EVALUATION OF CROP WATER CONSUMPTION USING WATER FOOTPRINT FOR SUSTAINABLE WATER MANAGEMENT IN TEHRAN, IRAN

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FPAS 2020 3

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By

SOMAYEH REZAEI KALVANI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

October 2019

DEDICATION

This thesis is dedicated to

My lovely husband:

With love, respect and a bunch of memories
Indeed, we belong to Allah and indeed to Him we will return.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

EVALUATION OF CROP WATER CONSUMPTION USING WATER FOOTPRINT FOR SUSTAINABLE WATER MANAGEMENT IN TEHRAN, IRAN

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October 2019

Chairman : Amir Hamzah Sharaai, PhD
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The escalation in water use around the world has become a concern. Recently, Iran is facing high water crisis due to unsustainable water management. The objectives of this study are to evaluate the surface and ground water footprints for all crops in Tehran from 2008 to 2015, to estimate the shortage of surface and groundwater in agricultural sector between 2014 and 2015, as well as to assess the variability of per capita Water Footprint (WF) from 2008 to 2015. The evaluation of the blue and green WFs is done according to the WF approach. The evapotranspiration has been evaluated using CROPWAT software. For the first time, the Geographic Information System (GIS) data and fieldwork are utilized to determine ground and surface WFs. The sum of the green and blue WF of crop production had increased from 986,857,963 m^3/year (2008) to 1,097,738,205.2 m^3/year (2015). Besides that, it is indicated that the groundwater is under severe stress (agricultural groundwater scarcity accounted 0.95) for the production of crops alongside moderate surface water stress (agricultural surface water stress accounted 0.4). Although Tehran is facing a serious issue on the groundwater stress, the additional production of agricultural crops (e.g. pear, peach and cherry) is traded to other areas, with extensive scale of production. However, external WF had the largest contribution in WF of crops consumption, accounting 90% of total WF. Tehran province lost 26.691 million cubic meter (MCM) of blue water because of the exportation of pear, peach and cherry. The largest per capita WF is allocated to the wheat and the rice consumptions, accounting 189 and 49 m^3/cap/year respectively. Tehran can take advantage of importing water intensive crops (wheat and rice). 2.88 billion m^3 of water resources in Tehran was saved due to the international and inter provisional crop trade (2008–2015). The production of cereal crops (wheat, barley and maize) consumed 283.776 MCM and 152.460 MCM of groundwater and surface water resources respectively, accounting for 52% of agricultural blue WF (2008-2015). It is recommended to reduce cereal crops production in Tehran province since the production of cereal crops consumed half of the total water withdrawal in the agricultural sector. Moreover, the production of fruits (cherry, pear and peach) for exporting should be reduced. Residents of Tehran consumed a large volume of wheat in their diet, twice larger compared with global average. Therefore, increasing food security by changing food consumption pattern at regional scale is recommended. Reduction in consumption of wheat or replacing it with other crops is suggested. Hence, it would be beneficial to account WF of various dietary changes in future WF evaluation. Wheat should be produced in areas of Iran with humid and semiarid climates because the production of wheat in a humid climate consumes the largest amount of green water and a lower amount of blue water resources. This research reveals that it is crucial to have suitable water management to decline water scarcity stem from agricultural division in the future. Additionally, reducing water footprint, increasing productivity, and appropriate agricultural water management are recommended. Apart from that, agricultural groundwater and surface water scarcity indices are more appropriate compared to the existing indicators because these indicators are able to reveal environmental impact of crop production and assist stakeholders in the assessment of groundwater and surface water management policies.

