajewala Head works is lost through seepage during transit in the present water carrier system comprising of Western Yamuna Canal system and River Yamuna. To minimize the en-route losses, a parallel pucca channel has been constructed from Munak to Haiderpur. This channel of 102 km has been constructed by the Haryana Govt as a deposit work on behalf of Government of Delhi. The estimated cost of the Channel is ` 520 crores. Delhi is expected to have increased availability of about 95 MGD within the existing releases at Munak on commissioning of this channel.

Renuka Dam, Kishau Dam and Lakhwar Vyasi Dam are proposed to be constructed so that Delhi gets its due share in Yamuna water as per Yamuna Water Sharing Agreement signed in May, 1994. The approved allocation of Yamuna water to each state is presented in Statement No. 13.7. About 275 MGD water will be available to Delhi from Renuka Dam. Delhi will also get 372 MGD water from Kishau reservoir and 135 MGD from Lakhwar Vyasi reservoir.

Availability of water in the premises of households living in planned colonies is reported at 78% compared to just 51% in slums.

Observations during the field study shows community level taps are shared between 10 and 30 households.

Water was observed to be available for 1 to 2 hours of water supply.

It takes 35% of households more than one hour daily to fetch water, sometimes extending upto 3 hours.

The majority of respondents spend 30-60 minutes daily.

(Source : URL 3)

Table 3.3 Future projects to meet rising water demand of Mumbai (Source: URL 1)

Future Projects	**Supply(MGD)**
Munak to Haiderpur Pucca Channel	95
Renuka Dam	275
Kishau Dam	372
Lakhwar Vyasi Dam	135

*As of July, 2019 Land Acquisition for Renuka Project is yet to be done. Although the DPR for the project has been finalized. But it seems highly unlikely to be completed by 2021.

Table 3.4 Year wise supply and demand of water and population data

Year	**Demand (MGD)**	**Supply (MGD)**	**Source of column-II and column-III**	**Population (millions)**	**Demand LPCD**	**Source of column-V**
I	**II**	**III**	**IV**	**V**	**VI**	**VII**
2001	828	650	DJB	13.8	227.1	Census 2001
2011	1020	855	DJB	16.7	277	Census 2011
2017	1140	925	MOSPI Report 2017-18	19	292	indiaonlinepages.co

2021 (projected)	1840* 1380**	925	*DDA **DJB	23	430	Delhi Govt.
2041 (projected)	2064* 1584**	1712	*DDA **DJB	25.8	430	Delhi Govt.

3.1.2 Indirect water footprint

3.1.2.1 Methodology

$WF_{Indirect}$= Indirect WF = Water being used indirectly in products such as food, clothes, petrol etc.

Mathematically,

$$\mathbf{WF_{indirect} = \Sigma\ ^{n}{}_{p=1}\ WF_p}$$

$WF_p = WC_p * w$

where,

WF_p = Water footprint of p^{th} product

p=1, 2…m

WC_p = Water coefficient (m^3/ton or L/Kg)

w = weight of product p consumed (ton or kg)

3.1.2.2 Inventory

1.Agricultural Products:

The water footprint Network has quantified the water footprint of crops using a grid-based dynamic water balance model that considers local environmental factors such as climate, soil factors etc (Mekonnen and Hoekstra, 2011).

A total of 88 agricultural products were considered in this section with 75 products in crops and 13 products in livestock to study consumption pattern in detail (refer to appendix Table A.1). Most of the consumption values of the crop and livestock products have been taken from a report published by the Ministry of Statistics and Programme Implementation, Government of India titled as "Household Consumption of Various Goods and Services in India 2011-12" or NSS 68 (NSSO, 2014). The National Sample Survey Office (NSSO) surveyed in June 2011 to July 2012 of 128 blocks and 951 households in schedule 1 and 945 households in schedule 2 through interviews of a representative sample of households selected randomly through a scientific design in the urban areas of Maharashtra. The schedules of inquiry used by NSSO were of two type schedule 1 and schedule 2 as per recommendations of an expert group that suggested the most suitable reference period for each item of consumption. The two types differed in the reference periods used for the collection of consumption data. Schedule Type 1, for specific categories of relatively infrequently purchased items, including clothing and consumer durables, it collected information on consumption during the last 30 days and the last 365 days. For other categories, including all food and fuel and consumer services, it used a 30-days reference period. Schedule Type 2 used 'last 365 days' (only) for the infrequently purchased categories, 'last 7 days' for some categories of food items, as well as pan, tobacco, and intoxicants, and 'last 30 days' for other food items, fuel, and the rest.

Above assumption is based on the fact that consumption pattern or food habits of agricultural products in urban areas of a state will tend to remain the same. For example, urban areas of West Bengal have high consumption of rice. Therefore, it can be assumed that the consumption of rice in Kolkata (capital of West Bengal) will be similar. Pal et al. (2009) gives average consumption of rice by an adult in Kolkata of 319.56 g/day and according to the report "Household Consumption of Various Goods and Services in India 2011-12" or NSSO, 2014 (pg. 55) rice consumption in urban West Bengal is 208.1 g/day which seems logical and validates our assumption. Also, sensitivity analysis is performed to account for this assumption and to have a probable range.

To validate the reliability of data collected from NSSO (2014), average consumption of India for different crop and livestock products was compared with the data on average food consumption given by FAO (URL 6). Data of a few products obtained from NSSO (2014) was again compared with Indian migration study on dietary pattern in Indian adults (Harris et al., 2017). NSSO (2014) data was also compared with other reports given by NSSO for different years. Comparisons showed significant evidence to consider NSSO (2014) as a reliable data source. The variations in the studies could be attributed to the difference in their questionnaire, interview process, sampling method and reference period.

2. Livestock products:

For example, a goat is raised for its meat. To breed a goat it needs food to eat, water to drink and for other purposes like cleaning etc. Water used in the entire life cycle of a farm animal is called as water footprint of livestock product. It has been calculated in the "Green, blue and grey water footprint of farm animals and animal products" by Mekonnen and Hoekstra.

3. Miscellaneous products:

Much research has been done on water footprint by crops and animal products, but products such as petrol, electricity, cold drinks, clothes etc also have water embedded in them. Data is available as many researchers have found out the virtual water for these products.

Table 3.5 List of miscellaneous products considered in this report

Miscellaneous products	
Beer	Total no. of clothes
Wine	Fruit, juice and shake
Cold beverages	L.P.G.
Electricity	Chips
Kerosene P.D.S.	Bidi
Kerosene	Cigarettes
Petrol	Hookah tobacco
Coal	Leather boots

Consumption of Miscellaneous Products

Delhi is a rapidly growing city with many people working in the corporate sector, and western culture is catching up in Delhi. Therefore, all those products that are important in urban living were tried to be included in this study, which might have a huge water footprint according to the lifestyle of people living in Delhi. However, limited data is available, either consumption data was not available, or virtual water content of a product was not available. Finally, 16 different products or entities for which both consumption and virtual water content data could be collected were considered. Hence, the system boundary of this study was accordingly defined.

An attempt was made to find the consumption data of all 16 products, particularly for Delhi.

Table 3.6 Assumptions and source of consumption data of miscellaneous products

S. No.	Name of the product	Source	Assumptions
1	Liquor	Global Status report on alcohol and health 2018 (WHO, 2018) and URL 10	2.177 litre/capita-month sale of liquor in 2016-17 by a newspaper report in Delhi; Trend in Delhi was assumed to be same as that of India; There is an increase of 32.6% in alcohol consumption from 2010 to 2016 according to report given by WHO; Liquor consumption in Delhi in 2010-11 = 1.64 litre/capita-month
2	Petrol	PPAC: URL 11 and URL 12	Total petroleum products sold = 17090.3x10^3 MT in 2011-12; MS (Motor Spirit) or petrol = 10.12%; Population of Delhi in 2011=112.4 million; Per capita petrol consumption = 1.72 L/month/capita. Petrol consumption in Delhi should be much higher than 1.72 L/month/capita.
		URL 13	From newspaper report in 2011 it was found that Delhi had around 250 petrol pumps and on an average 10KL of petrol is sold each day; 10x10^3x250/12.5x30=5.96L/month-capita
3	Electricity	Prayas Group Report (Nhalur and Josey, 2012)	In year 2011-12, 1121 KWh per capita per year was consumed; KWh/capita/month = 93.41
4	Fruit juice and shake	NSSO 2014	Consumption data for Delhi was available
5	Chips	NSSO 2014	Consumption data for Delhi was used from MOSPI report.
6	Bidi	NSSO 2014	

7	Cigarettes	NSSO 2014	
8	Tobacco	NSSO 2014	
9	Cold drinks	NSSO 2014	
10	Kerosene	NSSO 2014	
11	Coal	NSSO 2014	
12	L.P.G.	NSSO 2014	
13	Total no. of clothes (calculated T-Shirt equivalent)	NSSO 2014	
14	Leather footwear	NSSO 2014	
15	Tea: cups	NSSO 2014	
16	Coffee: cups	NSSO 2014	
17	Cheese (Note: It is a dairy product considered in livestock product)	URL 17	

Virtual Water Content (VWC) of Various Crops and Products

The virtual water content values were primarily taken from the water footprint network (WFN) (URL 14) developed by Arjen Hoekstra in 2002. Water footprint network has quantified the volume of water required for the production of various crops and other goods at different regions according to local climatic conditions, evapotranspiration and other soil factors using data from FAO, WaterStat, CLIMWAT, CROPWAT, etc. Water footprint network has developed a series of manuals and research papers to quantify virtual water content for crops, livestock products, and other products. We used CROPWAT to calculate evapotranspiration, crop water requirement and virtual water content for rice and wheat in order to validate virtual water content data from literature.

An assumption has been made that virtual water content of a processed product is equal to its base product if the data was not available, for example virtual water content of milk products such as curd is taken equal to virtual water content of milk. It was assumed that most of the products imported in Delhi are grown and processed in Delhi itself. However if the data of virtual water content was not available for Delhi, Indian average virtual water content was considered. If Indian average was also not available global average virtual water content was considered. A preference order was formulated which has been enlisted in Appendix table A.1 for each product. Preference order is as follows:

Preference 1: Virtual water content of any crop or product for Delhi.

Preference 2: Virtual water content of any crop or product according to the average of India.

Preference 3: Virtual water content of any crop or product according to the global average.

However, some other references for virtual water content were also taken for a few products such as petrol and electricity, which are reported in Appendix Table A.1.

Indirect Water Footprint ($WF_{indirect}$)

The analysis included a total of 104 products. Appendix Table A.1 has a complete list of consumption, virtual water content, assumption, and sources for each product. Summation of water footprint of each product gives total indirect water footprint of Delhi. Analysis of water footprint from each product assisted us in finding key contributors. Products were grouped into 14 different categories to get water footprint flow diagram similar to material flow diagram. To find the change in total water footprint due to change in dietary pattern and due to uncertainty in data collected scenario-based sensitivity analysis was performed. Sensitivity analysis was done by assuming variations in different product categories and finding the change in total water footprint.

Forecast Method

We collected data from different NSSO reports on household consumption of various commodities. However, there was limited data available for the years 1993-94, 1999-00, 2004-05, 2009-10 and 2011-12. Commodities assessed by NSSO has changed significantly over the years therefore many products in NSSO 2014 for the year 2011-12 were missing in the previous studies done by them. Also, data in NSSO study of 1999-00 was not comparable and hence was not considered in the analysis. Further analysis revealed that data of study in the year 2011-12 was an extension of study done in 2009-10. Therefore, effectively there were 3 data points which were insufficient for using any statistical tool.

Data of average per capita consumption of India for various agricultural products from FAO from the year 1961 to 2013 shown in Appendix Fig. A.1 to Fig. A.37 was considered (URL 15). Linear and multiple non-linear regressions were used to find best fit curve and trend line for each product. In order to find outlier in time-series curve, box plot of residuals was used to de-trend the curve and making time series stationary. Equations from best fit curve of each product were then used to forecast consumption for the year 2021. Estimated consumption for different agricultural products has been reported in Appendix Table A.2.

The trend of consumption of crop and livestock products for Delhi is assumed the same as for average India. Estimated consumption for the year 2021 of average India was converted to consumption of Delhi using equation 3.5. A conversion factor was defined as the ratio of consumption data of a product p given by NSSO for Delhi in the year 2011 to the consumption data of same product p given by FAO for average India in the year 2011. The equation used to find consumption for Delhi in the year 2021:

$$C_{2021,p} = C, Estimated\,FAO_{\,2021,p} \times \frac{C,NSSO_{2011,p}}{C,FAO_{2011,p}} \qquad (3.5)$$

where,

$C_{2021,p}$: Consumption for product p (Delhi 2021)

$C, NSSO_{2011,p}$: Consumption for product p (Delhi, 2011) (Source: NSSO, 2014)

$C, FAO_{2011,p}$: Consumption for product p (Indian average, 2011) (Source: URL 6)

$C, Estimated\,FAO_{\,2021,p}$: Consumption for product p (Indian average, 2021)

$$\text{Conversion Factor} = \text{CF} = \frac{C{,}NSSO_{2011,p}}{C{,}FAO_{2011,p}} \quad (3.6)$$

Note: Virtual water content for any product p (VWC_p) was assumed to remain constant temporally. Also, while forecasting, we excluded miscellaneous water footprint and groundwater use from our system boundary.

Method to Calculate Virtual Water Loss in Agricultural Practices

Food loss is the decrease in edible food mass in production, post-harvest, and processing stages in the food supply chain. Food losses at retail and final consumption are called as food waste, and it relates to retailers' and consumers' behaviour. The causes of food losses and waste in developing countries such as India are mainly connected to financial, managerial and technical limitations in harvesting techniques, storage and cooling facilities in severe climatic conditions, infrastructure, packaging, and marketing systems (Gustavsson et al., 2011).

FAO calculates losses by assisting different countries by producing guidelines on cost effective data collection methods. Other method used by FAO is to use food balance sheets (FBS) and using hierarchical linear model for estimation of food loss (Tayyib et al., 2016).

The virtual water loss due to inefficiencies in production, processing, packaging, and distribution has been calculated using data from FAO for the South and Southeast Asia in the year 2007 to 2009 as reported in Table 3.4. The rate of losses and waste was assumed to remain the same during the period 2011 to 2021.

Table 3.7 Percent lost and wasted for different agricultural products (URL 16)

Product	Agricultural Production Losses	Post-harvest and storage Losses	Processing and packaging Losses	Distribution Losses	Losses before consumption	Consumption Losses	Remarks
Cereals	6.0	7.0	3.5	2.0	18.5	3.0	_
Oilseeds and Pulses	7.0	12.0	8.0	2.0	29.0	1.0	_
Fruits and Vegetables	15.0	9.0	25.0	10.0	59.0	7.0	_
Meat	5.1	0.3	5.0	7.0	17.4	4.0	_
Fish and Seafood	8.2	6.0	9.0	15.0	38.2	2.0	_
Milk and Cheese	3.5	6.0	2.0	10.0	21.5	1.0	_
Spices and Nuts	6.0	7.0	3.5	2.0	18.5	3.0	Assumed same as losses in cereals
Sugar	6.0	7.0	3.5	2.0	18.5	3.0	Assumed same as losses in cereals

Eggs	6.0	7.0	3.5	2.0	18.5	3.0	Assumed same as losses in cereals

Water coefficient

Water required for the unit mass production of a product is known as water coefficient. According to the availability of data the water coefficient for any product is given as follows:

Priority 1: Water coefficient of a product in Delhi

Priority 2: Indian average water coefficient of a product

Priority 3: Global average water coefficient of a product

Example: Taking the first row from Appendix table:

Items	Quantity per 30 days (kg*)	Water coefficient (L/Kg)	Total water (Litres)
Rice – P.D.S.	0.20	3819.00	756.16

The quantity of rice- P.D.S used in a month when multiplied with water required to grow 1 Kg of rice gives total water required. The same approach is followed throughout the table.

