Daria Nepomilueva

Water scarcity indexes

Water availability to satisfy human needs

Helsinki Metropolia University of Applied Sciences

Bachelor’s Degree

DP in Environmental Engineering

Thesis

23.04.2017

Author(s) Title Number of Pages Date	Daria Nepomilueva Water scarcity indexes: water availability to satisfy human needs 24 pages 23 April 2017
Degree	Bachelor's Degree
Degree Programme	DP in Environmental Engineering
Specialisation option	Water, waste and Environmental Engineering
Instructor(s)	Kaj Lindedahl, Principal Lecturer Dr. Minna Paananen Porkka, Academic English Lecturer

Water scarcity becomes an issue in different parts of the world, and it is predicted to continuously expand over greater territories and to affect a greater share of the world population and environment. Furthermore, water plays a vital role in agriculture and food security in every part of the world. In that context, many researchers and scientists have developed indexes aiming to measure the level of water scarcity. The indexes vary greatly depending on the level of complexity, the amount of data required and the measurement objectives. Each index has advantages and limitations; therefore, it is important to comprehend the applicability of indexes in real life.

This thesis presents the most widely used indexes measuring water scarcity with respect to the water required to satisfy human needs and places additional focus on the index measuring the water required for agricultural use. The thesis also discusses the usability of water scarcity indexes in the decision-making process and is based on a scientific literature review.

Findings suggest that none of the indexes can provide an exclusive solution for water scarcity measurement and be used as a tool in decision-making process. Therefore, in order to get more reliable and usable results combination of indexes have to be used.

Keywords	water scarcity, water poverty, index, decision-making

Contents

List of Abbreviations

AWM	Agricultural Water Management
AWPI	Agricultural Water Poverty Index
FAO	Food and Agriculture Organization of the United Nations
HDI	Human Development Index
IWMI	International Water Management Institute
SDG	Sustainable Development Goals
UN	United Nations
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization
WPI	Water Poverty Index

List of Tables and Figures

1 Introduction

It is generally accepted that water is most crucial and valuable resource for human life from all the perspectives from survival purposes to an increase in wealth. A considerable number of researches recognise the global trend of increasing water demand and decreasing water availability; therefore, the vast amount of regions are subject to water scarcity issues.

In recent years, researchers have developed various water scarcity quantifying tools aiming to measure water scarcity within the region or country and to support decision-making and policy elaboration to address water scarcity. These tools are named indexes, and there are dozens of such indexes which vary depending on index comprehensiveness ranging from simple and straightforward to complex and multidimensional, or on measurement objectives from water necessary to satisfy human needs to water required to preserve biodiversity or the environment.

The large number of indexes makes it almost impossible to cover the whole range; therefore, the scope of this thesis is limited to the indexes measuring water availability to satisfy human needs and concentrates just on the water used for human activities excluding the water requirement of environment or biodiversity. Additionally, the thesis excludes indexes evaluating the state of water resources influenced by natural phenomena. It focuses on the most common indexes and addresses their evolution from a more simple to a more holistic and complex approach; it even describes the comprehensive index customized to measure water availability for agricultural purposes. The thesis presents the advantages and limitations of each index in question and discusses the applicability of indexes in decision-making and policy development processes.

2 Water scarcity

This chapter will give an overview of water as a vital resource for human survival and well-being as well as any human activity; it will provide general data on water availability on the globe. Various types of water use will be listed and defined and the importance of water resource for every aspect of human life will be emphasized. Additionally, an attempt will be made to differentiate such widely used terms as *water stress* and *water scarcity,* and the list of various water scarcity factors with possible reasons for such scarcity will be provided.

2.1 Water as valuable finite resource

According to water encyclopedia [1], water is the essential resource for any life on the planet. Water availability dictates where people can live and determines the quality of their life; additionally, water sufficiency has a strong correlation with the rate and degree of society development within a certain region.

It is common knowledge that people utilize water for a variety of activities. The U.S. Geological Survey [1] defined several main purposes of water use in order to analyze the current and to forecast the future water demand. The U.S. Geological Survey list includes the water used for commercial, domestic, industrial, irrigation, livestock, mining, public supply and thermoelectric power purposes.

Molle and Mollinga [2, 530] have combined some of the water demands and listed the following categories of water use:

(U_1) Drinking water. This category refers to the water that is recognized as the human right. As stated by the United Nations Committee on Economic, Social and Cultural Rights, “the human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic use.” [3, 19].

Therefore, this category can be accounted as the most essential. According to the World Health Organization (WHO) [4, 2], the human needs 2.5 – 3 litres per day for survival depending on, for example, the climate and the individual physical health.

(U_2) Domestic water. This category indicates the water that is used by household on daily bases mainly for hygiene, cooking, washing dishes, laundry and watering the garden [1]. According to WHO [5], in order to ensure human primary needs, about 50 to 100 litres of water per person is required.

(U_3) Food security needs. This category, according to Molle and Mollinga [2, 530], features the water that is used for agricultural or livestock purposes usually by farmers or individuals who grow food for their own consumption as a life necessity and for survival.

(U_4) Economic production. This category includes the water used for the production of goods (industrial and mining use etc.). The human is relying just economically on such production, and water shortage or surplus does not directly influence their domestic or drinking water requirements [2, 530].