Keywords: Blue water footprint; water consumption; CROPWAT model; Agricultural water Management

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENILAIAN PENGGUNAAN AIR TANAMAN MENGGUNAKAN JEJAK AIR UNTUK PENGURUSAN AIR LESTARI DI TEHRAN, IRAN

Oleh

SOMAYEH REZAEI KALVANI

Oktober 2019

Pengerusi : Amir Hamzah Sharaai, PhD
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Peningkatan penggunaan air di seluruh dunia telah menjadi suatu kebimbangan. Baru-baru ini, Iran menghadapi krisis air yang tinggi disebabkan oleh pengurusan air yang tidak lestari. Objektif-objektif bagi kajian ini adalah untuk menilai jejak air permukaan dan bawah tanah untuk semua tanaman di Tehran dari tahun 2008 hingga 2015, untuk menganggarkan kekurangan permukaan dan air bawah tanah di sektor pertanian antara 2014 dan 2015, serta untuk menilai kebolehubahan jejak air per kapita dari tahun 2008 hingga 2015. Penilaian terhadap jejak air biru dan jejak air hijau dilakukan mengikut pendekatan jejak air. Evapotranspirasi telah dinilai menggunakan perisian CROPWAT. Buat pertama kalinya, kerja lapangan dan data Sistem Maklumat Geografi (GIS) digunakan untuk menentukan jejak air bawah tanah dan permukaan. Jumlah pengeluaran jejak air hijau dan jejak air biru telah meningkat daripada 986,857,963 m^3/tahun (2008) kepada 1,097,738,205.2 m^3/tahun (2015). Di samping itu, ini menunjukkan bahawa air bawah tanah berada di bawah tekanan yang serius (kekurangan air bawah tanah pertanian menyumbang kepada 0.95) bagi pengeluaran tanaman di samping tekanan air permukaan yang sederhana (tekanan permukaan air pertanian menyumbang kepada 0.4). Walaupun Tehran menghadapi masalah tekanan air bawah tanah yang serius, penambahan pengeluaran tanaman pertanian (contohnya pir, pic dan ceri) diperdagangkan ke kawasan lain, dengan skala pengeluaran yang luas. Walau bagaimanapun, jejak air luar merupakan penyumbang terbesar dalam jejak air bagi penggunaan tanaman, iaitu 90% daripada keseluruhan jejak air. Wilayah Tehran kehilangan 26.691 juta meter padu air biru kerana pengeksportan pir, pic dan ceri. Jejak air per kapita terbesar diperuntukkan kepada pengeluaran gandum dan beras, masing-masing dengan 189 dan 49 m^3/kap/tahun. Tehran boleh mengambil kesempatan dengan mengimport tanaman intensif air (gandum dan beras). Sebanyak 2.88 bilion m^3 sumber air di Tehran dapat diselamatkan dengan perdagangan tanaman antarabangsa dan antara wilayah (2008–2015). Pengeluaran tanaman bijirin (gandum, barli dan jagung) menggunakan 283.776 juta m^3 dan 152.460 juta m^3 sumber air bawah tanah dan permukaan air masing-masing menyumbang 52% jejak air biru

pertanian untuk tahun 2008 hingga 2015. Adalah disyorkan untuk mengurangkan pengeluaran tanaman bijirin di wilayah Tehran setelah mereka dikenal pasti sebagai tanaman dengan penggunaan air biru yang tinggi. Pengeluaran bijirin mengambil separuh daripada jumlah pengeluaran air dalam sektor pertanian. Selain itu, pengeluaran buah-buahan (ceri, pir dan pic) untuk tujuan pengeksportan perlu dikurangkan. Penduduk Tehran menggunakan jumlah gandum yang besar dalam diet mereka, dua kali lebih besar berbanding purata global. Oleh itu, peningkatan keselamatan makanan dengan mengubah pola penggunaan makanan pada skala serantau adalah disyorkan. Adalah dicadangkan agar mengurangkan penggunaan gandum atau menggantikannya dengan tanaman lain. Oleh itu, ia akan memberi manfaat kepada jejak air pada masa hadapan sekiranya corak perubahan pemakanan dapat dipelbagaikan. Penyelidikan ini mendedahkan bahawa ia adalah sangat penting untuk mempunyai pengurusan air yang sesuai untuk menurunkan masalah kekurangan air yang berpunca daripada sektor pertanian pada masa akan datang. Di samping itu, mengurangkan jejak air, meningkatkan produktiviti dan pengurusan air pertanian yang sesuai adalah disyorkan. Selain itu, indeks kekurangan bekalan air bawah tanah dan air permukaan lebih sesuai berbanding indikator sedia ada kerana penunjuk ini dapat mendedahkan impak alam sekitar terhadap pengeluaran tanaman dan membantu pihak berkepentingan dalam penilaian dasar pengurusan air bawah tanah dan air permukaan.