3.2 Carbon footprint

3.2.1 Methodology

Sector-wise emission factor approach will be used where six different sectors will be considered namely electricity generation sector, transport sector, industries, domestic energy sector, agriculture and livestock sector. Emission coefficient or emission factors can be used from various sources, which when multiplied with the activity level will give total emissions (Ramachandra & Shwetmala, 2012).

Mathematically,

$GHG_s = \Sigma^{6}_{s=1} \Sigma^{n}_{i=1}$ Activity $Level_{i,s}$ x Emission $Factor_{i,s}$

where,

s= sth sector

i= ith product

Table 3.8 Sources of emission factors for various sectors

Sector	**Emission factor source**
Electricity generation:	Chakraborty et al., 2008
Transport	Das and Parikh, 2004
Industries	ALGAS, 1998
Domestic energy	Smith et al., 1998
Agriculture	Sahai et al., 2007
Livestock	Singhal et al., 2005

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Water Footprint of Delhi in 2011

The average water footprint of a person living in Delhi in the year 2011 estimated to be ~2900 lpcd with ~858 grams of average food consumption in a day. Detailed flow of water footprint from different products within system boundaries of this study is shown in Fig. 4.1. Food products (crop and livestock products) contribute ~84% of total water footprint.

Direct water received in Delhi in 2011 was about 277 lpcd through various lakes and groundwater sources, which is ~9% of total water footprint. All the development plans for an area are formulated by the government according to water demand of nearby cities (DJB, 2014). However, it contributes to one-tenth of total stress on freshwater resources.

It can be said that a sustainable city should be able to take care of its direct water requirements because regardless indirect water stress is to be bore by rural areas. Alternatives to meet direct water requirement were explored for Delhi. The ground water level has gone down predominantly in the state of Delhi (there was fall in about 72%, rise in 25% and no change in 3% of the 1633 wells tested) between January 2015 to January 2016 (Central Ground Water Board, 2016). However, a marginal increase in water levels of Delhi (capital of Delhi) was found out by long term water level analysis.

The rise is in range of 0.02 to 0.05 m/year during both pre-monsoon and post-monsoon seasons. This marginal rise in water level may be due to leakages from water supply pipelines (Gupta, 2013). Another reason can be due to seepage from various lakes and leakage from stormwater drains in Delhi. Hence, an opportunity to increase the use of groundwater for non-drinking purposes and in industrial use can be further explored. Groundwater in Delhi is not meeting the standards (Parasnis, 2015). However, it can be treated to meet water demand during shortage in water supply by DJB. Volume of annual average rainwater in Delhi is ~333 lpcd. In the year 2011 water supply by DJB was 257 lpcd. Therefore, Delhi has a huge potential of rainwater harvesting. Direct water stress Delhi puts on freshwater resources which are in the outskirts of Delhi can be reduced by rain water harvesting and use of ground water.

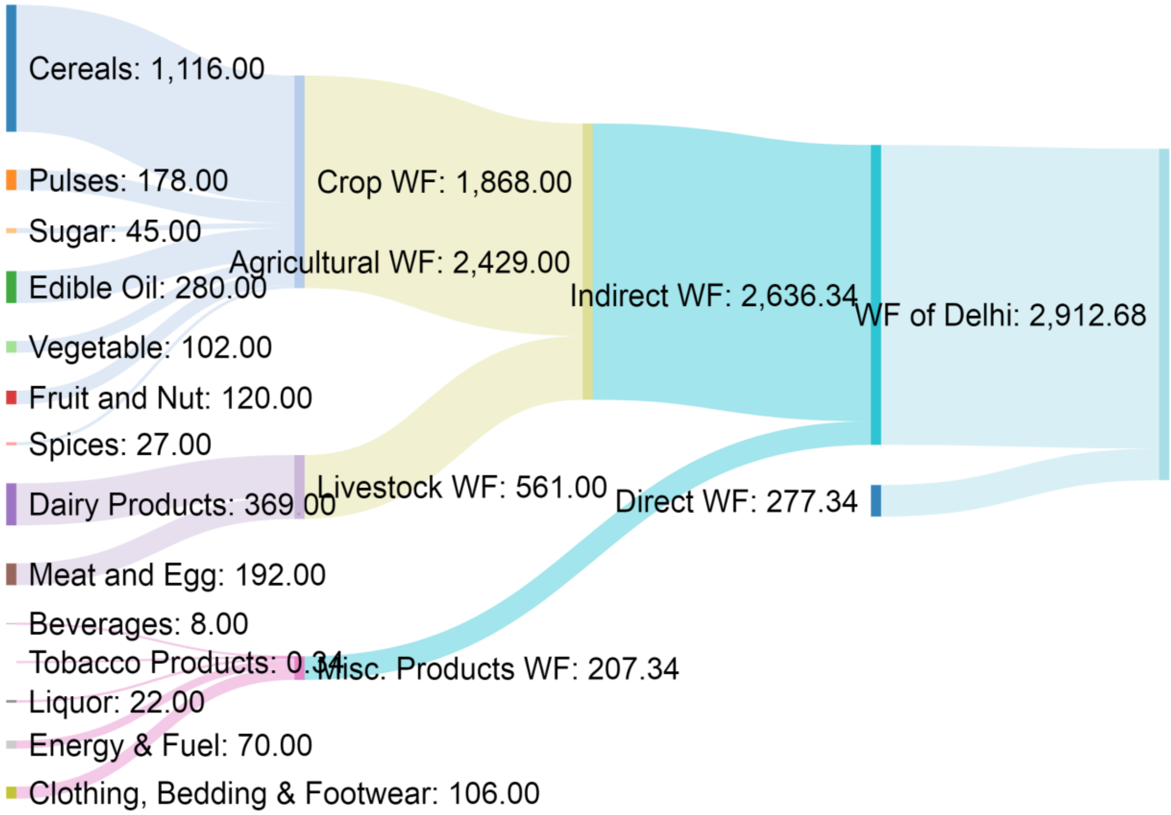

Figure 4.1 *Water footprint flow of Delhi (2011) in lpcd*

We obtained crop water footprint as ~1870 lpcd, 64% of the total water footprint. Consumption of cereals, pulses, and edible oil takes ~84% of crop water footprint. Cereals alone contribute to ~60% of crop water footprint. Consumption of rice products and wheat products has a 91.7% share in cereals and contribute to ~18% and ~21% of total indirect water footprint, respectively. On an average 106 grams of rice products and 145 grams of wheat products were consumed with a water footprint of 480 litres and 554 litres in a single day.

Water footprint of livestock products is 561 lpcd, which is ~19% of the total water footprint. High consumption of milk (~166 grams/day) leads to high water footprint of dairy products. Water footprint of meat per unit consumed is relatively high (~7000 l/kg) but lower consumption of meat results in lower water footprint, i.e. 192 lpcd.

Water footprint of production of agricultural products in urban areas is nearly zero because no agricultural practices takes place in Delhi which is true any city. Therefore it can said that entire pressure of agricultural produce for cities and the water footprint associated with it is on rural areas. Hence, rural areas can be the primary target to achieve higher water savings in agricultural sector which is the key contributor with 85-90% of total water footprint.

Average agricultural yield of India is lower than that of global average (Sharma et al., 2018). Therefore, practices such as multilayer farming and regenerative farming which helps in effective use of land and water can be adopted in India. Modern techniques such as drip-irrigation and hydroponic farming can drastically reduce the crop water requirement. Government policies can play a crucial role in water savings by tweaking existing price support system. Farmers are tend to sow crops which can provide them higher returns without considering the water availability and climatic conditions. This results in crop failure with huge economic and water loss associated in the process (Jayaram and Mathur, 2015).

Comparison between the consumption based agricultural water footprint between urban and rural areas has been made. Similar methodology was adopted to find water footprint of rural Delhi as done for Delhi. Detailed list of products considered and their respective water footprint are in Appendix Table A.3. It was found that rural region of Delhi has 2372 lpcd as agricultural water footprint in comparison to 2429 lpcd in Delhi. In fact, rural Delhi has higher crop water footprint i.e. 2002 lpcd compared to 1868 lpcd in Delhi. This is primarily because of higher consumption of cereals such as rice and wheat. Results revealed lower water footprint of livestock product in rural Delhi. It was estimated to be 370 lpcd due to lesser consumption of meat products in rural Delhi while for Delhi it was 560 lpcd.

This comparison signifies that average agricultural water footprint of a person living in urban or rural area will be similar due to higher consumption of cereals and lower consumption of meat products in rural areas. Main difference in water footprint can be due to lifestyle and purchasing power people possess in urban and rural areas which we have considered in miscellaneous products. Miscellaneous products contribute ~7% of the total water footprint, i.e. 200 lpcd. Water footprint of energy requirement in 2011 through petrol, kerosene, coal, and electricity is ~70 litres per person per day. This is lower than average water footprint of clothes bought, i.e. 106 lpcd.

4.2Water Footprint of Delhi in 2021

Water footprint for Delhi would be ~3000 lpcd in 2021, based on projected input data of food products adapted from FAO database and neglecting miscellaneous products due high degree of uncertainty involved. Although it is expected that miscellaneous products are going to increase exponentially with changing lifestyle of people in urban areas. Other product which can shoots up consumption-based water footprint are electronic gadgets. These products couldn't be included in this study due to lack of availability of data. However, to bring awareness about the water footprint associated, products in cities can come with WF label similar to energy star label. Cess on higher WF consumption can be formulated to induce behavioural change.

There would be 12.8% increase in total water footprint and ~6.5% increase in per day consumption from 858 grams per day in 2011 to 914 grams in 2021 of a person. A ~4% decrease in water footprint was found in cereals, the product with the highest individual contribution. Spices and sugar consumption and water footprint has shown a marginal decrease. All other product categories have shown increased water footprint. A detailed consumption change for different products is given in Appendix Table A.2. The water footprint of overall crop sector has been found to increase marginally by 2%. Livestock water footprint is going to increase due to a shift in dietary patterns. Several projects are underway to increase direct water supply by 66% in Delhi by DJB. Relative contribution of water footprint for the year 2011 and 2021 is shown in Fig. 4.4 to Fig. 4.7. Comparison of the flow of water footprint through various product categories in the year 2011 and 2021 has been made in Fig. 4.2 and Fig. 4.3.

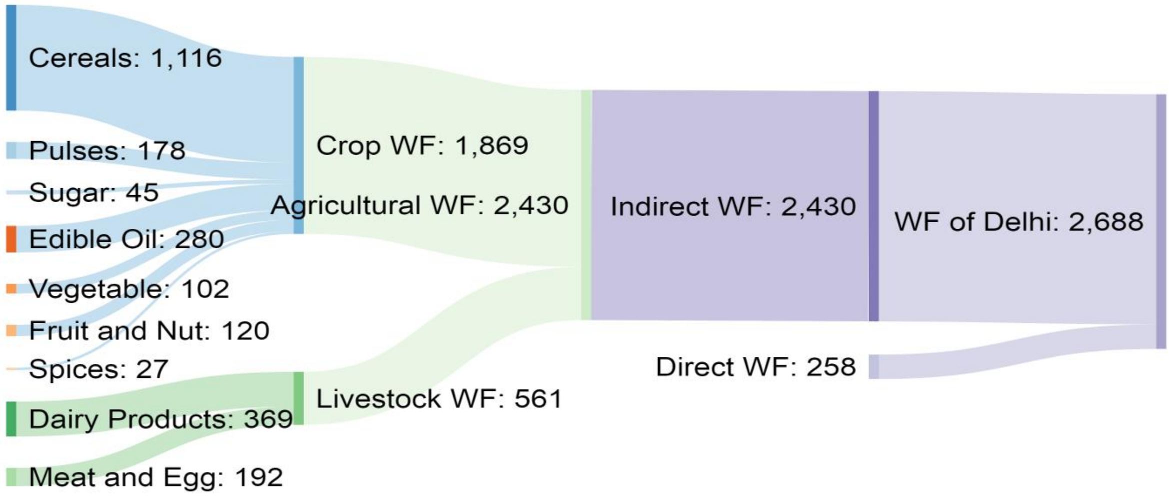

Figure 4.2 *Water footprint flow in Delhi 2011 in lpcd (excluding misc. products and groundwater*

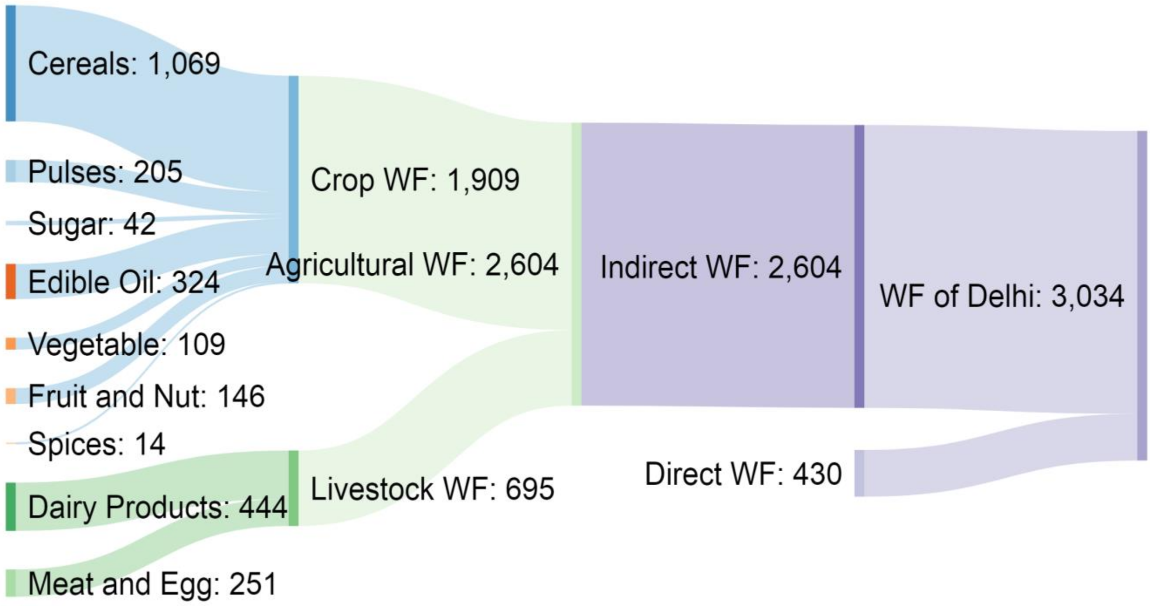

Figure 4.3 *Water footprint flow in Delhi 2021 in lpcd (excluding misc. products and groundwater*

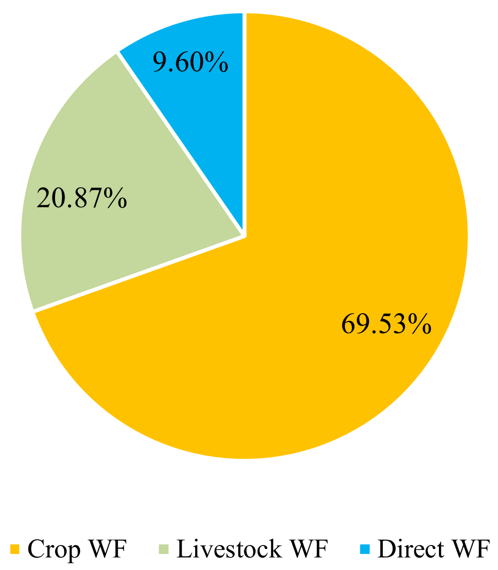

Figure 4.2 Sectoral water footprint in Delhi (2011)