(U_5) Environmental needs. This category determines the water used by the ecosystem which the human is a part of. If the water quality and the amount or elongation of water cycle are not sufficient for sustentation of the ecosystem, it can lead to various negative outcomes like health effects from water pollution or biodiversity loss [2, 530]. Eutrophication is considered to be the most common water quality issue which originates from the increase of phosphorus and nitrogen concentration in water due to industrial effluents, runoffs from farms, or sewage systems. Polluted waters cannot be used for drinking, hygienic, agricultural or industrial needs. Therefore, a direct correlation between water quality and the quantity of water suitable for use can be observed [6].

According to the World Business Council for Sustainable Development (WBCSD) [7], more than 660 million people in the world lack the access to clean drinking water. The agriculture consumes the biggest amounts of fresh water with more than 70 % of world's water used for irrigation. Around 80 % of the used water that is returning back to nature is estimated to be untreated, which, in turn, reduces the quality and thus the quantity of potentially usable water.

2.2 Water stress and water scarcity

At the beginning of the 20th century, the world population was 1.6 billion people, and by the beginning of 21st century, it was already 6.1 billion people [8]. The world population continues to increase and is predicted to exceed 9 billion by 2050. As many as 7.9 billion people live in less developed countries, whereas the population in more developed countries will remain on the same level of 1.2 billion [9].

While the population increasing, the world's water amount is still the same as it was centuries ago, which consequently leads to the increase of water demand and lack of water to satisfy the constantly growing demand. At the moment, according to the estimates of the International Water Management Institute (IWMI), around 1.2 billion people have limited or no access to safe water, and the demand is expected to increase by 40% by 2030 [10]. *Safe water* is the drinking water that does not contain harmful substances and pollutants such as bacteria or viruses, chemicals and toxic metals [11], however, it could still have issues related to odor, color or taste [12].

The following figures, Figure 1 (on left) shows the increase of population in connection to the increase of water withdrawals during the last century, and Figure 2 (on right) displays the decreasing trend of water availability during the last century.

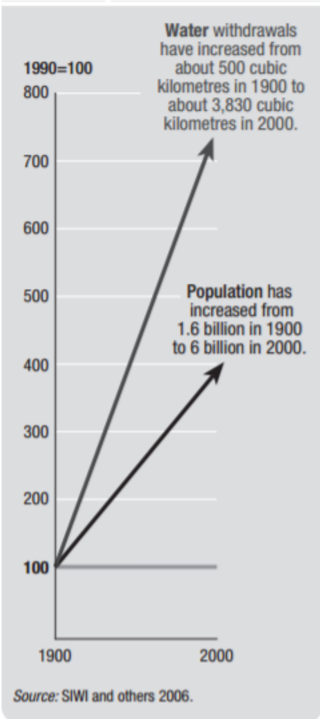

Figure 1. Water withdrawals/ population growth [3, 26].

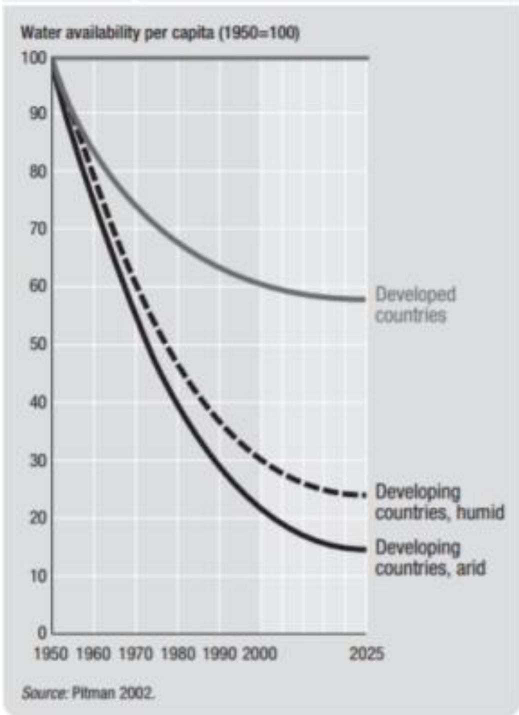

Figure 2. Water availability [3, 25].

As can be seen from Figure 1, the population growth will lead to the increase in water use and withdrawals for personal (drinking and hygiene), industrial (production of goods) and agricultural (irrigation and livestock) use. Consequently the water availability will decline, as shown in Figure 2.

Such a relationship between water use and water availability is called the water stress index. Water Stress Index is a tool used by the United Nations (UN) and other organizations to define whether the water stress is likely to appear in some region. Regions where water use exceeds the water supply levels most probably are going to experience the water stress [13].

Various literature sources use *water stress* and *water scarcity* as interchangeable or complementary terms; therefore, definitions vary. For example, according to Pacific Institute [14], *water stress* is more comprehensive and extensive definition which *water scarcity* is considered to be part of, along with qualitative and quantitative water availability. Figure 3 on this page illustrates the share of *water scarcity* in the broader *water stress* concept presented by Pacific institute. *Water stress* is considered to be a capability of meeting the human demand for water, whereas *water scarcity* refers to the proportion of water used to water available for use within the region and in time, *water scarcity* is measured in physical quantities (volumes). If some region has a heavy stock of highly polluted water, it means that region does not experience water scarcity but it suffers the extreme water stress because great volumes of water are not utilizable.