Kata Kunci: Jejak air biru; penggunaan air; Model CROPWAT; Jejak air biru; pengurusan air pertanian

ACKNOWLEDGEMENTS

I wish to thank my committee members who were more than generous with their expertise and precious time. A very special thanks goes to Dr. Amir Hamzah Sharaai, my committee chairman for his countless hours of reflecting, reading, encouraging, and his invaluable feedback. Furthermore, I would like to thank Prof Amir Hossein Hamidian, for his feedback. I am very grateful for his valuable guidance, and support with his wide knowledge. I wish to thanks associate professor Dr Latifah Abd Manaf for her feedback. I am deeply indebted to Prof Arjen Hoekstra, for his invaluable guidance and supporting. Prof Arjen has helped me solve every tiny issue in my study, with his valuable experiences. I would like to express my special thanks of gratitude to Dr Ashok Chapagain for introducing me the concept of water footprint in E-learning water footprint course.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AWS	Agricultural Water Stress
WSI	Water Stress Index
GIS	Geographic Information System
CWR	Crop Water Requirement
CWU	Crop Water Use
ET	Evapotranspiration
MAJ	Ministry of Agriculture Jihad
VW	Virtual Water
WSS	Water self-sufficiency
WA	Water Availability
ISO	International Organization of Standardization
EWR	Environmental Water Requirement
IMO	Iran Meteorological Organization
WUE	Water Use Efficiency
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
WF	Water Footprint
MCM	Million Cubic Meters

CHAPTER 1

INTRODUCTION

1.1 Research Background

Freshwater is the most crucial finite resource (Nazari et al., 2018) that plays an important role to achieve food security and sustainable development in economic sector (Jianguo et al., 2015). Irrigation for agriculture consumes more than 70% of global ground and surface water (FAO, 2013). It is reported that the irrigated groundwater makes up 43% from the overall water usage worldwide (Siebert et al., 2010). The high water consumption by agricultural sector limits water availability for other sectors (Oki & Kanae, 2006). Nearly all approaches for water governance are engaged to the surface water and when it comes to groundwater governance, there is inattentiveness that leads to further deterioration of available water resources (Gleeson et al., 2012). Unsustainable method for the abstraction of groundwater is obvious in many countries (Umar, 2004). Globally, the agricultural subdivision is accountable for greater than 70% of freshwater abstraction, as well as 90% of the consumptive water use (Döll & Zhang, 2009). Therefore, it is important to identify the category of the source of water for irrigation, so as to apprehend the consequences of anthropogenic on the water resources (Burke, 2002). In order to recognize water stress, it is essential to estimate the green and blue water's consumptive use in the agricultural sector (Rockstrom & Falkenmark, 2006; Hoekstra et al., 2011).

Allen (1996) introduced the concept of virtual water for the first time which defines the volume of water that embodied in the products through the production process. The virtual water trade was a convenient alternative to decline the local water stress in water scarcity regions by importing products from water abundant areas (Suweis et al., 2011). Approximately 90% of water is allocated for food sector and the remaining 10% is consumed for domestic sector. Hoekstra (2002) created water footprint (WF) which is different from traditional water consumption accounting. The traditional water consumption accounts for blue water consumption while WF addresses multi-dimensional indicator (with regards to time and location) of water consumption. It evaluates direct and indirect water consumption by dividing water consumption to different colors including blue, green and grey WF. Blue water footpint (WF) is the volume of ground and surface water that is evaporated and incorporated into products. However, green water footprint (WF) is defined as the volume of rainwater that is consumed. Besides, it defines the volume of water that is accumulated in the soil as soil moisture. The grey water footprint (WF) is the indicator for evaluation of water pollution (Hoekstra et al., 2011). WF can be evaluated at various scales from small catchment to global scale. WF in a geographic division area can be computed by summing up the internal (the volume of water from domestic water resources that are used to produce products for local consumption) and external WF (the volume of water that is used from outside the border to produce goods imported from outside the region) (Mekonnen & Hoekstra, 2011a).