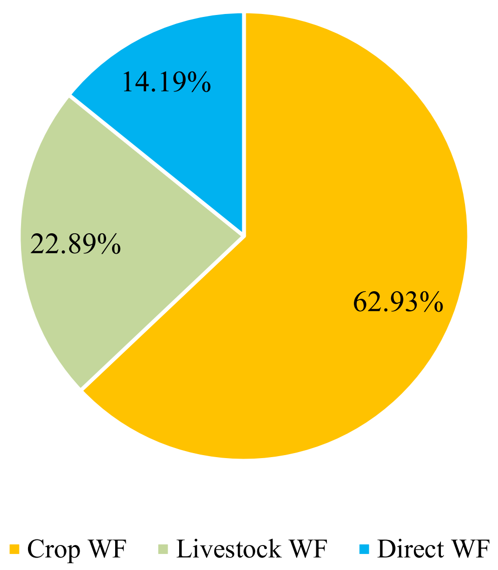

Figure4.4 Sectoral water footprint in Delhi (2021)

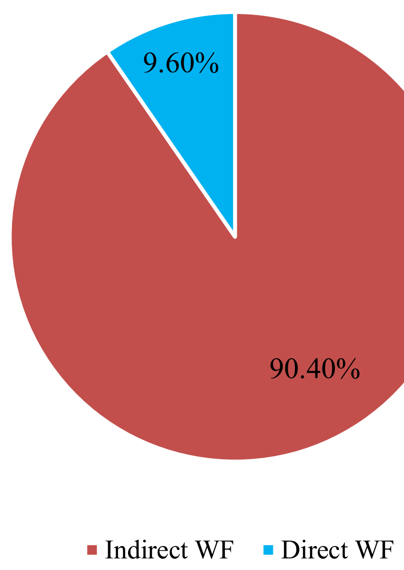

Figure4.3 Distribution of type of water footprint in Delhi (2011)

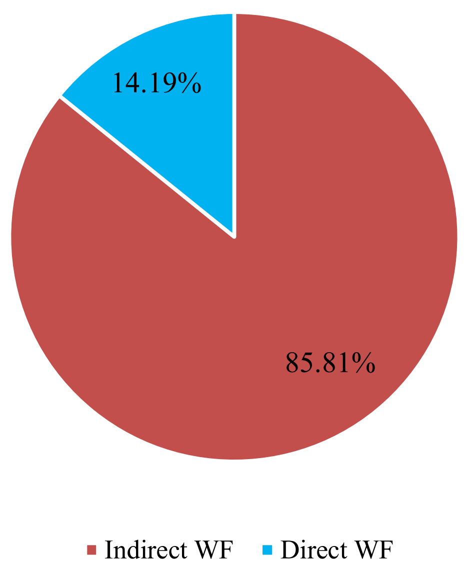

Figure4.5 Distribution of type of water footprint in Delhi (2021)

4.3 Virtual Water Loss in Agricultural Products

Due to inefficiencies in agricultural practices, the average virtual water lost in the year 2011 was 11239 million litres per day (MLD). Hence, virtual water lost due to inefficiencies in agricultural practices, storage and transportation was 3.5 times the total direct water supplied to Delhi by DJB i.e. 3200 MLD in the year 2011. Virtual water lost due to such inefficiencies is going to increase to 12060 MLD in the year 2021 if the rate of loss of agricultural products remains the same. Loss in the production phase of cereals alone is 6% which is equivalent to 1066 MLD for the year 2011. If somehow, we could achieve 5% as loss in the production phase of cereals, it could result in water savings of ~189 MLD.

Behavioural change to reduce the wastage of food should be encouraged. Average virtual water lost due to food wasted was 1243 MLD in the year 2011 which is ~39% of total direct water supply of Delhi. If rate of food wasted remains the same virtual water loss will rise to 1303 MLD in the year 2021. Average virtual water lost for different products has been tabulated in Table 4.1.

It can be concluded enormous potential of water savings is there in India by reducing the losses in sowing, storage and transportation phases as well as by reducing the food wasted. It can ultimately lower the pollution levels in the streams by higher dilution.

For rural regions, emphasis should be on sowing seasonal crops according to climatic conditions, soil productivity and water availability. Cities can play a crucial role in decreasing indirect losses by connecting them with rural areas through efficient transportation systems. Proper storage facilities for agricultural products can be used as an indicator for sustainable cities and can aid in water savings.

Table 4.1 Virtual water lost (MLD) in the life cycle of various agricultural products in the year 2011 and 2021 according to losses rates given by FAO (URL 16)

Agricultural Products	**Delhi-2011**		**Delhi-2021**	
	Virtual Water lost before consumption (MLD)	**Virtual Water lost after consumption (MLD)**	**Virtual Water lost before consumption (MLD)**	**Virtual Water lost after consumption in (MLD)**

Cereals	3289	533	3148	510
Oilseeds and pulses	2377	82	2741	95
Fruits and vegetables	3275	389	3426	406
Meat	369	85	482	111
Fish and seafood	92	5	75	4
Milk and Cheese	1280	60	1539	72
Spices and Nuts	285	46	326	53
Sugar	134	22	125	20
Eggs	139	22	197	32
Total	11239	1243	12060	1303

4.4 Sensitivity Analysis for Estimated Water Footprint

It was found that out of 38 categories of products, 5 products were contributing 73% of indirect water footprint, and the rest 33 products contributed the remaining 27%. Two scenarios were made to find sensitivity:

Scenario A: Variation in total water footprint due to variation in the water footprint of 33 products (contributing 27% of indirect water footprint) was studied as shown in Fig. 4.8 Other 5 products were assumed to have exact values of their water footprint.

Scenario B: Variation in total water footprint due to variation in the water footprint of 5 products (contributing 73 % of indirect water footprint) was studied as shown in Fig. 4.9. Rest 33 products were assumed to have exact values of their water footprint.

Sensitivity analysis can be used to understand the variation in total water footprint due to variations in data collected for consumption and for virtual water content. Standard deviation in both the parameters is unknown. Results from Fig. 4.8 and Fig. 4.9 can be used to find probable range of total water footprint according to the assumed uncertainty in both the parameters.

Also, results of sensitivity analysis can be used to estimate the change in total water footprint with the change in dietary pattern. If average meat consumption doubles from what was in the year 2011, total water footprint will increase by 5.4%. However, it was expected to change by a significantly higher margin. This can be attributed to low consumption of meat in 2011.

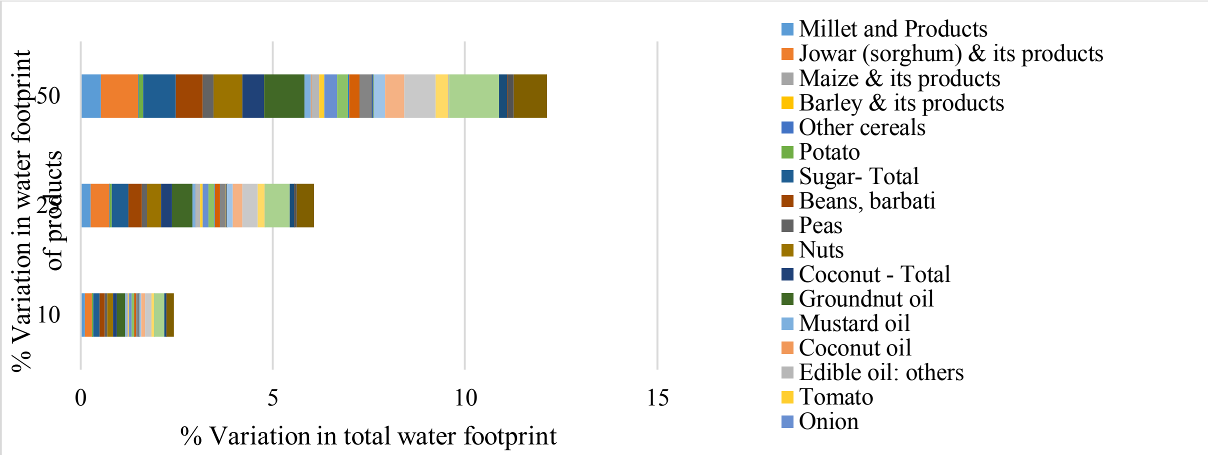

Figure4.6 Percent variation in total water footprint with different percent variations in products according to scenario A

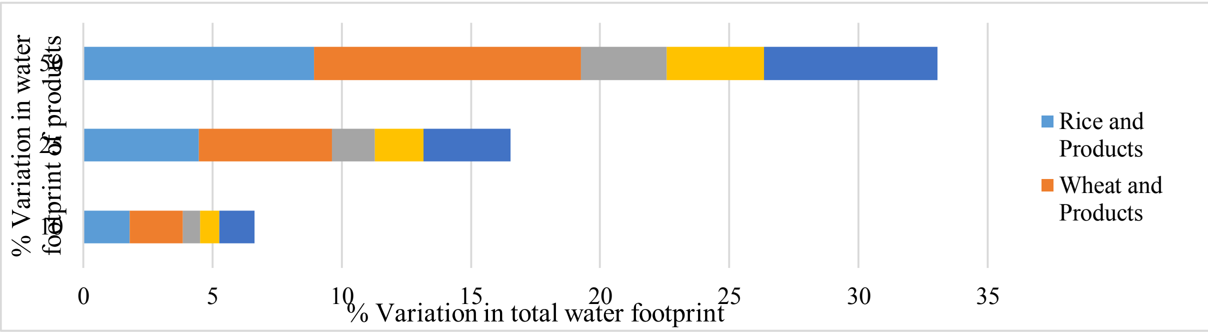

Figure4.7 Percent variation in total water footprint with different percent variations in products according to scenario B

4.5 Comparison of Results with Literature

Comparison of crop water footprint of different regions estimated in a study by Kampman (2007) has been done as shown in Fig. 4.10. Kampman (2007) used top-down approach to find crop water footprint of different regions in India. Exchange of water footprint through crop trade within a state was not accounted by Kampman (2007).

Production and trade data was used for calculation in Kampman (2007) while we used consumption data to calculate the same. Water footprint of production and consumption of a region can never be the same because exchange of crops and other commodities happen through trade. However, we used data from such studies to get an approximation.

Delhi and Delhi both being comparable cities, it was expected that crop water footprint would be similar. However, crop water footprint of Delhi is low because most of the products are consumed as processed products which cannot be accounted in crop trade. In our study, we have considered processed products such as flour, cheese and others.

Similarly, Hoekstra and Chapagain (2007) estimated water footprint of different nations which gives a sense that water footprint of India and its neighbouring nations is lower than global average as shown in Table 4.2. This may be attributed to the fact that these nations have lower average food consumption (URL 20).

Table 4.2 Comparison of water footprint of various regions by different studies. *(Different system boundaries were considered as shown for respective studies. The figures of Delhi were calculated in this study)*

Water Footprint	WF	Year	Categories Considered
Global average[a]	3296	1997-01	Domestic and industrial (internal) water use and agricultural products
Nepal[a]	2315	1997-01	
Bangladesh[a]	2446	1997-01	
India[a]	2485	1997-01	
West Bank[b]	3057	1998-2002	
Netherlands[c]	4222	2001-2005	Agricultural products
Hong Kong[d]	4727	2010-13	Average diet of Hong Kong
	2224	2010-13	Vegetarian diet

Average India[e] *based on adult survey from 4 cities*	3268 (SD=1148)	2005-07	Water footprint associated with diet of adults in Bangalore, Hyderabad, Lucknow and Nagpur
Delhi	2430	2011-12	Agricultural products (crops and livestock products)
	2688	2011-12	Domestic and industrial (internal) water use and agricultural products

a: Hoekstra and Chapagain (2007); b: Nazer et al. (2008) ;c: Oel et al. (2009); d: Vanham et al. (2017); e: Harris et al. (2017)

Study done by Nazer et al. (2008) finds out the water footprint of average diet in Hong Kong and how it can be changed by changing diet. A vegetarian will have 2224 lpcd while water footprint of diet in Hong Kong was 4727 due to high intake of animal products. Study conducted by Harris et al. (2017) on water footprint of diet by average adult from Bangalore, Hyderabad, Lucknow and Nagpur found 3268 lpcd as water footprint. It is expected that if all age groups were to be included in this study water footprint would be lower because of higher food consumption by adults. Our estimate of 2688 lpcd as water footprint due to consumption of crop and livestock products is comparable with both the studies.

Food consumption in Delhi is lower than of global average and it is expected to rise by ~6.5% from 2011 to 2021. If more people turn non-vegetarian along with increased consumption of animal products in their diet, it will have ripple effect on the rise of consumption based water footprint as demonstrated by Vanham et al. (2017) through his study on Hong Kong. However, change in dietary pattern is an individual's choice which can be a slow process. Measures can be taken to reduce loss and wastage of agricultural products which can show immediate results, ultimately helping farmers of Delhi.

Change in diet might take years to show significant change at per capita scale. It becomes important to find a way to decrease water footprint at individual scale and that is why water footprint labels and cess on higher water footprint consumption can play a major role in paving a path for sustainable future for cities like Delhi.

Measures can be taken to reduce both direct and indirect water footprint within Delhi. Direct water footprint can be decreased by rain water harvesting. General trend of lesser the rain more emphasis on rain water harvesting should be discontinued. Minimum percent of rain water harvesting could be set by the government. Reuse of water utilised by industries can be enforced. Ground water can be effectively used for non-drinking purposes. This will help in supply of treated water to all class of people whether rich or poor. Indirect water footprint can be reduced by lowering consumption and wastage of all commodities at individual level. City administration can plan installation of proper storage facility and effective connectivity with rural areas. Use of best available techniques in agriculture sector can be key to reduce water footprint of India.

CHAPTER 5

SUMMARY AND FUTURE SCOPE

5.1 Summary

- Food products including crops and livestock have shown significant contribution, i.e. ~90% of total water footprint (2900 lpcd) in Delhi.
- Rice and wheat products are the major contributors in crop water footprint due to high consumption.
- There is no major water footprint contribution (less than 8% of total water footprint) of products essential in urban living considered in this study.
- Agricultural water footprint of urban Delhi came out to be similar to that of rural Delhi as 2429 lpcd and 2002 lpcd respectively for the year 2011.
- Our estimations showed that cereal consumption could decrease by ~4.2% from 2011 to 2021.
- Overall consumption of livestock products is estimated to increase by ~24%, chicken consumption might increase by ~45%.
- Results suggest indirect water footprint will have a marginal rise of ~7% from 2011 to 2021.
- Results suggest, increase of 12.8% in total water footprint of Delhi from 2011 to 2021 is primarily because of direct and livestock water footprint increase. Direct water footprint is estimated to increase by 66% in this period.
- Potential water savings through reduced wastage of food products was explored. It was estimated 1243 MLD of virtual water was lost in Delhi by food wastage in the year 2011.
- Potential water savings through use of modern techniques and water management in agricultural practices was explored. It was estimated 11239 MLD of virtual water was lost in the year 2011 in production, storage and transportation phases.
- It was found that out of 38 categories of products, 5 products were contributing 73% of indirect water footprint, and the rest 33 products contributed the remaining 27%.

This study finds the water saving potential and alternatives for Delhi. A novel attempt was made to forecast water footprint of a city using regression models for each product. The same methodology can be used to find water footprint of other cities.

Water footprint as an indicator is a partial decision-making tool for proper management of environmental resources. Therefore, it is important to integrate it with other environmental, social and economic indicators to be used as sustainability indicator for a city. It was desirable to find uncertainty in the results estimated but unavailability of relevant data was a limitation.