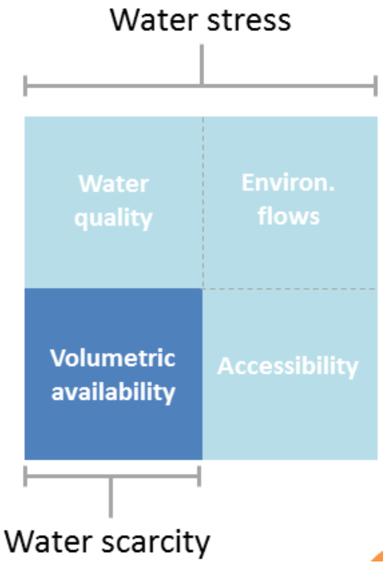

Figure 3. Water scarcity as a part of Water Stress Concept [14].

Contrary to previous statement, according to Science Daily [15], *water scarcity is* defined as a more extensive concept which includes water stress, water shortage and water crisis.

In other sources, the term *water stress* simply refers to the lack of water to meet the demand for certain period of time, whereas the term *water scarcity* refers to incessant and long-term water deficit or stress [16].

According to FAO [17, ix], *water scarcity* is a more relative and dynamic term which refers to the lack of stability between availability and consumption; it can strengthen with the increase of water demand and weaken if specific actions are taken to meet the increased demand.

In this paper, a distinction will not be made between these terms; therefore, whether the term *water stress* or the term *water scarcity* is used, it will mean the lack of sufficient water resources to satisfy the demand in a certain country, region or town.

Since the term *water scarcity* has been defined, it is important to determine the reasons of its occurrence. Most of the literature sources distinguish two main reasons for water scarcity:

(S_1) Physical scarcity which originates naturally in desert or arid regions where water availability is restricted by nature; or in some cases, poor water management and distribution upstream can cause physical scarcity downstream [10].

(S_2) Economic scarcity refers to a scarcity when water cannot be utilized due to the lack of resources, proper management, or simple inability to pay for the access to a water source [10].

In addition to the previous two water scarcity factors, Molle and Mollinga [2, 531] distinguish three additional factors:

(S_3) Managerial scarcity refers to poor management and maintenance of water resources, such as damages along the distribution network or water pollution due to the introduction of external substances, and as a consequence of the water system malfunctioning, the demands cannot be met.

(S_4) Institutional scarcity refers to the scarcity which is very similar to the economic and managerial scarcities with the main difference in the inability to predict and cope with change in demand and supply and to provide appropriate technologies.

(S_5) Political scarcity refers to situations when people are restricted from the access to water source under a political prohibition.

Combining the water use type (described in first chapter and denoted with U_1 - U_5) with water scarcity factor (described above and denoted with S_1 – S_5) the variety of possible cases and situations are created. For example, U_3S_2 represents the situation when there are sufficient quantities of water for agriculture but farmer cannot afford it. U_4S_3 can be the case when manufacturers cannot utilize the water for the production due to poor management upstream. U_1S_4 is the case of inability to use water for drinking purposes because of quality deterioration. $U_{3/4}S_5$ cases are common in Southern Africa when water scarcity arise due to political restrictions. [2, 531]

However, the abovementioned scenarios are not covering all possible situations. Scarcity could vary in time by being temporary or continuous, which is the most threatening to drinking and domestic water uses and could be considered as failure to comply with human rights. In some cases scarcity may decelerate and restrict the potential growth or economic development, for example, due to the physical shortage of water for manufacturers or farmers. [2, 531]

Concluding everything stated above, authors say that water scarcity issues are not that straightforward and cannot be addressed by simple increase of investments or adaptation of technologies. The water-human relation is more complex, it depends on population distribution over a specific area, impact from human activities on the environment and conversely influence of the environment on human life. Additionally, it depends on the ability of different sectors of society to utilize financial resources, incorporate knowledge and technologies, or use its authority to control the access to water resources. [2, 532]

There are a lot of studies conducted on current and forecast water stress/scarcity in different parts of the world. For example, the World Resources Institute predicts that 36 countries around the world will suffer from the extreme water stress [18].