Over the past decades, vast numbers of water scarcity indicators have been modified and used to indicate and assess the level of water use by human activity compared to freshwater resource availability (Savenije, 2000; Damkjaer & Taylor, 2017; Hoekstra et al., 2012; Mekonnen, 2014). The most popular water scarcity indicator is based on annual run off to the population (Falkenmark, 1989) and the annual water withdrawal to water availability (Raskin, et al., 1997; Rijsberman, 2004; Alcamo, Flörke, & Märker, 2007; Oki & Kanae, 2006). This is important to sustain the environment by considering Environmental Water Requirement (EWR) in water scarcity indicator by subtracting EFR from water availability (Smakhtin, Lanka, Revenga, & Döll, 2004). Most water scarcity indicators are based on total water stress (Smakhtin, Revenga and Döll, 2004; Ma et al., 2015; Zeng, Liu, & Savenije, 2013). However, other evaluation are according to the blue WF to blue water availability (Pfister & Bayer, 2014; Hoekstra et al., 2012; Zhuo et al., 2019; Jing Liu et al., 2017; Veettil & Mishra, 2016; Zhuo et al., 2016). Hoekstra evaluated blue water scarcity by dividing blue WF to blue water availability after taking away environmental water requirement (Hoekstra, 2016). Nearly all techniques are neglecting the importance of assessing surface and groundwater scarcity indicators. Besides, the weakness of these indicators is the estimation of surface and groundwater, to which it is deemed as one category (Hoekstra, 2016). To cover the weakness, this study assesses ground and surface WF independently when estimating ground and surface water stresses in the agricultural region.

Understanding groundwater can avoid overutilization in the control of water resources. Furthermore, it provides the utmost importance in prioritizing the use of surface and groundwater in the agricultural region (Tillotson 2014). Identifying the category of the water resources helps to establish illegal groundwater extraction. Besides, the surface and groundwater scarcity index in agricultural sector is more relevant compared to the current indicators due to its ability to disclose the environmental consequences of crops production towards the ground and surface water resources, especially in the arid regions that consume a large amount of blue water. Additionally, it assists stakeholders in considering guideline management that concerns surface and groundwater issues in the agricultural sectors.

1.2 Research Questions

The research is designed to pursue the following research questions:

1. Is agricultural groundwater footprint larger than surface water footprint?
2. Is agricultural groundwater footprint more unsustainable compared to surface water footprint?
3. How is the trend of water footprint of crops production and consumption in Tehran province from 2008 until 2015?

1.3 Specific Objectives of the Study

This study is designed to achieve the following specific objectives:

1. To compare the ground and surface water footprint trends of different crop products from 2008 to 2015.
2. To determine ground and surface water stress.
3. To analyze per capita WF of different crops (2008-2015).
4. To reallocate wheat production in different climate zones of Iran

1.4 Problem Statement

Water is life. This statement refers to the worth of water for individuals and life on all planets. Water consumption during the last century has dramatically increased as population growth increased (Organización de las Naciones Unidas, 2005). Freshwater resource is reducing considerably all over the world (Forouzani & Karami, 2011). Approximately 97% of water on our planet is not freshwater, but is actually made up of salt water. Only 2.5% of water in the world is freshwater. Nearly 80% of this freshwater is captured as ice. The remaining 20 percent are available as ground and surface water (FAO & Wosm, 2013). Moreover, water crisis is an important issue as twenty percent of the world's population lives in water shortage areas (Hoekstra, 2016). Moreover, a fifth of the world population suffer from water scarcity. Besides, Water crisis is a crucial issue because approximately 1.2 billion people face severe water scarcity (Rijsberman, 2004), which are heightened as a result of industrial, agriculture, and domestic water use (Wada et al 2013). The sharp decrease in per capita water consumption is due to population growth (Zahavian, Khosravi, & Ghodsi, 2010). Besides, the distribution of water all over the world is not equal. Population growth and economic development are major causes of water scarcity in some regions around the globe (Rijsberman, 2004). The agricultural sector is responsible for 85% of global freshwater consumption (Organización de las Naciones Unidas, 2005).