5.2 Conclusions

Water footprint of Delhi was ~2900 lpcd in the year 2011 with ~90% as indirect and 10% as direct water footprint. Direct water footprint self-sufficiency can be achieved by techniques such as groundwater use and rain water harvesting. Agricultural water footprint, with ~90% contribution, is estimated to increase by ~7% from ~2400 lpcd to ~2600 lpcd due to change in dietary patterns from 2011 to 2021. Virtual water lost in a day through loss of agricultural products is about 3.5 times the direct water supply of Mumbai in the year 2011. Techniques such as effective connectivity with rural areas and proper storage facilities can be used to reduce virtual water loss. Modern technologies can be implemented in rural areas to reduce agricultural water footprint. Improvement of 1% in average agricultural production losses can save ~900 MLD of water extraction from various water resources.

5.3 Future Scope

- Water footprint of consumption depends on age and buying capacity of a person. Correlation between age, per capita income and water footprint can be further explored.
- An optimization model can be formulated according to crop season, demand, water availability, soil conditions in order to decrease overall water footprint of agriculture sector.
- Uncertainty studies can be used to find probable range of water footprint for a city.

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Appendix

Table A.1 Indirect WF for the various products in Delhi (2011)

S.No.	Items	Quantity per 30 days per capita (kg*)	Type	Preference	VWC (l/kg)	WF (litres)	Remarks
1	Rice – P.D.S.	0.198	Cereals	1	4515	893.97	_
2	Rice – other sources	2.747	Cereals	1	4515	12402.705	_
3	Chira/Flattened rice	0.212	Cereals	1	4515	957.18	_
4	Khoi, lawa(puffed rice)	0.002	Cereals	1	4515	9.03	_
5	Muri(puffed rice)	0.022	Cereals	1	4515	99.33	_
6	Other rice products	0.012	Cereals	1	4515	54.18	_
7	Wheat/atta – P.D.S.	0.326	Cereals	1	3817	1244.342	_
8	Wheat/atta – other sources	3.819	Cereals	1	3817	14577.123	_
9	Maida/wheat flour	0.026	Cereals	1	3817	99.242	_
10	Bread: bakery	0.177	Cereals	1	3817	675.609	_
11	Other wheat products	0.009	Cereals	1	3817	34.353	_
12	Jowar(sorghu	0.49	Cereals	1	3137	1537.13	_

	m) and its products						
13	Bajra(pearl millet) and its products	0.174	Cereals	1	4851	844.074	_
14	Maize and its products	0.003	Cereals	1	2905	8.715	_
15	Barley and its products	0	Cereals	2	1966	0	_
16	Small millets and its products	0.005	Cereals	1	2905	14.525	_
S.No.	**Items**	**Quantity per 30 days per capita (kg*)**	**Type**	**Preference**	**VWC (l/kg)**	**WF (litres)**	**Remarks**
17	Ragi(African millet) and its products	0.003	Cereals	1	2905	8.715	_
18	Other cereals	0.006	Cereals	1	3531	21.186	Average of WF all cereals-rice+wheat+millet+sorghum+maize+barley
19	Arhar/Pigeon pea , tur	0.412	Pulses	1	5869	2418.028	_
20	Gram: split	0.098	Pulses	1	3384	331.632	_
21	Gram: whole	0.038	Pulses	1	3384	128.592	_
22	Moong/Green Gram	0.151	Pulses	1	7207	1088.257	_
23	Masur/Red Lentil	0.081	Pulses	2	6652	538.812	_

24	Urd/Black lentils	0.046	Pulses	1	7207	331.522	_
25	Other pulses	0.041	Pulses	2	3078	126.198	_
26	Gram products	0.001	Pulses	1	3384	3.384	_
27	Besan or gram flour or chickpeas flour	0.099	Pulses	1	3384	335.016	_
28	Other pulse products	0.017	Pulses	2	3078	52.326	_
29	Sugar – PDS	0.017	Sugar	2	1391	23.647	_
30	Sugar – other sources	0.917	Sugar	2	1391	1275.547	_
31	Gur/brown sugar	0.045	Sugar	2	1391	62.595	Assumed equal to refined sugar
32	Mustard oil	0.058	Edible oil	2	4738	274.804	__
33	Groundnut oil	0.188	Edible oil	2	9056	1702.528	Ground-nut oil and its fractions refined but not chemically modified
34	Coconut oil	0.005	Edible oil	2	3113	15.565	Coconut (copra) oilandits fractions refined but not chemically modified
S.No.	**Items**	**Quantity per 30 days per capita (kg*)**	**Type**	**Preference**	**VWC (l/kg)**	**WF (litres)**	**Remarks**
35	Refined oil	0.728	Edible oil	2	8363.5	6088.628	Average of Sunflower + Soybean

							given by NSS 68
36	Edible oil: others	0.046	Edible oil	2	7240	333.04	47%- refined oil; 28% mustard oil; 9.5%- groundnut oil given by NSS 68
37	Potato	0.887	Vegetable	2	213	188.931	_
38	Onion	0.97	Vegetable	2	538	521.86	_
39	Tomato	0.723	Vegetable	2	302	218.346	_
40	Brinjal	0.351	Vegetable	2	146	51.246	Also known as eggplant
41	Carrot	0.092	Vegetable	2	192	17.664	_
42	Palak(spinach)/other	0.745	Vegetable	2	144	107.28	_
43	Green chillies	0.2	Vegetable	2	285	57	_
44	Cauliflower	0.394	Vegetable	2	100	39.4	_
45	Cabbage	0.319	Vegetable	2	180	57.42	_
46	Gourd, pumpkin	0.113	Vegetable	2	238	26.894	_
47	Peas	0.151	Vegetable	2	3040	459.04	_
48	Beans, barbati	0.157	Vegetable	1	7207	1131.499	_
49	Lemon (no.)	2.366 (x0.05)	Vegetable	2	611	72.28	_
50	Other vegetables	0.472	Vegetable	2	207	97.704	_
51	Banana (no.)	8.588 (x 0.12	Fruit and nut	2	415	427.68	_

		g/number)					
52	Watermelon	0.088	Fruit and nut	2	362	31.856	_
53	Pineapple (no.)	0.023(x1)	Fruit and nut	2	305	7.015	_
54	Coconut (no.)	0.406(x0.68)	Fruit and nut	2	2255	622.56	_
55	Green coconut (no.)	0.213(x0.6)	Fruit and nut	2	2255	288.19	Assumed WF equal to coconut
S.No.	**Items**	**Quantity per 30 days per capita (kg*)**	**Type**	**Preference**	**VWC (l/kg)**	**WF (litres)**	**Remarks**
56	Guava	0.048	Fruit and nut	2	1525	73.2	_
57	Papaya	0.086	Fruit and nut	2	922	79.292	_
58	Mango	0.187	Fruit and nut	2	1525	285.175	_
59	Apple	0.271	Fruit and nut	2	1812	491.052	_
60	Grapes	0.098	Fruit and nut	2	238	23.324	_
61	Groundnut	0.256	Fruit and nut	2	3420	875.52	_
62	Dates	0.019	Fruit and nut	2	3030	57.57	_
63	Cashewnut	0.011	Fruit and nut	2	15340	168.74	_
64	Walnut	0.002	Fruit and nut	2	11721	23.442	_
65	Other nuts	0.01	Fruit and nut	2	12426	124.26	Average of almond-19537; hazelnut-6876; pistachios-10864
66	Pears/nashpati	0.003	Fruit and nut	2	1287	3.861	_

67	Berries	0.003	Fruit and nut	2	897	2.691	_
68	Ginger (gm)	72.512	Spices	2	1556	112.828672	_
69	Garlic (gm)	105.071	Spices	2	1268	133.230028	_
70	Dhania/Coriander (gm)	35.595	Spices	2	949	33.779655	Coriander seeds
71	Turmeric (gm)	39.493	Spices	2	1556	61.451108	_
72	Black pepper (gm)	5.468	Spices	2	8333	45.564844	_
73	Dry chillies (gm)	73.705	Spices	2	285	21.005925	WF taken equal to green chilly
74	Oilseeds (gm)	23.963	Spices	2	8023	192.255149	_
75	Other spices (gm)	50.138	Spices	2	4054	203.259452	_
76	Milk: liquid (litre)	4.953	Dairy products	2	2134	10569.702	Unsweetened milk
77	Milk: powder	0.001	Dairy products	2	6378	6.378	_
78	Curd	0.059	Dairy products	2	4281	252.579	_
S.No.	**Items**	**Quantity per 30 days per capita (kg*)**	**Type**	**Preference**	**VWC (l/kg)**	**WF (litres)**	**Remarks**
79	Ghee/hard fat	0.039	Dairy products	2	2547	99.333	Milk and cream not concentrated and unsweetened

							exceeding 6% fat
80	Butter	0.003	Dairy products	2	2068	6.204	Buttermilk, curdled milk
81	Cheese(kg)	0.02[a]	Dairy Products	2	6793	135.86	Cheese, blue-veined
82	Eggs (no.)	3.409(x0.055)	Meat and egg	2	7531	1412.024	_
83	Fish, prawn	0.175	Meat and egg	3	1974	345.45	farmed fish and crustaceans fed commercial aquafeed
84	Goat meat/mutton	0.107	Meat and egg	2	5187	555.009	_
85	Beef/ buffalo meat	0.08	Meat and egg	2	16482	1318.56	_
86	Pork	0.004	Meat and egg	2	6026	24.104	Swine cuts, fresh or chilled
87	Chicken	0.27	Meat and egg	2	7736	2088.72	_
88	Others: birds, crab, etc.	0.002	Meat and egg	2	7736	15.472	WF taken equal to turkey
89	Tea: cups (no.)	7.145	Beverages	3	27 l/cup	192.915	based on the use of 3 gram of black tea per cup
90	Coffee: cups (no.)	0.207	Beverages	3	130 litre/cup,	26.91	based on the use of 7 gram of roasted coffee per cup
91	Cold drinks (L)	0.096	Beverages	2	221[p]	21.216	_
92	Fruit juice and shake (no.)	0.045(x0.3*1.1)	Beverages	2	636	9.444	Fruit and veg. juice unferment unspiritd
93	Bidi(no.)	2.448(x0.2x10-3)	Tobacco products	2	2627	1.286	Tobacco, unmanufactured,

							partly or wholly stemmed or stripped
94	Cigarettes (no.)	1.29	Tobacco products	3	3.7 l/no.[q]	4	_
95	Tobacco(gm)	6.673	Tobacco products	2	2627	4.773	Tobacco, unmanufactured, partly or wholly stemmed or stripped
S.No.	**Items**	**Quantity per 30 days per capita (kg*)**	**Type**	**Preference**	**VWC (l/kg)**	**WF (litres)**	**Remarks**
96	Liquor (litre)	1.64[b]	Beverages	2	408	669.12	95% beer made by malt; 5% wine
97	Electricity (std units)	93.41[c]	Energy and Fuel	3	1.143 m^3/ MWh[r]	106.76	_
98	Kerosene (litre)	0.521	Energy and Fuel	2	273[s]	142.233	Source: GaBi; System Boundary: Production phase
99	Petrol (litre)	5.8[d]	Energy and Fuel	2	278[s]	1612.4	Source: GaBi; System Boundary: Production phase
100	Coal (kg)	0.041	Energy and fuel	2	125[s]	5.125	Source: GaBi; System Boundary: production and trasportation
101	L.P.G. (kg)	2.155	Energy and Fuel	*	112[s]	241.36	Source: GaBi; System Boundary: production and trasportation via pipeline for US

102	Leather footwear (pair)	0.044	Clothing, Bedding and Footwear	2	17710	389.62	WF of leather is used and not of the final product; Taking the weight of a leather boot pair = 0.5 kg
103	Total no. of clothes (T Shirt equivalent)	0.955	Clothing, Bedding and Footwear	3	2720 L/no.[t]	2597.6	Assuming - Jacket = 8x;shawl=4x;kurta=pajama-4x;shorts=0.5x;lungi=4x;scarf=0.5x;sari=8x
104	Bed sheet (no.)	0.02	Clothing, Bedding and Footwear	3	9750L/no.[t]	195	–

*Unless otherwise specified;

References for WF (unless otherwise specified): Preference 1: Kampman, (2007); Preference 2: Chapagain and Hoekstra (2004); Preference 3: Mekonnen and Hoekstra (2011);

Reference for consumption data: NSSO, 2014 unless otherwise specified; a: URL 17; b: URL 10; c: URL 18; d: URL 13; p: Ercin et al. (2011); q: Zafeiridou et al. (2018); r: URL 19; s: GaBi Database; t: Chapagain et al. (2005)

Table A.2 Estimation of consumption of agricultural products and water footprint of Delhi for the year 2021

S.No	**Product Name**	**2011-NSSO Consumption (Delhi) (kg/month)**	**2011-FAO Consumption (Indian Average) (kg/month)**	**Estimated 2021-FAO Consumption (Indian Average) (kg/month)**	**Conversion Factor = $\frac{[2011-N}{[2011-F}$**	**Estimated 2021-Delhi (kg/month)**	**% Change in Consumption from 2011to 2021**	**VWC (l/kg)**	**WF-2021 (l/c/month)**
1	Rice and Products	3.193	5.902	5.813	0.5410	3.145	-1.513	4515	14198.21
2	Wheat and Products	4.357	4.904	4.818	0.8885	4.280	-1.759	3817	16338.08

3	Millet and Products	0.182	0.743	0.616	0.2450	0.151	-17.102	4765	718.98
4	Jowar (sorghum) and its products	0.490	0.425	0.217	1.1529	0.250	-48.951	3137	784.68
5	Maize and its products	0.003	0.542	0.495	0.0055	0.003	-8.741	2905	7.95
6	Barley and its products	0.005	0.083	0.084	0.0602	0.005	0.826	1966	9.91
7	Potato	0.887	1.939	1.985	0.4575	0.908	2.367	213	193.40
8	Sugar-Total	0.979	1.672	1.563	0.5855	0.915	-6.499	1391	1273.29
9	Beans, barbati	0.157	0.286	0.283	0.5490	0.155	-1.142	7207	1118.57
10	Peas	0.151	0.15	0.167	1.0067	0.168	11.496	3040	511.81
11	Pulses and Products	0.984	0.744	0.856	1.3226	1.132	15.036	5441	6158.78
12	Nuts	0.279	0.114	0.171	2.4474	0.417	49.578	4272	1782.92
13	Coconut – Total	0.403	0.461	0.575	0.8742	0.503	24.690	2255	1133.14
14	Groundnut oil	0.188	0.108	0.094	1.7407	0.163	-13.048	9056	1480.38
15	Refined oil	0.728	0.055	0.069	13.2364	0.909	24.817	8364	7599.62

16	Mustard oil	0.058	0.173	0.152	0.3353	0.051	-12.367	4738	240.82
17	Coconut oil	0.005	0.017	0.079	0.2941	0.023	365.294	3113	72.42
18	Edible oil: others	0.046	0.01	0.046	4.6000	0.212	360.000	7240	1531.98
19	Tomato	0.723	1.001	0.893	0.7223	0.645	-10.769	302	194.83
20	Onion	0.970	1.06	1.312	0.9151	1.201	23.801	538	646.07
21	Other Vegetables	2.686	4.65	4.870	0.5776	2.813	4.727	169	476.10
22	Lemon	0.118	0.119	0.196	0.9930	0.194	64.101	611	118.61
23	Banana	1.031	1.551	1.575	0.6640	1.046	1.459	415	433.92
24	Apple	0.271	0.188	0.135	1.4415	0.195	-27.975	1812	353.68
25	Pineapple	0.023	0.097	0.110	0.2379	0.026	13.476	305	7.96
26	Dates	0.019	0.018	0.019	1.0556	0.020	3.029	3030	59.31
27	Grapes	0.098	0.071	0.163	1.3803	0.225	129.333	238	53.49
28	Fruits, Others	0.415	1.919	2.286	0.2163	0.494	19.124	1147	567.12
29	Spices Total	0.406	0.179	0.091	2.2678	0.207	-49.106	1979	408.87
30	Beef/ buffalo meat	0.080	0.103	0.103	0.7767	0.080	-0.291	16482	1314.72