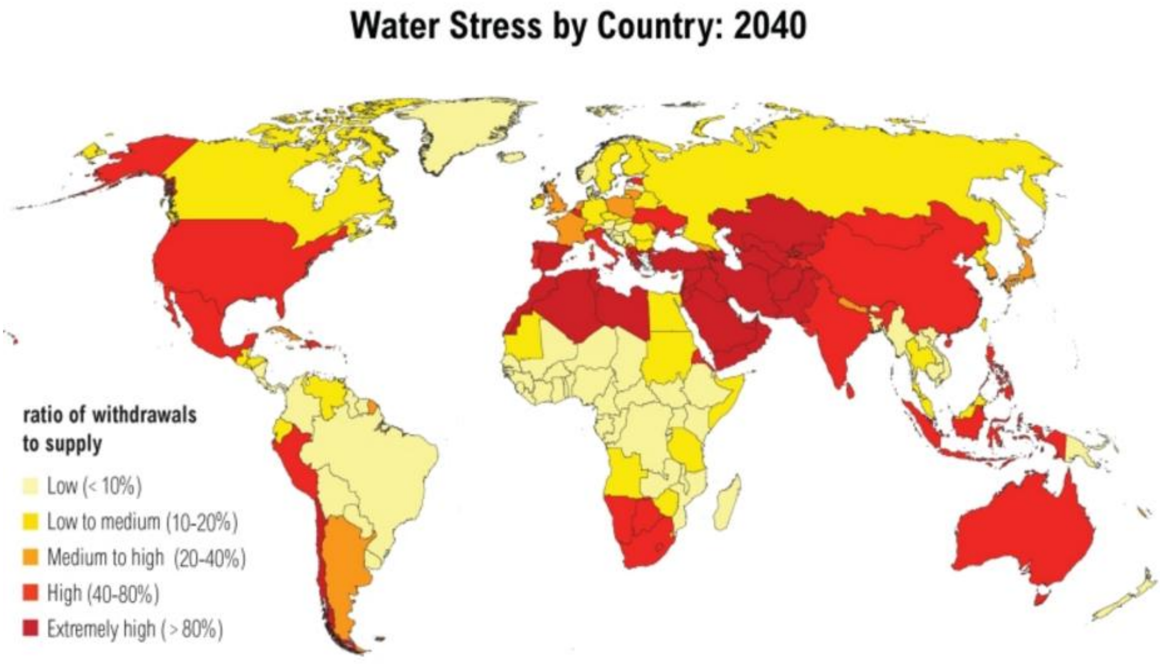

Figure 4. Water stress forecasts for 2040 [19, 5].

On the basis of Figure 4 above, it is possible to conclude that more than half of world population will be living under medium to extremely high water stress; most countries suffering from extreme water stress are located in North Africa, Middle East and Asia.

In order to address and mitigate the water scarcity issues it is important to determine the reasons and the level of the scarcity in a particular country or region. The following chapter will describe several generations of indexes and indicators attempting to evaluate and measure the water scarcity.

3 Water scarcity measurement tools

This chapter will describe different indexes developed through years used to provide computable value of water stress or scarcity level in country, region or town. Indexes description will include the main characteristics and limitations, as well as advantages and disadvantages of each concept. The thesis will explain in more detail the Water Poverty Index concept of the holistic water scarcity measurement tool.

Due to the great amount of existing water measuring indexes, the limits of the thesis shall be set. This thesis solely concentrates on indexes that are used to measure or evaluate water availability to satisfy human needs (domestic and agricultural) excluding such aspects as water required by the environment or biodiversity.

3.1 Indicators and indexes

First of all, terms *indicator* and *index* need to be defined. According to the Oxford Dictionary [20], *indicator* is a tool, instrument or device that gives the information on the status of something or on what is the situation. Additionally, Free Dictionary [21] states that *indicator* is the set of statistical data that accumulatively represents the state of something.

According to the Oxford Dictionary [20], *index* is the standardized value providing the magnitude of a physical parameter or observed event. Additionally, Cambridge Dictionary [22] states that *index* is the set of values that is utilized for the comparison of the variations of thing to each other or to the standard; it is a value that represents how frequent is the occurrence of certain event.

In this thesis both terms *indicator* and *index* will be used interchangeably and defined as the summarized value of the set of statistical data or tool which is used for the comparison of condition, state or occurrence of observed phenomena.

In compliance with definitions stated above, indicators/ indexes are the instruments that are used to summarize data sets into simpler and easier to handle form which on its turn generate some positive aspects and limitations. According to Prof. Dionysis Assimacopoulos [23], the large amount of data is reduced to its main components which concentrate on keeping the key points of the evaluated condition. The results are easy to understand, interpret and utilize for the comparison. However, as a drawback, such data reduction can lead to data loss. Additionally, every index is limited to overall data availability. Nevertheless, it is mentioned that if indicator calculation is properly designed, the data loss would not have any significant impact on the final result. Therefore, it is crucial that the indicator is developed by the professional who has an understanding of the indicator design and measurement targets.

3.2 Water stress/scarcity indexes

This part will describe the different generations of water stress/scarcity measuring indexes with their limitations and benefits. As mentioned above, during year's great variety of indexes was developed and it will be challenging to cover them all. Therefore, this study focuses on several most commonly used indexes which cover the whole range from most simple to more complex, and will review those indexes from the perspective of human needs satisfaction.

3.2.1 Falkenmark Indicator or Water Stress Indicator

In 1989, Swedish water expert Falkenmark developed one of the most widely used indicator to measure water stress [24], the indicator is based on the measure of water availability per capita per year within the country or region [25]. In order to define the water stress, the classes presented in Table 1 were developed. The level of 1,700 m^3/capita/year is used as threshold, and the countries or regions that fall into the categories under 1,700 m^3/capita/year are considered to experience water stress [26, 2].

Table 1. Water barrier differentiation proposed by Falkenmark (1989).