Iran is facing severe water scarcity. Water use in Iran was approximately 4.5 billion m^3 in 1963. Consumption was increased dramatically to more than 93 billion m^3 in 2006 (Zahavian, Khosravi, & Ghodsi, 2010). Besides that, most of the rivers and lakes are now dried up (Keshavarz & Karami, 2016). Lake Urmia, which is located in the west of Iran, has shrunk due to overexploitation upstream (Fathian et al. 2014). The drying up of Lake Urmia has contributed to biodiversity degradation (Abbaspour, 2012) salt storms (Eimanifar & Mohebbi, 2007), and a negative impact on the economy in the west part of Iran. Moreover, in the center of Iran, the Zayandeh-Rud River has also dried up. The drying up of Zayandehrud poses challenges in the agricultural, industrial, and domestic sectors in the center of the country (Madani Larijani 2005). Moreover, per capita water usage has also declined sharply (Zahavian, Khosravi, & Ghodsi, 2010). The water crisis in Iran is not only limited to the reduction in surface water but also includes groundwater depletion (Madani, 2014). Reduction in groundwater level in Iran is attributed to human activity, especially agricultural activity (Khaki et al., 2018). The average groundwater depletion in Iran from 2002–2012 was approximately -9 mm/year (Khaki et al., 2018).

Over the last 40 years, groundwater depletion has occurred in Tehran due to an increase in water consumption and the effect of dams (Masoud & Khamehchiyan, 2016). Most of the Qanats in Tehran are now dried up, decreasing in number from 522 branches in 1970 to 167 in 2012 (Masoud & Khamehchiyan, 2016). Besides, land subsidence has also occurred in some parts of Tehran resulting from the over exploitation of groundwater resources (Haghighi & Motagh, 2019). The mean groundwater level in Tehran has reduced by 12 m from 1984 to 2011. Besides, the number of exploited wells has also increased from 3900 in 1968 to 32518 in 2012 (Masoud & Khamehchiyan, 2016).

It is forecasted that the mean annual supply of renewable water per person will decrease from 1,750 m^3 (in year 2005) to 1,300 m^3 (in year 2020). A country will be identified as a water scarcity area when water availability for one person is lower than 1,700 m^3 (Rockstrom & Falkenmark, 2006). Iran with a population of more than 70 million people (2005) is among the countries facing the most severe water shortage in the world (Madani, 2014). Besides that, the level of groundwater in Tehran decreased as a result of reduction in rainfall and inappropriate water management (Khaki et al., 2018). The reasons for water scarcity in Iran are: 1) unsustainable water management; 2) population growth; and 3) unsustainable agricultural water use (Madani, 2014). It is claimed that the major causes of water shortages in Iran is inappropriate water management (Foltz, 2002). It is forecasted that Iran will experience a reduction in average annual rainfall by nearly 25% by 2050 (Ragab & Prudhomme, 2002). This could lead to an increase in the frequency and duration of drought events in Iran (Monireh Faramarzi, 2010).

There have been lack of studies on WF of Iran crops consumption (Hoekstra & Mekonnen, 2011; Hoekstra & Chapagain, 2007; Karandish & Hoekstra, 2017), on WF of cereal crops throughout different provinces in Iran (Ababaei & Etedali, 2016); on WF of the cement industry in western Iran (Hosseinian & Nezamoleslami, 2018; Ababaei & Ramezani, 2017) on the virtual in Iran (Yousefi, et al., 2017), and (Faramarzi et al., 2010). Besides, there is lack of attention to province WF and water saving assessment. Okadera et al. (2015) applied the “top-down” approach to evaluate WF of energy supplies in a province of China (Okadera et al., 2015). Besides, Zhao et al. (2018) and Chen (2017) assessed WF in all the provinces of China.

However, the weakness of WF method is it does not evaluate blue water separately as ground and surface WF. Besides that, ground and surface WF are evaluated as one category, which is as blue WF. In this work, the various types of waters are assessed individually by using GIS data and fieldwork for the first time.