31	Goat meat/mutton	0.107	0.052	0.060	2.0577	0.124	15.596	5187	641.57
32	Pork	0.004	0.025	0.021	0.1600	0.003	-16.800	6026	20.05
33	Chicken	0.270	0.154	0.224	1.7532	0.393	45.417	7736	3037.35
34	Fish, prawn	0.175	0.298	0.244	0.5872	0.143	-18.121	1974	282.85
35	Others: birds, crab, etc.	0.002	0.012	0.012	0.1667	0.002	3.338	7736	15.99
36	Cheese, Butter, Ghee	0.062	0.234	0.336	0.2650	0.089	43.628	3894	346.71
37	Eggs	0.187	0.198	0.282	0.9454	0.267	42.434	7531	2010.18
38	Milk and products	5.013	7.018	8.406	0.7143	6.004	19.773	2160	12969.77
	TOTAL	25.755				27.561			79114.118

* No trend available

Table A.3 Consumption of agricultural products and associated water footprint for rural Delhi (2011) (NSSO, 2014)

S.No.	Items	Quantity per 30 days per capita	Type	Preference	VWC (l/kg)	WF (litres)	Remarks

		(kg*)					
1	Rice – P.D.S.	1.128	Cereals	1	4515	5092.920	_
2	Rice – other sources	2.110	Cereals	1	4515	9526.650	_
3	Chira/Flattened rice	0.149	Cereals	1	4515	672.735	_
4	Khoi, lawa(puffed rice)	0.003	Cereals	1	4515	13.545	_
5	Muri(puffed rice)	0.034	Cereals	1	4515	153.510	_
6	Other rice products	0.015	Cereals	1	4515	67.725	_
7	Wheat/atta – P.D.S.	1.308	Cereals	1	3817	4992.636	_
8	Wheat/atta – other sources	3.005	Cereals	1	3817	11470.085	_
9	Maida/wheat flour	0.019	Cereals	1	3817	72.523	_
10	Bread: bakery	0.041	Cereals	1	3817	156.497	_
11	Other wheat products	0.011	Cereals	1	3817	41.987	_
12	Jowar(sorghum) and its products	1.300	Cereals	1	3137	4078.100	_
13	Bajra(pearl	0.564	Cereals	1	4851	2735.964	_

	millet) and its products						
14	Maize and its products	0.013	Cereals	1	2905	37.765	
15	Barley and its products	0.041	Cereals	1	1966	119.105	
16	Small millets and its products	0.013	Cereals	1	2905	37.765	_
17	Ragi(African millet) and its products	0.005	Cereals	2	2905	9.830	_
S.No.	**Items**	**Quantity per 30 days per capita (kg*)**	**Type**	**Preference**	**VWC (l/kg)**	**WF (litres)**	**Remarks**
18	Other cereals	0.009	Cereals	1	3531	31.779	Average of WF all cereals- rice+wheat+ millet+sorghum+maize+ barley
19	Arhar/Pigeon pea , tur	0.367	Pulses	1	5869	2153.923	_
20	Gram: split	0.135	Pulses	1	3384	456.840	_
21	Gram: whole	0.013	Pulses	1	3384	43.992	_
22	Moong/Green	0.149	Pulses	1	7207	1073.843	_

	Gram						
23	Masur/Red Lentil	0.056	Pulses	2	6652	372.512	_
24	Urd/Black lentils	0.071	Pulses	1	7207	511.697	_
25	Other pulses	0.018	Pulses	2	3078	55.404	_
26	Gram products	0.001	Pulses	1	3384	3.384	_
27	Besan or gram flour or chickpeas flour	0.080	Pulses	1	3384	270.720	_
28	Other pulse products	0.018	Pulses	2	3078	55.404	_
29	Sugar – PDS	0.081	Sugar	2	1391	112.671	_
30	Sugar – other sources	0.963	Sugar	2	1391	1339.533	_
31	Gur/brown sugar	0.053	Sugar	2	1391	73.723	Assumed equal to refined sugar
32	Mustard oil	0.001	Edible Oil	2	4738	4.738	_
33	Groundnut oil	0.039	Edible Oil	2	9056	353.184	Ground-nut oil and its fractions refined but not chemically modified

34	Coconut oil	0.001	Edible Oil	2	3113	3.113	Coconut (copra) oilandits fractions refined but not chemically modified
35	Refined oil	0.882	Edible Oil	2	8363.5	7376.607	Average of Sunflower + Soyabean given by NSS 68
36	Edible oil: others	0.061	Edible Oil	2	7240	441.640	47%-refined oil; 28% mustard oil; 9.5%-groundnut oil given by NSS 68
37	Potato	0.822	Vegetable	2	213	175.086	_
38	Onion	0.918	Vegetable	2	538	493.884	_
39	Tomato	0.653	Vegetable	2	302	197.206	_
40	Brinjal	0.472	Vegetable	2	146	68.912	Also known as eggplant
41	Carrot	0.029	Vegetable	2	192	5.568	_

42	Palak(spinach)/ other	0.709	Vegetable	2	144	102.096	_
43	Green chillies	0.254	Vegetable	2	285	72.390	_
44	Cauliflower	0.284	Vegetable	2	100	28.400	_
45	Cabbage	0.257	Vegetable	2	180	46.260	_
46	Gourd, pumpkin	0.065	Vegetable	2	238	15.470	_
47	Peas	0.030	Vegetable	2	3040	91.200	_
48	Beans, barbati	0.133	Vegetable	1	7207	958.531	_
49	Lemon (no.)	2.103(x0.05)	Vegetable	2	611	64.246	_
S.No.	**Items**	**Quantity per 30 days per capita (kg*)**	**Type**	**Preference**	**VWC (l/kg)**	**WF (litres)**	**Remarks**
50	Other vegetables	0.472	Vegetable	2	207	97.704	_
51	Banana (no.)	8.588(x0.12)	Fruit and Nut	2	415	427.680	_
52	Watermelon	0.092	Fruit and Nut	2	362	33.304	_
53	Pineapple (no.)	0.006(x1)	Fruit and Nut	2	305	1.830	_
54	Coconut (no.)	0.233(x0.6	Fruit and	2	2255	451.850	_

		8)	Nut				
55	Green coconut (no.)	0.089(x0.6)	Fruit and Nut	2	2255	120.417	Assumed WF equal to coconut
56	Guava	0.049	Fruit and Nut	2	1525	74.725	_
57	Papaya	0.042	Fruit and Nut	2	922	38.724	_
58	Mango	0.141	Fruit and Nut	2	1525	215.025	_
59	Apple	0.082	Fruit and Nut	2	1812	148.584	_
60	Grapes	0.069	Fruit and Nut	2	238	16.422	_
61	Groundnut	0.342	Fruit and Nut	2	3420	1169.640	_
62	Dates	0.008	Fruit and Nut	2	3030	24.240	_
63	Cashewnut	0.002	Fruit and Nut	2	15340	30.680	_
64	Walnut	0.001	Fruit and Nut	2	11721	11.721	_
65	Other nuts	0.000	Fruit and Nut	2	12426	0.000	Average of almond-19537; hazelnut-6876; pistachios-10864

66	Pears/nashpati	0.002	Fruit and Nut	2	1287	2.574	_
67	Berries	0.012	Fruit and Nut	2	897	10.764	_
68	Ginger (gm)	65.876	Spices	2	1556	102.503	_
69	Garlic (gm)	113.085	Spices	2	1268	143.392	_
70	Dhania/Coriander (gm)	37.324	Spices	2	949	35.420	Coriander seeds
71	Turmeric (gm)	44.776	Spices	2	1556	69.671	_
72	Black pepper (gm)	6.578	Spices	2	8333	54.814	_
73	Dry chillies (gm)	120.446	Spices	2	285	34.327	WF taken equal to green chilly
74	Oilseeds (gm)	29.301	Spices	2	8023	235.082	_
75	Other spices (gm)	44.280	Spices	2	4054	179.511	_
76	Milk: liquid (litre)	3.252	Dairy Products	2	2134	6939.768	Unsweetened milk
77	Milk: powder	0.000	Dairy Products	2	6378	0.000	_
78	Curd	0.037	Dairy Products	2	4281	158.397	_
79	Ghee/hard fat	0.008	Dairy Products	2	2547	20.376	Milk and cream not concentrated and unsweetened exceeding 6% fat

80	Butter	0.000	Dairy Products	2	2068	0.000	Buttermilk,curdled milk
81	Cheese(kg)	0.000	Dairy Products	2	6793	0.000	Cheese, blue-veined
82	Eggs (no.)	1.774(x0.055)	Meat and Egg	2	7531	1412.024	_
S.No.	**Items**	**Quantity per 30 days per capita (kg*)**	**Type**	**Preference**	**VWC (l/kg)**	**WF (litres)**	**Remarks**
83	Fish, prawn	0.090	Meat and Egg	3	1974	177.660	farmed fish and crustaceans fed commercial aquafeed
84	Goat meat/mutton	0.069	Meat and Egg	2	5187	357.903	_
85	Beef/ buffalo meat	0.024	Meat and Egg	2	16482	395.568	_
86	Pork	0.000	Meat and Egg	2	6026	0.000	Swine cuts, fresh or chilled
87	Chicken	0.207	Meat and Egg	2	7736	1601.352	_
88	Others: birds, crab, etc.	0.004	Meat and Egg	2	7736	30.944	WF taken equal to turkey

	TOTAL				4515	2371.930	

APPENDIX 2

Trend line for various agricultural products:

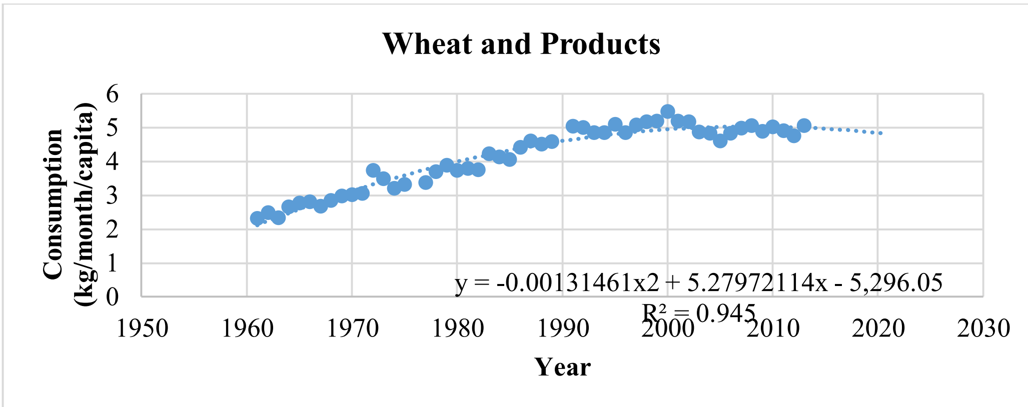

Figure A.1 Consumption of wheat and products

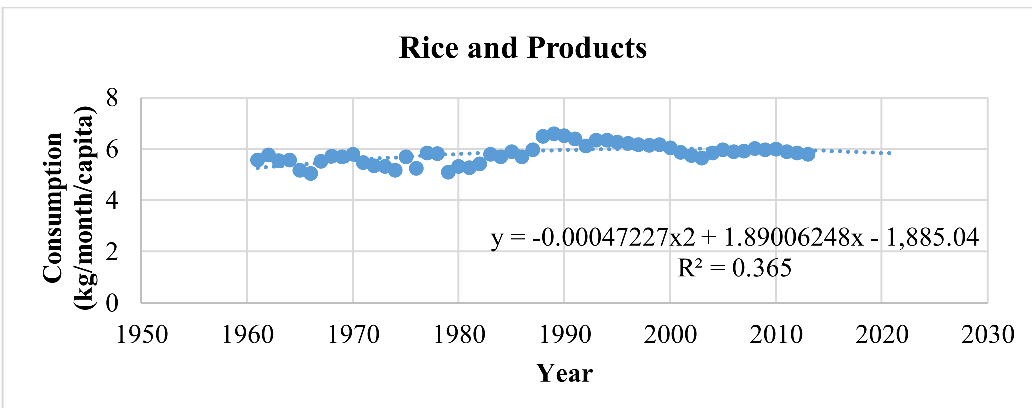

Figure A.2 Consumption of rice and products

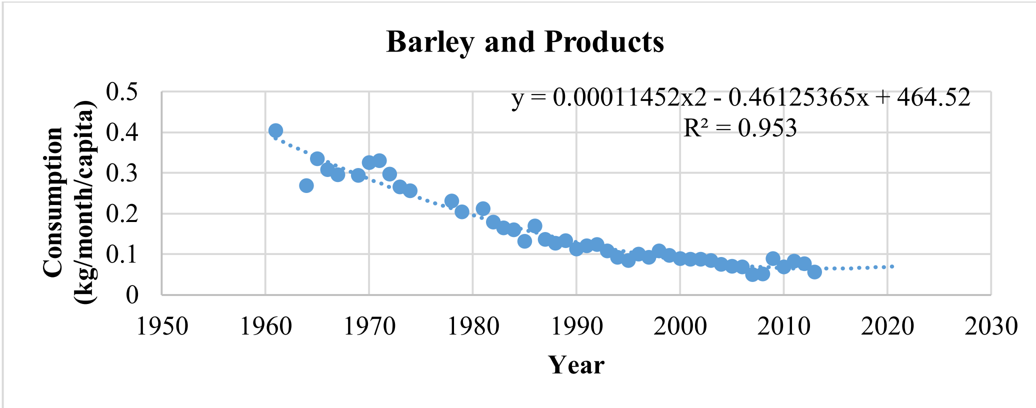

Figure A.3 Consumption of barley and products

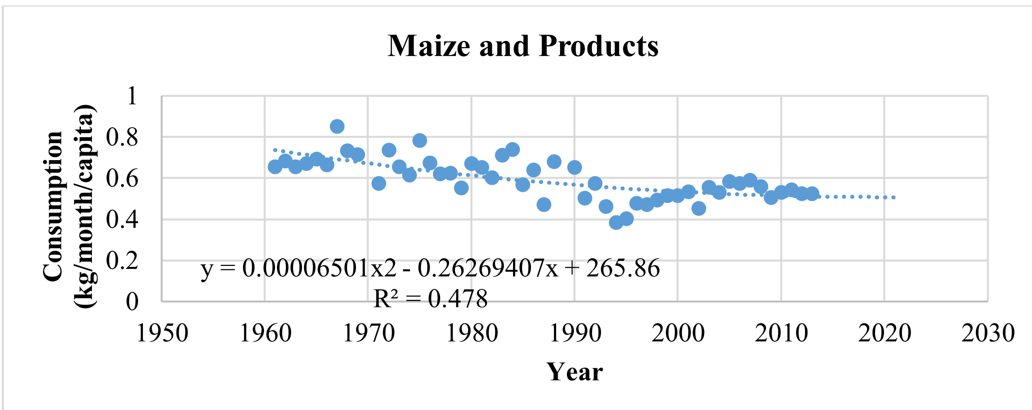

Figure A.4 Consumption of maize and products

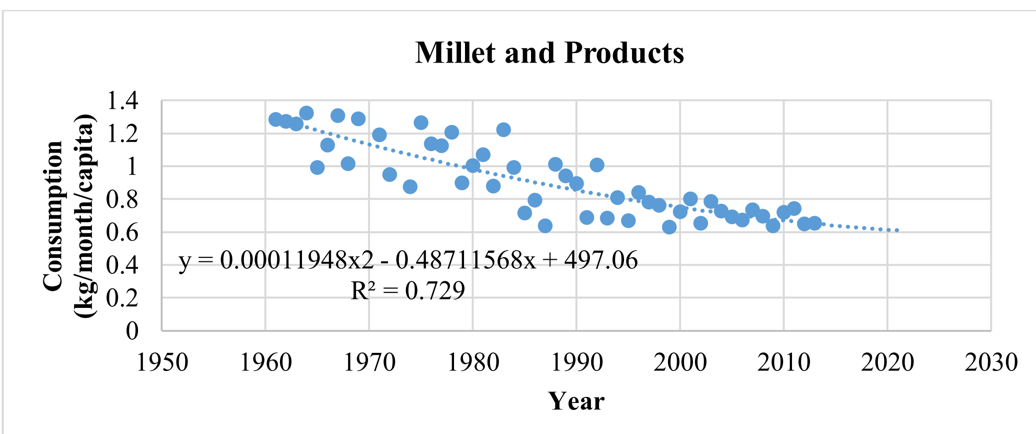

Figure A.5 Consumption of millet and products

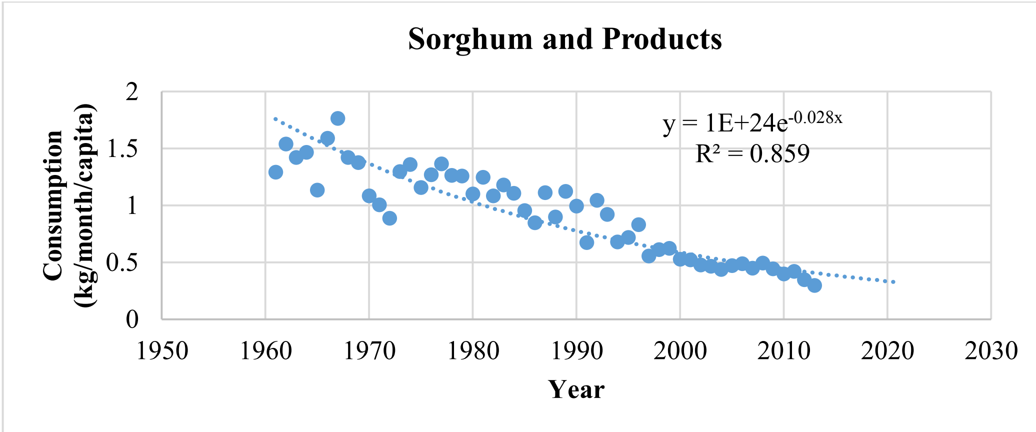

Figure A.6 Consumption of sorghum and products

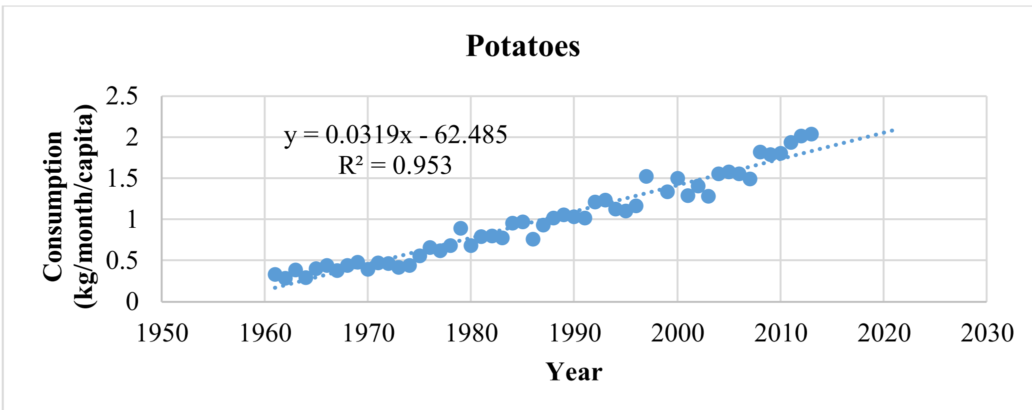

Figure A.7 Consumption of potatoes

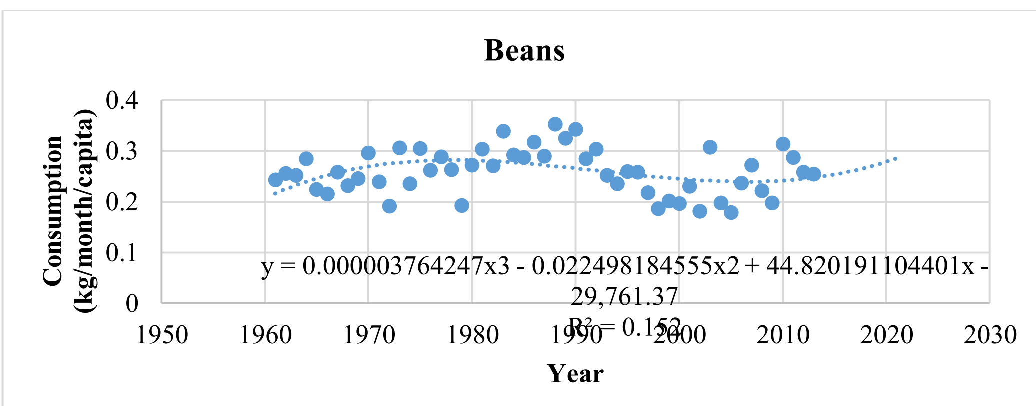

Figure A.8 Consumption of beans

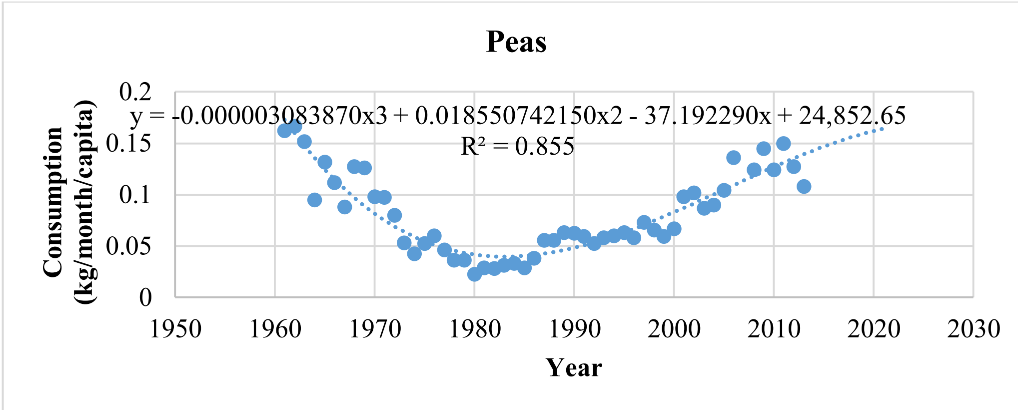

Figure A.9 Consumption of peas

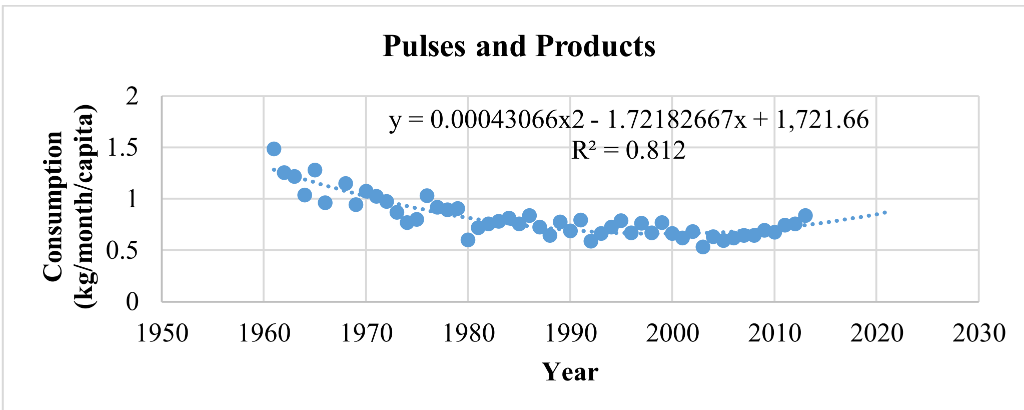

Figure A.10 Consumption of pulses and products

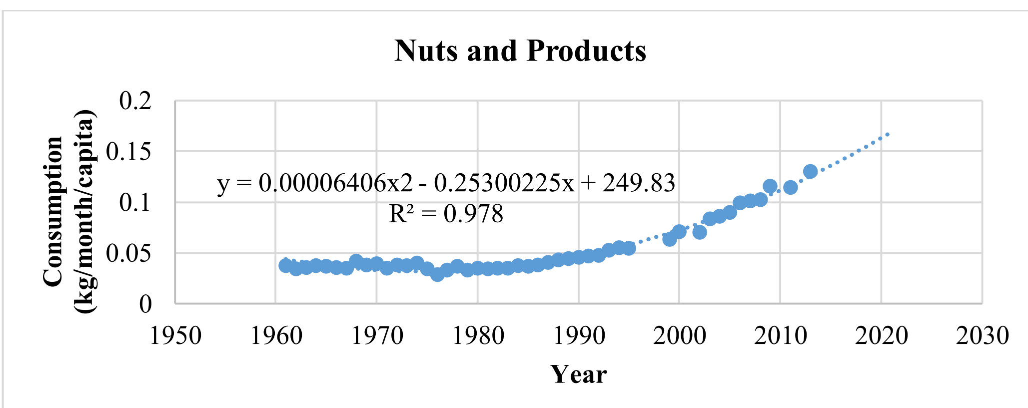

Figure A.11 Consumption of nuts and products

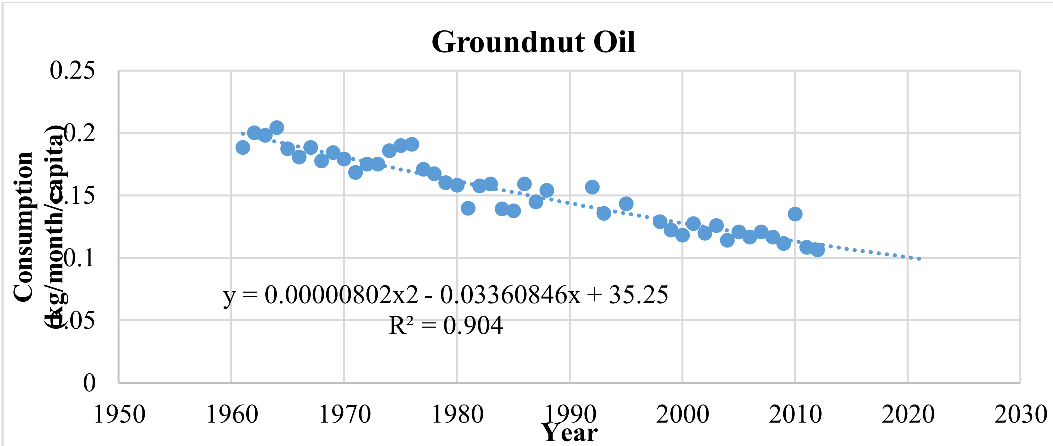

Figure A.12 Consumption of groundnut oil