Index(m3/capita/year)	**Class**
>1,700	No Stress
1,000-1,700	Stress
500-1,000	Scarcity
<500	Absolute Scarcity

The Falkenmark Indicator is commonly used to assess the water stress on the country scale; therefore, usually the required data is easily accessible and the results are straightforward, easy to use and interpret [27, 1]. Despite the stated advantages, this approach to water stress evaluation has its limitations:

- Simple thresholds ignore the differences in water demand between the countries determined by the climate and culture, etc.
- The use of national annual averages for evaluation occludes comprehension of the water stress at the smaller scale [26, 2] and omits the seasonal water availability variations.
- The indicator disregards the water quality or water accessibility [24]. The Falkenmark Indicator might represent the sufficiency of water resources, but, in reality, the water might be polluted or stored deep underground making it unavailable for use.
- It also does not take into account the artificial water sources such as desalination plants which increase the amount of available water [25].

3.2.2 Basic Human Needs Index

The Basic Human Needs Index is a water stress index developed by Gleick (1996) evaluates instead of water availability the water used to satisfy the basic human needs such as water for drinking, cooking and hygiene. It is assumed that in total 50 litres of water per day is required, of which approximately 5 litres/person/day for drinking, at least 35 litres/person/day for sanitation and hygiene, and 10 litres/person/day for cooking. These minimum requirements are suggested as thresholds for water supplier's regardless the demand determined by culture or climate. [27, 2]

Like the Falkenmark Index, the Basic Human Needs Index is assessing the water use on country scale, therefore, disregarding the regional variations and water quality. Since it takes into consideration just households' water requirements (where the data is usually unreliable and deficient), it ignores the other water uses such as industrial, agricultural or environmental [24].

3.2.3 Social Water Stress Index

Ohlsson has altered the Falkenmark Indicator by taking into account the society's *adaptive capacity* or, in other words, the ability of the society to adjust to water stress conditions by using economic, technological or other approaches [26, 2]. Ohlsson used the Human Development Index (HDI) as a weighted measure of the Falkenmark Indicator. He stated that society's adaptive capability depends on wealth allocation, level of education, and political engagement which are evaluated by HDI [27, 2].

3.2.4 Water Resource Vulnerability Index

All previously described indicators do not take into consideration the water demand variations between the countries [24]. Therefore, the Water Resources Vulnerability Index or WTA ratio was designed which measures water scarcity as a ratio of total annual water intake to total water resources available. On the basis of this index, when the annual withdrawals are around 20-40 % of the annual supply, the country is considered to experience water scarcity and severe water scarcity if withdrawals overstep 40 %. The 40 % threshold is named *criticality ratio,* which is the proportion of water withdrawals for human use to the total renewable water resources [27, 4].

Even though this method takes into account the countries' water demand, unlike the Falkenmark Indicator, it has some limitations:

- From the overall data on water availability, it is very difficult to discriminate the amount of water available for human use [26, 2],
- Like the Falkenmark Index, it disregards the artificial water resources such as desalination plants, which may increase the water supply,
- It neglects the withdrawals that are recycled and reused,
- It does not consider the country's capability to adjust to water scarcity through implementation of new technologies or infrastructure [25] or the society's ability to adjust to water scarcity [28, 8].

3.2.5 International Water Management Institute (IWMI) Indicator

In the attempt to solve the issues related to previously described approaches, the International Water Management Institute (IWMI) developed a method that takes into consideration the portion of the renewable water resource available for human requirements (ensured by current water infrastructure) with respect to primary water supply [26, 2]. Its scope includes the country's existing infrastructure like desalination plants which increase the water resources available; instead of total water intake, it takes into account the water withdrawn for the consumption, and evaluates country's adaptability such as capacity for infrastructure enhancement [25].

On the basis of the IWMI study results, countries are divided into two water scarcity categories:

- *physically water scarce* are the countries that would not be able to satisfy the future water demand regardless the investments into infrastructure [25] or improvement of the water management system [26, 2]. It includes countries where more than 75% of river flows are withdrawn for human activities (industry, agriculture or domestic use). However, according to Molden, cited in Brown and Matlock [27, 8] it does not mean that dry regions are water scarce because “physical water scarcity includes: acute environmental degradation, diminishing groundwater, and water allocations that support some sectors over others”.

- *economically water scarce* are the countries that possess sufficient water resources but would not be able to meet future water demand without investments [26, 2], infrastructure enhancement and performance improvement [25]. It refers to the countries where less than 25% of river flows are withdrawn for human activities (industry, agriculture or domestic use) [27, 8].

In 2008 the IWMI conducted a study on a global scale and mapped countries based on their water scarcity category [27, 8]. The results of the study are presented in Figure 5.