Recently, most research carried out in the field of water scarcity evaluation has only focused on blue water scarcity but not many have separately evaluated ground and surface water resources. In most methods, ground and surface water are both evaluated as blue water and there has been no evaluation that separates them. In this work, the agricultural ground and surface water were accounted individually, followed by an assessment made on the agricultural ground and surface water scarcity indicators.

1.5 Significance of the Study

The agricultural sector in Iran is responsible for more than 90 percent of water consumption (Madani, 2014). Because of unavailability of surface water, most of the water for agricultural consumption is groundwater (Madani, 2014). The water crisis in Iran is attributed to: 1) the high population density; 2) inefficient agriculture water use in the agriculture sector; 3) unsustainable water management; and 4) industrial development (Madani, 2014). It is claimed that approximately 90% of limited water resources in Iran is allocated to the inefficient agricultural sector (Madani, 2014). Therefore, it is essential to account for the water consumption in Tehran to reduce its negative effect on water resources. This study can help decision makers to prioritize water consumption in order to achieve optimal water consumption in the agricultural sector (Tillotson, Liu, Guan, & Pahlow, 2014). Hence, measuring water consumption and evaluating its impacts are crucial steps to reducing the negative impacts of water scarcity.

Water scarcity has particular impacts on the environment (Pfister, Koehler, & Hellweg, 2009). The first warming signal is drought, which can lead to biodiversity degradation (Hoekstra et al., 2012). Water scarcity has a potential to affect three areas; human health, ecosystem quality, and resources. In regard to human health, water deficiency can lead to malnutrition as a result of lack of water for irrigation in agriculture sector. Moreover, in terms of ecosystem quality, water scarcity can lead to an increase in the rates of biodiversity degradation. Besides, water shortages are the major reason for overusing groundwater sources, which can lead to the increase in the amount of salt in groundwater sources (Pfister et al., 2009). It is claimed that water shortages will increase considerably all over the world, bringing with it problems associated with water scarcity, which will also increase. This includes environmental degradation and insufficient food (Alcamo et al., 2007). In addition, water shortages can lead to drought, biodiversity degradation, malnutrition, and desertification (Pfister, Verones, & Mutel, 2014). Globally, the agricultural activity is a segment known for its maximum use of water resource (Motagh et al., 2008). It is accountable for over 92% of freshwater usage in Iran (Zehtabian, Khosravi, & Ghodsi, 2010). The utilization of freshwater resources in acitivities related to the agricultural sector leads to the depletion of water resources for other consumers (Forouzani & Karami, 2011).

Assessment of water consumption is an essential ingredient in any plan aimed at mitigating water shortages (Steduto et al., 2012). A variety of methods to evaluate water use in the supply chain have been developed. Allen (1998) introduced virtual water, which accounts for water consumption in other countries. Hoekstra et al. (2002) introduced a tool to measure water consumption in the supply chain of products in regard to time and location, which is known as the water footprint concept (Hoekstra

& Hung, 2002). WF can provide good opportunities for companies and governments to assess water consumption through the use of a stable method to recognize hotspots. Water footprint is identified as an instrument for management to estimate the sustainability of water resources (Hoekstra, 2011). The water footprint network is a powerful tool that accounts for the water consumption of mankind. It also enhances sustainable water management (Hoekstra et al., 2011). Additionally, the water footprint method reveals useful information for the agricultural sector and for the government in prioritizing crop production at high temporal and spatial resolution (Zotou & Tsihrintzis, 2017). WF is identified as a robust tool for assisting decision makers in achieving optimal water management (Aldaya, Martínez-Santos, & Llamas, 2010). Besides that, labelling food with these footprints can mitigate adverse environmental impacts on customers by informing them about the environmental impacts of water use on the supply chain of commodities (Leach et al., 2016). The water footprint method produces a comprehensive evaluation, which contains information on different dimensions of water use. First, it contains geographical information. For example, consuming 1 m^3 of water for producing goods in water abundant areas is significantly different from consuming the same volume of water in water-stressed areas. The second aspect is time: water consumption in dry and wet seasons results in different impacts on the water resources. Third, water footprint assesses both direct and indirect water use through the supply chain of products (Hoekstra et al., 2011). The fourth aspect is color: in the water footprint method, water consumption is dived into blue, green, and grey water footprints. The blue water footprint is defined as the volume of surface and groundwater that is used to produce products. The green water footprint is the volume of rainwater that is consumed to produce goods. The grey water footprint is an index for evaluation of water quality (Hoekstra et al., 2011).