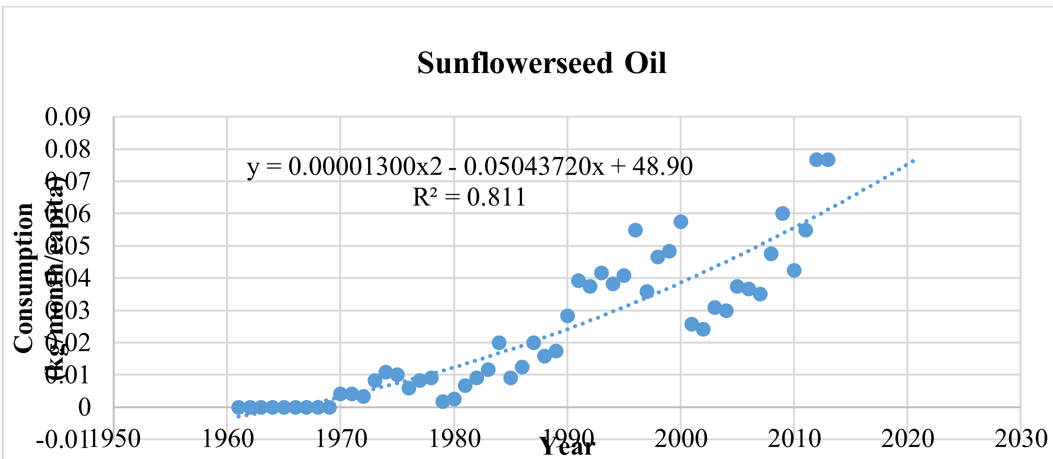

Figure A.13 Consumption of sunflower seed oil

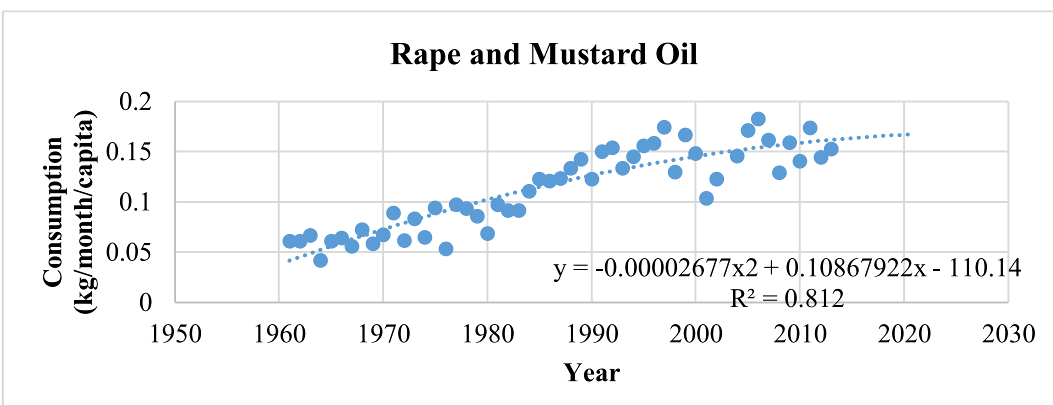

Figure A.14 Consumption of rape and mustard oil

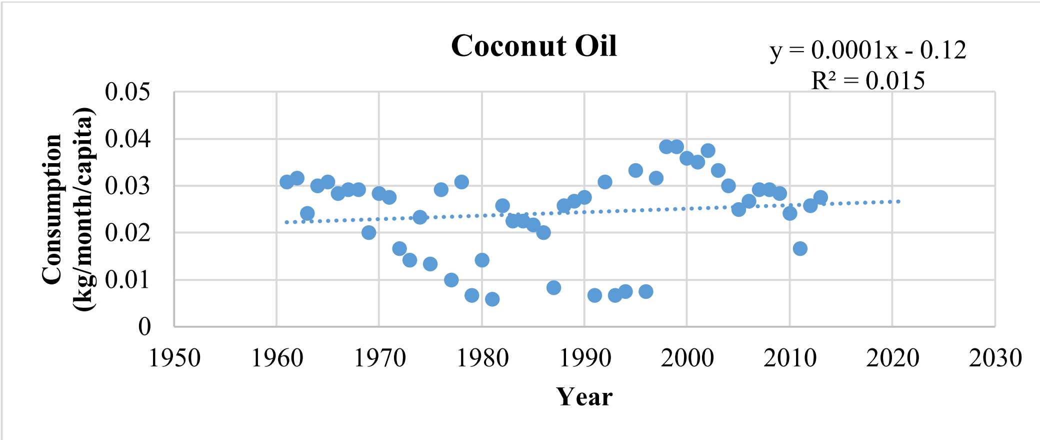

Figure A.15 Consumption of coconut oil

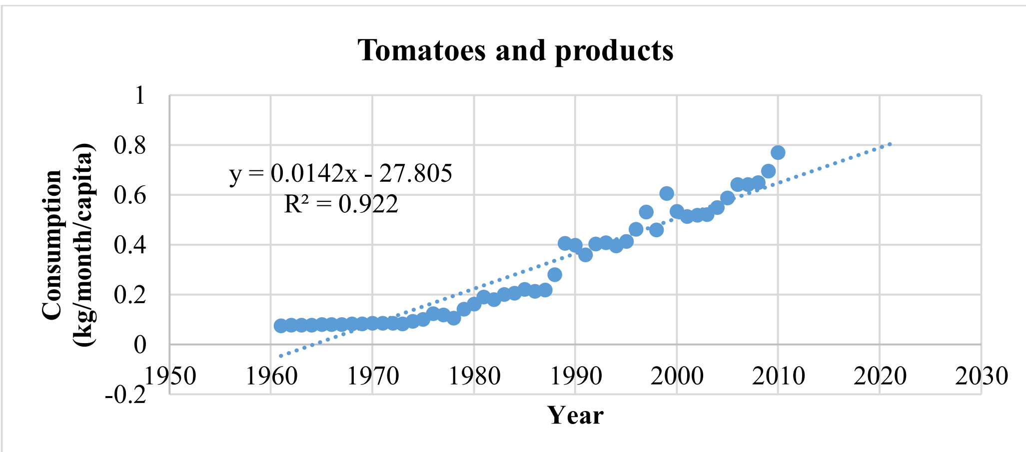

Figure A.16 Consumption of tomatoes and products

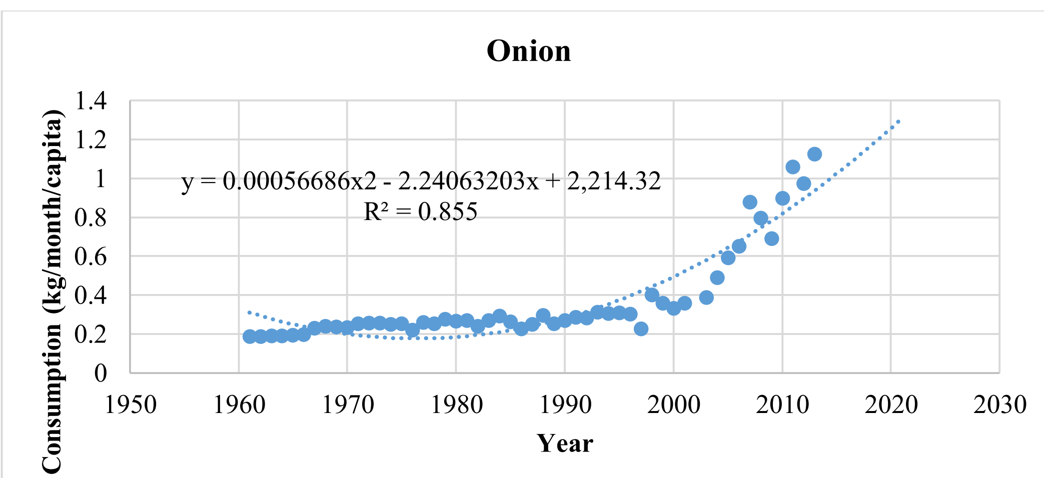

Figure A.17 Consumption of onions

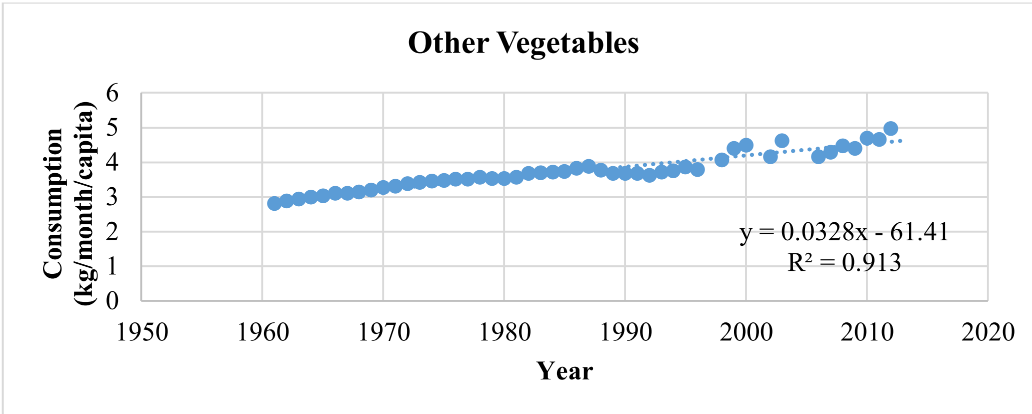

Figure A.18 Consumption of other vegetables

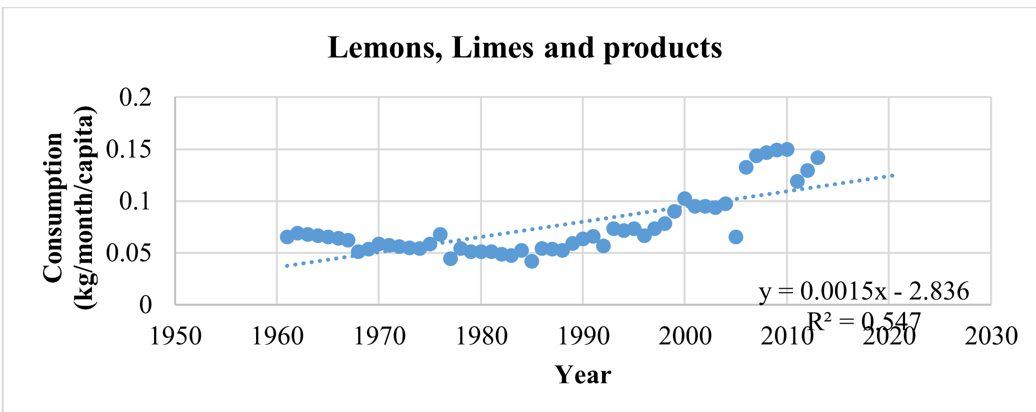

Figure A.19 Consumption of lemon and products

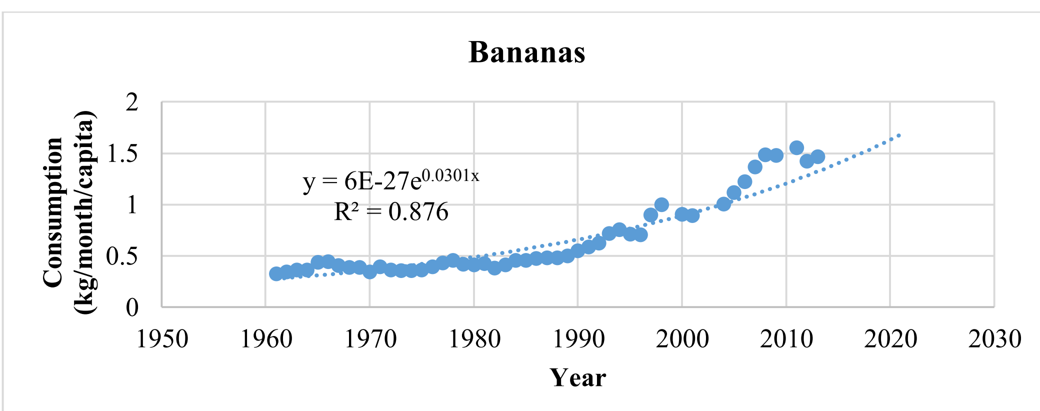

Figure A.20 Consumption of bananas

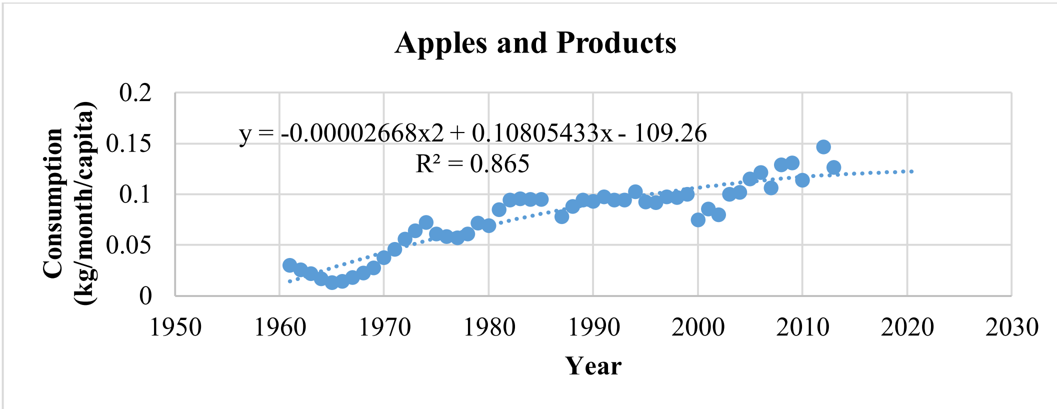

Figure A.21 Consumption of apples and products

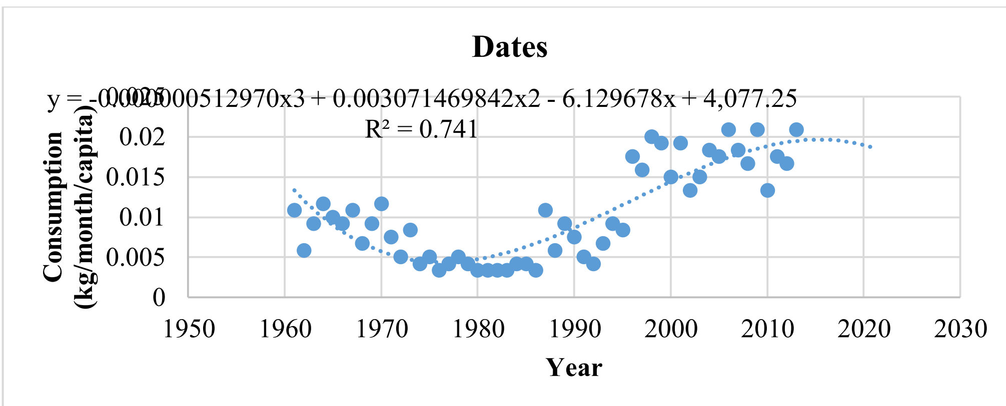

Figure A.22 Consumption of dates

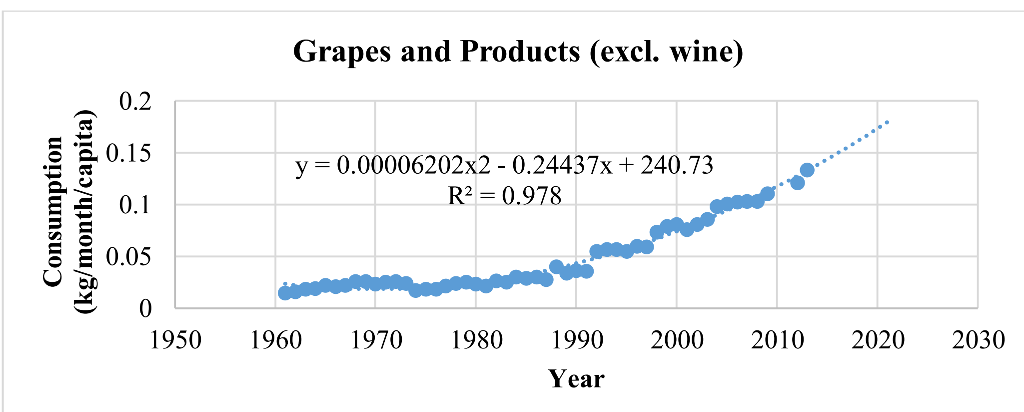

Figure A.23 Consumption of grapes and products

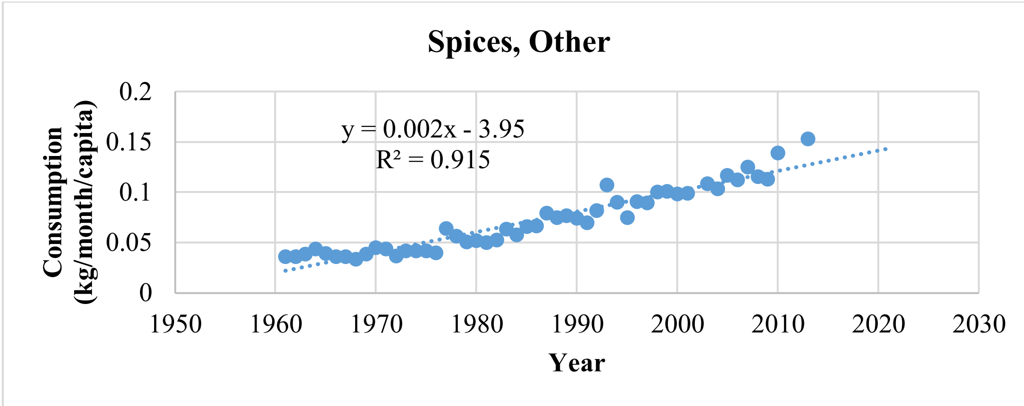

Figure A.24 Consumption of other spices

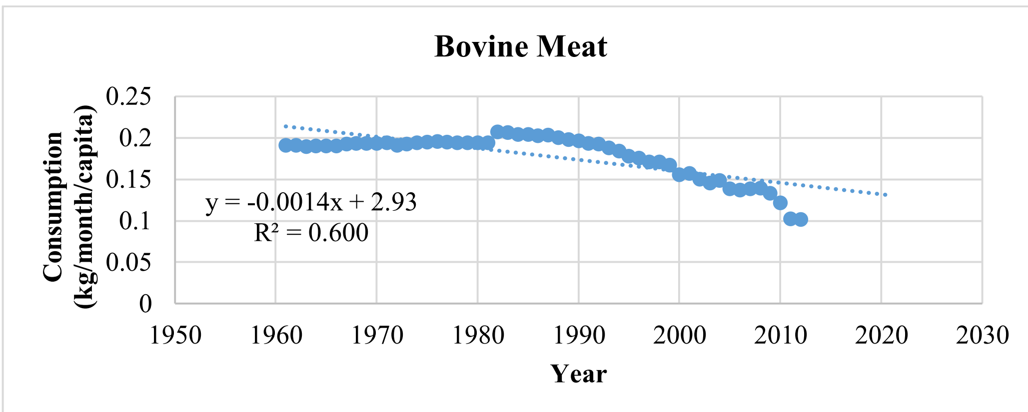