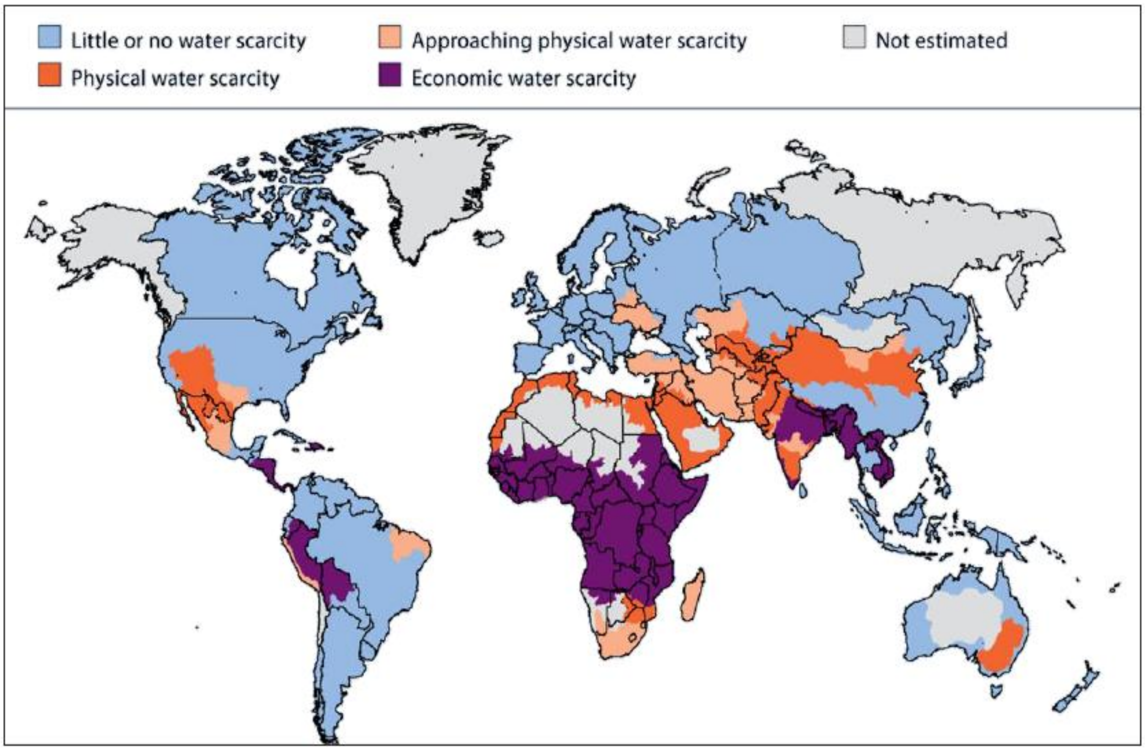

Figure 5. Areas of physical and economical water scarcity [27, 9].

As can be seen from the Figure 5, the majority of the countries that are *economically water scarce* are located in Central and Southern Africa with some countries in South-

East Asia and South America, whereas the majority of the countries that are *physically water scarce* are located in Asia with some countries in North and South Africa, and some regions in Australia and South parts of North America.

The IWMI approach is more comprehensive and complex, which leads to some complications in results assessment; it is not as simple and straightforward as the interpretation of the Falkenmark Indicator and requires expert evaluation [26, 2]. Such complexity makes it rather incomprehensible to the wider public [28, 8]. Since this method analyses water scarcity on a larger scale, it does not take into consideration the adaptive capacity of individuals [25], or whether they have an access to safe water [26, 2], or the economic situation in the country and wealth of individuals, which can significantly influence the adaptive capability by use of water saving technologies or import of food (reducing water requirements for agriculture purposes within the country) [25].

3.2.6 Water Poverty Index

In the attempt to solve the issues ignored by the IWMI approach, Sullivan [29, 1203-1205] developed the holistic Water Poverty Index (WPI). Sullivan emphasizes the importance of enclosure in the measurement of such aspects as physical water availability both for human (agriculture, industry and domestic use) and environmental needs, water quality and share of population with an access to safe water as well as time taken by the individuals to collect water, water management issues and both social and economic dimensions of poverty.

Lawrence, Meigh and Sullivan [30, 5] defined five key components (with sub-components) of the index. Table 2 presents these key components with a short review of what they include.

Table 2. WPI key components.

Resources	physical availability of water resources with respect to water total amount, fluctuation and quality [31]
Access	The population’s accessibility to safe water, sanitation and irrigation [30, 6] as well as time and distance required to collect water [32, 191-192]
Capacity	The efficiency of water management system [33, 9]. Population wealth enables to purchase water saving technologies, additionally, the income is directly correlated with level of education

	which determines the ability to manage water supply [32, 192]
Use	The purposes for which the water is utilized such as manufacturing, agriculture or households [31]
Environment	The evaluation of water quality and stress [34, 260] as well as environmental integrity of water sources [31] The importance of water and the environment in the countries' regulatory policies [30, 7]

The final index score ranges from 0 to 100 [35, 55] and is the weighted average of these five key components [28, 8] with a maximum score of 20 assigned to each component [2, 535].

The complexity of this index could be perceived both as an advantage, taking into account all the issues that were ignored by the previously developed indicators, and as a disadvantage, making it difficult to interpret [26, 2] and requiring expert involvement [28, 8]. Additionally, due to the use of vast input data, this approach is more suitable for smaller-scale analysis [25] on a community level rather than on a country scale. Moreover, Rijsberman assert that holistic and complex WPI index would not substitute the simple and straightforward Falkenmark Indicator [26, 2].