Some studies regarding water footprint have shown that WF is the best method to advocate for water management at a local scale (Manzardo et al., 2016). Sabli et al. (2016) evaluated WF in the production of palm oil in Malaysia and Indonesia. The water footprint method was used to provide guidelines for the government to achieve sustainability in oil palm productions in both countries. Moreover, the impact of water consumption can also be evaluated through this method. Biodiversity degradation, land transformation, and river basin pollution are some environmental impacts of water consumption as a result of the production of palm oil accounted for water footprints for the production of rice in different regions in the world. They found that China, USA, and Thailand are responsible for approximately 90 percent of water consumption for rice production in the world. Water footprint in the agriculture section should be evaluated to manage sustainable water resources. These water footprint results can be used to formulate long-term policies for water management (Yoo, Choi, Lee, & Kim, 2014). Lu et al. (2016) assessed the WF and WUE (water use efficiency) of the production of winter wheat and maize spanning more than 35 years in China. They observed high seasonal variability in WUE and WF from the production of winter wheat and maize, which varied in yield with varying crop input. Blue WF was the largest water footprint in comparison to green and grey WF, which means that grain production is more dependent on irrigation. WF can be used to evaluate the volume of water used as well as water consumption. WF can also assist in assessing the environmental impacts of water use through the production process of good and services. Besides that, WF is a more complete and useful indicator than WUE, as it evaluates effective water use and its environmental impacts (Lu, Zhang, Chen, Shao, & Sun, 2016). In arid regions, more irrigation is needed to produce wheat (Cao, Wu, Wang, & Zhao, 2014).

It is claimed that groundwater is the most essential asset in the majority of countries because of its unlikelihood in creating contaminations, as well as its systematic distribution, advantageous feature and it is free from evaporation (Zektser and Everett, 2004). Most water resource research has focused on surface water management but not many have investigated the depletion of groundwater resources. The evaluation of ground and surface WF separately is important because it helps to know the status of groundwater and surface water. Moreover, groundwater footprint is an appropriate indicator for the assessment of sustainable water management (Nektarios, 2018). Besides that, ground WF can discover unsustainable groundwater consumption (Tom Gleeson et al., 2012). The assessment of groundwater footprint is important because groundwater footprint is identified as a powerful instrument for water management by providing helpful information for monitoring groundwater resources.. It is also an indicator of the sustainability of groundwater consumption (Gleeson, Wada, Bierkens, & van Beek, 2012). Besides, groundwater is identified as a strong tool to influence decision makers so water policies can be evaluated by using the groundwater footprint (Pérez et al., 2019). The groundwater footprint is identified as a strong tool for policy to balance water demand (Kourgialas, Karatzas, Dokou, & Kokorogiannis, 2018). The WF results can contribute towards enhancing water resource management and environmental conservation (Ababaei & Etedali, 2014).

Groundwater consumption is not sustainable in many regions around the world (Döll & Zhang, 2009; Umar, 2004). Globally, the agricultural subdivision is accountable for greater than 70% of freshwater abstraction, as well as 90% of the consumptive water use (Döll & Zhang, 2009). Therefore, an understanding of the type of water resources for irrigation is important since it can contribute to the evaluation of the human consequences on water reserves (Burke, 2002). Currently, due to a dramatic depletion in groundwater resources, understanding of the type of water has become a crucial issue (Siebert et al., 2010). Furthermore, rising requirement of groundwater and unsustainable groundwater consumption contribute to increased concern over groundwater scarcity and groundwater depletion (Tom Gleeson et al., 2012).