Figure A.25 Consumption of bovine meat

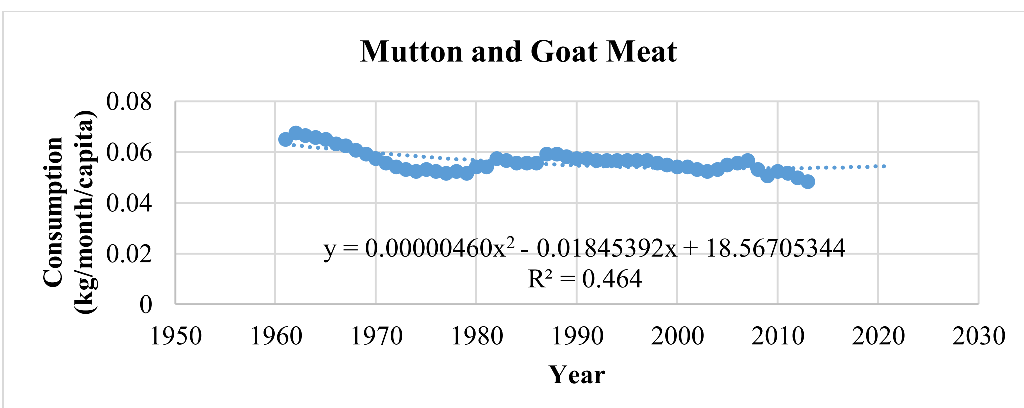

Figure A.26 Consumption of goat meat

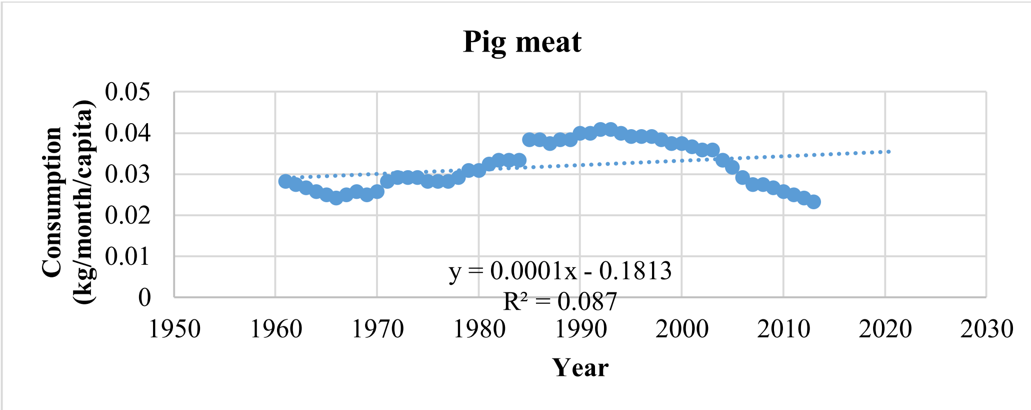

Figure A.27 Consumption of pig meat

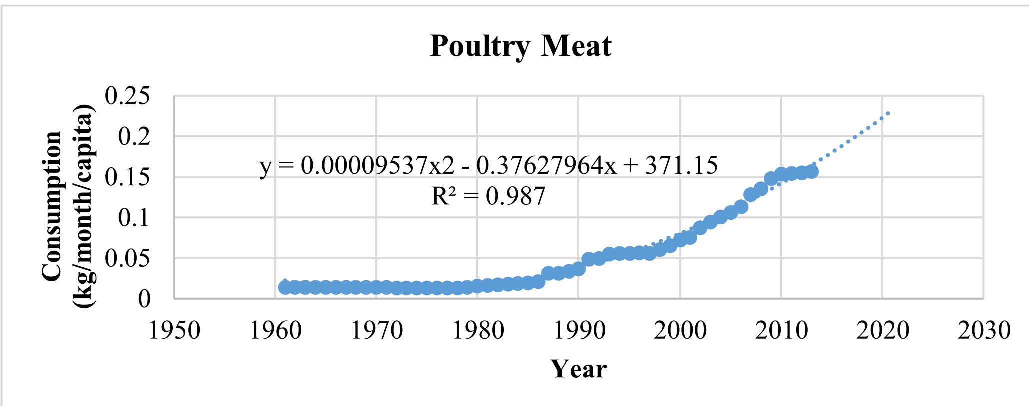

Figure A.28 Consumption of poultry meat

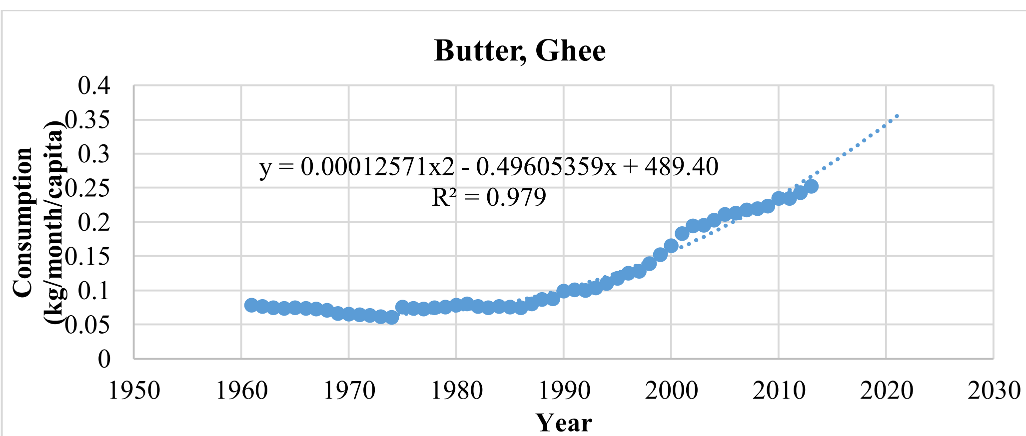

Figure A.29 Consumption of butter

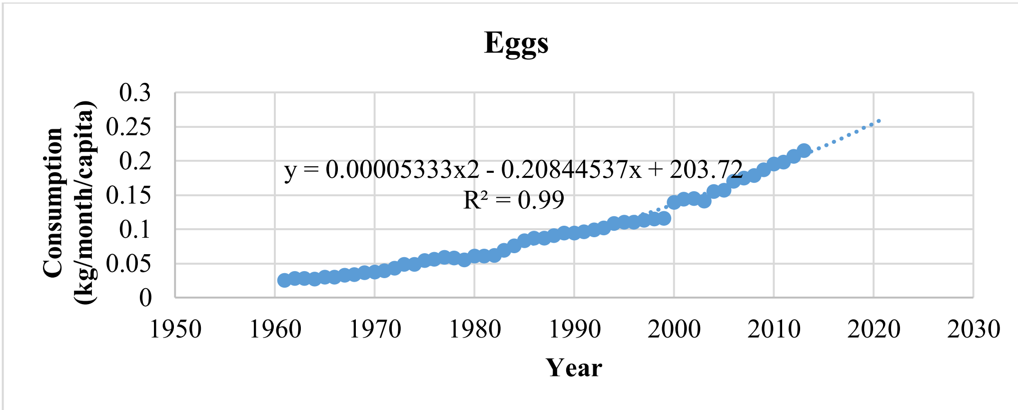

Figure A.30 Consumption of eggs

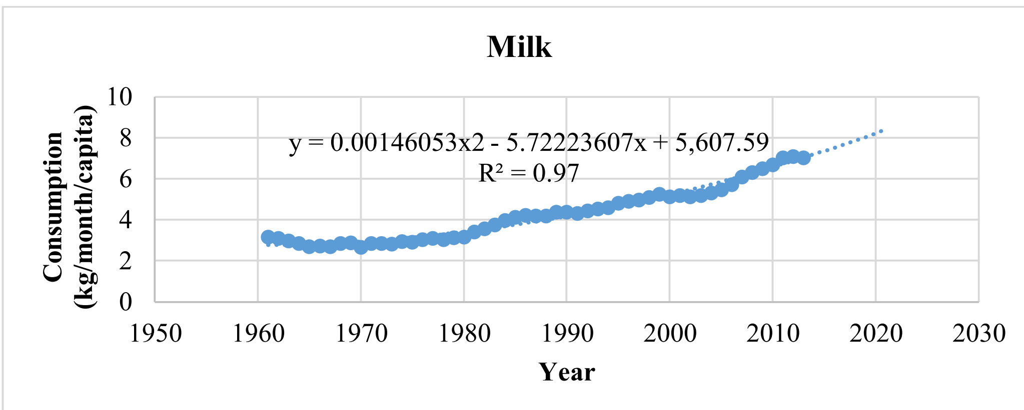

Figure A.31 Consumption of milk

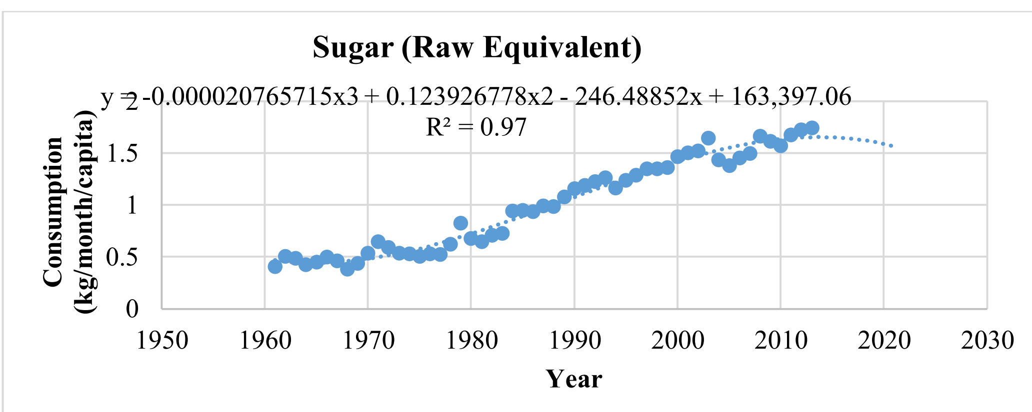

Figure A.32 Consumption of sugar

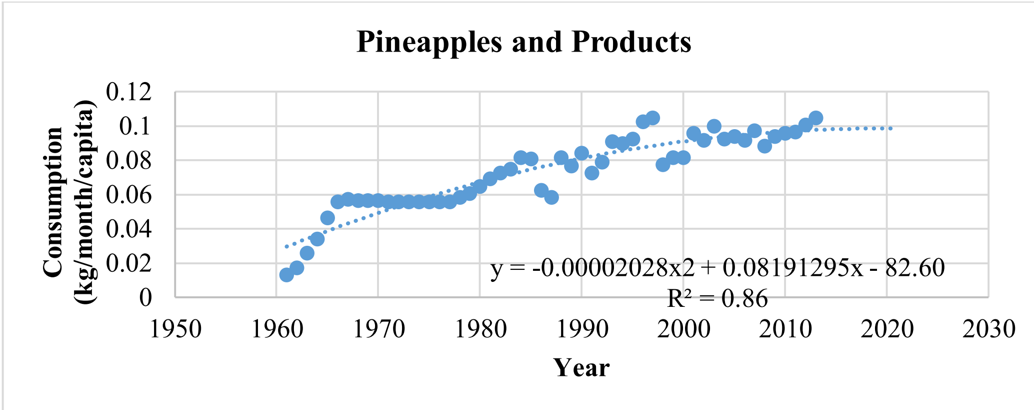

Figure A.33 Consumption of pineapples and products

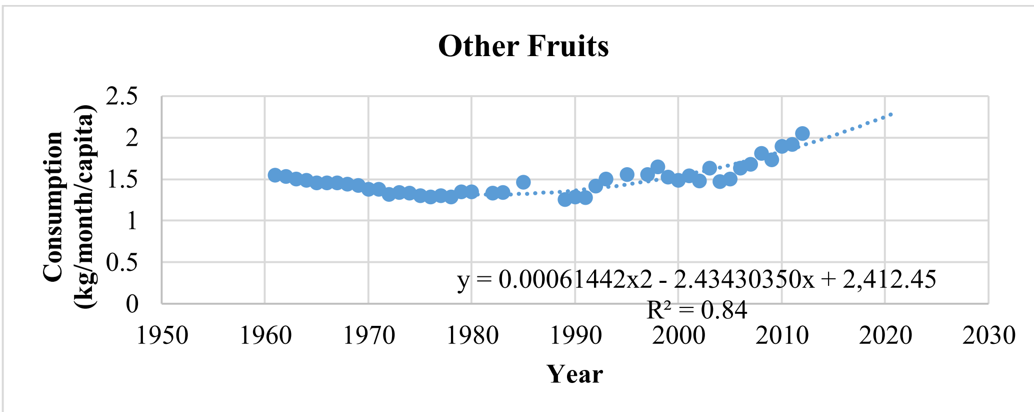

Figure A.34 Consumption of other fruits

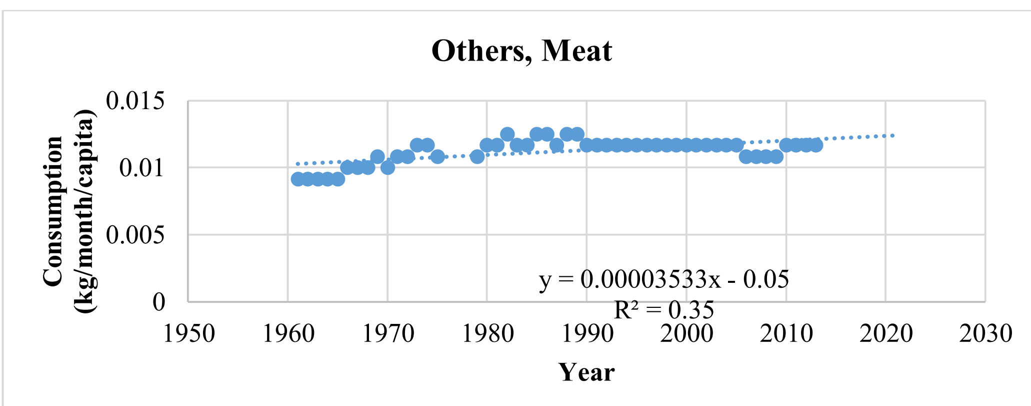

Figure A.35 Consumption of other meat products

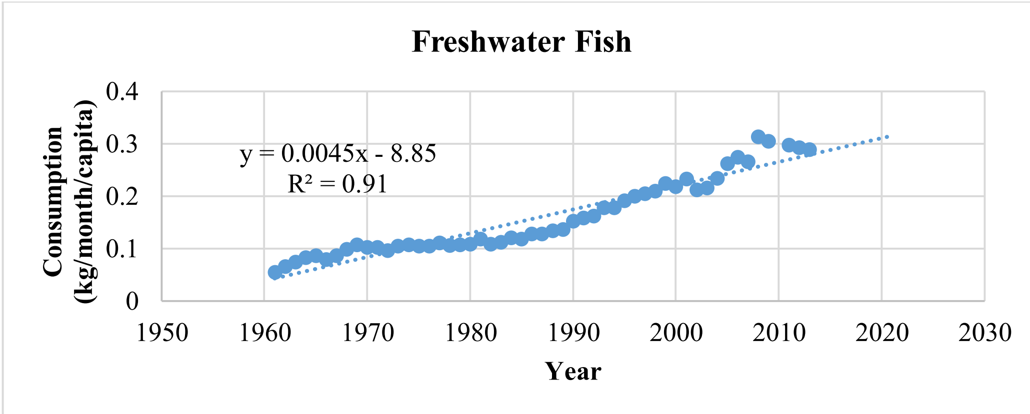

Figure A.36 Consumption of freshwater fish

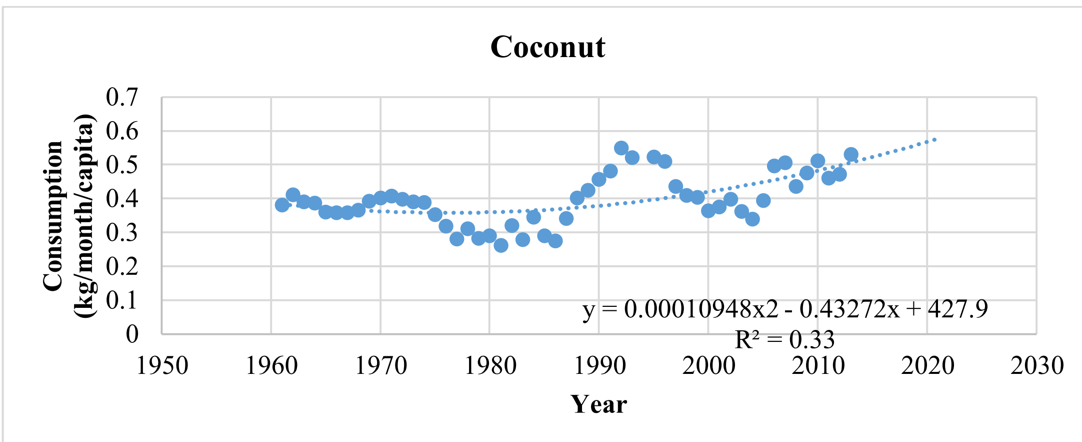

Figure A.37 Consumption of coconut