The WPI developers claim that the results of the analysis provide various advantages such as raise the awareness of the complexity of water scarcity problems, encourage rational decision making, can be used as a monitoring instrument, the single number result is an easy tool to represent or compare the situation in the location or in different countries [31]. Molle and Mollinga argue with that statement and assert that advantages are also weaknesses of complex indicators and claim that such multidisciplinary indicators mate diverse fragments assigned with arbitrary weight, which leads to mystifying combinations. For example, the WPI ranking of countries put side by side such countries as "New Zealand and Nicaragua, Papua New Guinea and Yemen, the USA and Laos, Peru and Switzerland, Thailand and Sweden". Some disadvantages of this approach arise when reviewing each of the 5 key components separately since each component consists of several sub-components, the single number result for one component might represent just one aspect and overshadow the other [2, 535-536]; therefore, it would be more reasonable to focus on selected variables rather than on the 5 components or on the final WPI score [35, 210].

Cho, Agwang and Opio [34, 258] agree that the comprehensive and complex WPI Index provide a tool for understanding the complexity of water related issues; however, they emphasize several challenges regarding the calculation and, in particular, the choice of dimension and weights, and recognition of the relevance of extra dimensions.

3.2.7 Agricultural Water Poverty Index

The previous chapter described several generations of indicators to assess the water issues on a global and local scale, and it can be seen that latest studies lead to the development of more comprehensive indicators that aim to take into account various aspects (the WPI described above) in order to address water issues. However, no indicators were measuring the water scarcity particularly for agricultural use [36, 419]. According to the International Water Management Institute [37, 43], the total water withdrawals are 3800 km^3, of which around 70% of water is used for irrigation [38]. Therefore, water is not just a resource for human survival, but it has an impact on overall wellbeing and food security. Furthermore, the agricultural water poverty is as complex and multidimensional as water poverty. Dimensions include not just the access to agricultural water resources, but the quality and quantity of these resources as well as population capability to use water efficiently [36, 419].

Therefore, Forouzani and Karami [36, 419-420] recognized a need to develop the multidimensional indicator to evaluate the water issues on a farm level, they named the indicator Agricultural Water Poverty Index (AWPI), which represents the agricultural water poverty as the crucial concept in agricultural development and as a tool in agricultural water management.

The AWPI likewise WPI consists of 5 key components with several sub-components, although their definition differ. Table 3 below presents these 5 key elements with description [36, 420-421].

Table 3. AWPI key components [39, 3].

Resources	Physical availability of water, total amount available for agriculture.
Access	The farmers' and land accessibility to agricultural water which includes the water distribution efficiency or soil infiltration potential.

Capacity	The efficiency of agricultural water management system within the farm and farmer's capability to manage agricultural water supply (level of education, knowledge, wealth and social capital).
Use	Reflects how effectively the water is used in terms of product per unit of water or money equivalent per unit of water, but writer emphasize that this choice is limited by lack of sufficient data [36, 422].
Environment	The evaluation of ecosystem impact on agricultural water quality and quantity. For example, soil degradation or its chemical deterioration causes adverse impact on water productivity. Consequently, the agricultural water quality has a direct correlation with water quantity available for use [36, 422-423].

The AWPI developers claim that this is the first indicator that attempts to evaluate the agricultural water issues by combining various elements of agricultural water system in a holistic and comprehensive manner. Similarly to WPI, it can be used as policy and decision-making, monitoring and comparative as well as water management improvement tool for farmers or communities. It can also provide valuable information on the reasons of water issues, and if conducted on regular bases, it provides important information on the effectiveness of, for example, mitigation actions and policies. [36, 420, 423]. However, Forouzani and Karami [36, 423] stress that in order to be effective the sub-components should be chosen and used carefully because of the lack of sufficient and reliable data as most of the data available is on country scale, whereas water issues are on location scale.

3.3 Indexes and indicators as a tool in decision-making process

According to Maria Pedro-Monzonis [28, 2], the indexes play an important role in decision-making and policy-development processes. Figure 6 illustrates the pathway from data acquirement to index calculation, defines the users and application of each step.

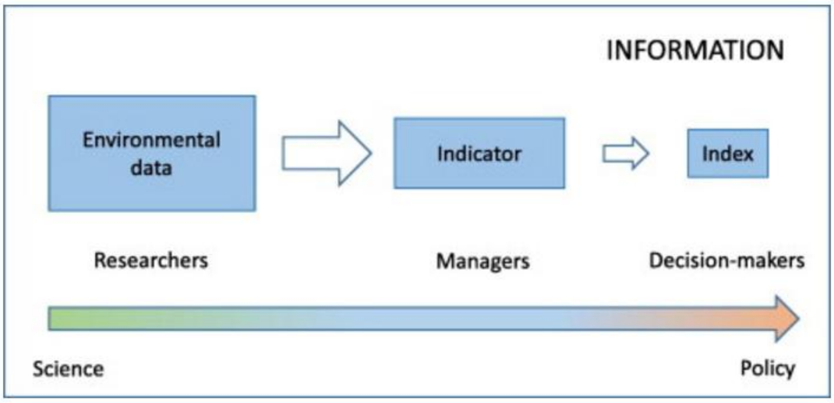

Figure 6. Aggregation of data in water resource management [28, 2].

Indicators provide the tools to measure (in numerical form) various elements of performance or accomplishment which are very difficult to evaluate otherwise. Moreover, indicators can be used to evaluate the effectiveness of actions and policies or as an instrument in policies development [33, 4] or indicate the opportunities for mitigation or development measures [28, 2].