1.5.1 Scope of the Study

In this study, the blue and green WF for production of crop is evaluated from year 2008 to 2015 to analyze the variability of WF trend in the Tehran province of Iran. The current assessment has been conducted at a provisional scale since evaluation of WF at local scales can produce more accurate results compared with global scales (Ababaei & Etedali, 2016). The year 2008–2015 was chosen for evaluation of WF because of data availability for these years. Besides, during these years the number of exploited wells has increased and water scarcity become identified as an important issue (Masoud & Khamehchiyan, 2016). The agricultural ground and surface WF are counted by using GIS data and fieldwork for the first time. Besides, the agricultural ground and surface water scarcity are assessed. Moreover, per capita WF of crops consumption is counted and groundwater saving and loss are evaluated in Tehran provoince (Tom Gleeson et al., 2012).

1.5.1.1 Limitation of The Study

The industrial sector is complex and the volume of water consumption in this sector is not considerable. Besides, industrial sector just consumed 1% of water resources in Tehran province (Ministry of Energy, Tehran, 2016). Moreover, due to the data unavailability in the industrial sector, it was omitted. Additionally, data for the production capacity of surface and groundwater are not recorded. In this study, evaluation is made using GIS data and fieldwork which are time consuming and laborious. Therefore, the volume of production is evaluated for one year and for other years. It is assumed that the ratio of ground and surface water is stable for each crop since the water resources for crop production are not changed.

1.5.1.1.1 Conceptual and Operational Definition of Terms

In present study some of terms are defined as follow:

Agricultural groundwater footprint: the volume of groundwater that is used for production of crops. Besides, it is defined as the volume of groundwater that is used for irrigation of crops. Moreover, it is defined as consumptive use of groundwater.

Agricultural surface water footprint: The volume of surface water that is consumed for production of crops. The volume of surface water that is incorporated into the products is not available in the catchment area. Moreover, it refers to the volume of surface water that is used for irrigation of crops in agricultural sector.

Agricultural groundwater scarcity indicator: It refers to the ratio of groundwater footprint to the groundwater availability.

Agricultural surface water scarcity indicator: It is defined as the ratio of surface water footprint to surface water footprint.

Blue water footprint: consumptive use of ground and surface water that it does not return back as return flow in catchment (Hoekstra et al., 2011).

Green water footprint: It refers to consumptive use of rainfall or the volume of water in soil as soil moisture (Hoekstra et al., 2011)**.**

Water footprint of crop production: The blue and green water footprint for production of crops.

Water footprint of crop consumption: The per capita blue and green water consumption as a result of crop consumption.

Groundwater saving: the volume of groundwater that is saved subsequent to the development of international and interregional crop progression.

Surface water saving: The volume of surface water that is saved as a result of international and inter regional crop trend.

Groundwater lost: The volume of groundwater that is consumed from the domestic water resources for exporting crops.

Surface water lost: The volume of surface water that is consumed from the domestic water resources for exporting crops.

Internal water footprint: The amount of water that is consumed from domestic water resources to produce crops for internal consumption.

External water footprint: The amount of water from foreign water resources that is imported to the region for domestic consumption.

Water consumption: It refers to the volume of water that is not available after use because it is evaporated or incorporated into crops. Besides, it does not return to the same catchment and at the same time (Hoekstra et al., 2011).

1.6 Structure of Thesis

The research is made up of five chapters:

Chapter 1 Introduction: Includes objectives of this project, project hypothesis and significance of study.

Chapter 2 Literature Review: It is the foundation of the research. It contains review of water footprint at different scales from residential to global scale in different sectors including agricultural, industrial, and domestic. Besides, it also covered different LCA method integrated with WF and WSI. Review of different WSI has been described. Moreover, conceptual framework is designed.

Chapter 3 Methodology: Described the methodology that has been used to evaluate ground and surface water footprint.

Chapter 4 Results and Discussion: Most of tables and figures are described in this chapter. It also includes the discussion of results.

Chapter 5 Summary, Implications, Recommendation and Conclusion: A summary of results, and conclusion. The recommendations for future research are described.

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