Authors admit that indexes have issues, especially complex indexes where the importance of some components can change with time or external forces can alter the political primary objectives. However, “the use of indices as tools has become widespread” [33, 4].

When it comes to complex indexes, it is crucial for improvement actions, prioritization and execution to present all components of the index [33, 4]. Moreover, researchers and decision-makers should bear in mind that every index has limitations; that is why the one and unique index suitable for any study objectives and purposes simply does not exist [28, 9]. Therefore, for most cases, it is important to use several indexes in order to get reliable and applicable results because relying on single index might lead to deceptive conclusions [25].

4 Agricultural water management

This chapter will attempt to draw attention to the linkage between food security, agriculture and water with the special emphasis being placed on the crucial role of water both for agriculture and consequently for food security. Additionally, the chapter will explain the Agricultural water management framework with its practices and approaches.

4.1 Food security/agriculture/water nexus

One of the UN's Millennium Development Goals is "Eradicating extreme poverty and hunger" and in order to meet this goal the following water related aspects need to be addressed [40, 18]:

- Access to safe water for human needs including industry and agriculture,
- Sensitivity to water associated impacts such as droughts or floods,
- Influence of the water scarcity on the effectiveness and productivity of agriculture,
- Ability to produce inexpensive food.

Agriculture plays a vital role in the fight against hunger, assists in coping with poverty, and it has a direct linkage to water [41, 1] since agriculture require more than 70% of all water available for human use. The inter-relation of these three elements (water, food and agriculture) illustrated in Figure 7 below.

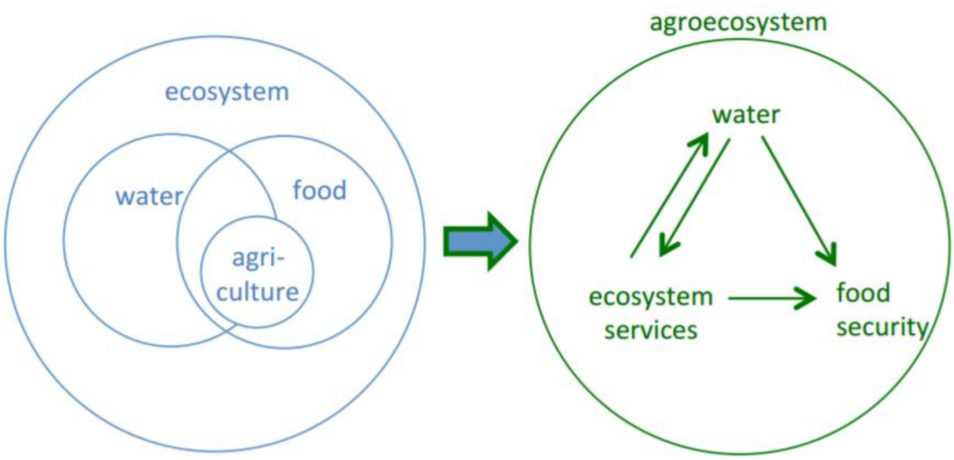

Figure 7. Water, agriculture and food as a part of ecosystem (on left), the role of water for food security in agroecosystem [37, 4].

Therefore, the investment in agriculture will enhance the productivity leading to higher farmers' income and food security, and consequently, giving rise to agricultural development through the return of the investment back to the farm (e.g. improvement of technologies or farmers education), so it creates the opportunity for continuous development. One of the major components of the investment in agriculture includes the adaptation of agricultural water management [42, 4-5, 9]. For example, several studies showed that improved irrigation has a direct positive impact on poverty reduction [3, 29-32] and farmers with an access to irrigation infrastructure have a higher income [43, 54].

4.2 Agricultural water management

As discussed in the previous paragraph, there is a need to sustain and improve food security, which arise due to population growth and consequent increasing water demand for agricultural purposes, by developing and enhancing agricultural water management systems from socio-economic, environmental and technical perspectives of agriculture, including efficient water use and productivity as yield capacity [44, 6-7] or in other words to use less water to produce more [38].

Agricultural water management (AWM) cover the variety of practices and approaches such as water harvesting, supplementary irrigation [45, 2], water reuse, water quality management as well as agriculture-ecosystem nexus [46]. Additionally, FAO makes a point of mentioning that these practices shall be applied at every stage from water resource to the end-user. During the 2nd World Irrigation Forum held in Chuang Mai, Thailand, the Ministers from several countries acknowledged the following:

> Agriculture Water Management (AWM) is key to enhancing water security, ensuring the sustainability of the surface and groundwater resource, achieving food security in a world confronted by limited natural resources while positively influencing the process of achieving almost all Sustainable Development Goals (SDG) [47].

Solely the improvement of water control increases the yield and reduces harvest failure, thereby enhancing the agricultural security and giving farmers the opportunity to grow diverse and expensive cash crops, providing the capacity to use new technologies and to implement new techniques [42, 5]. Some studies show that farmers' access to agricultural water management technologies reduces poverty [48, 32-33].

However, some regions lack the sufficient amounts of investments in agriculture because the investors (in most developing countries government and public agencies) see the investment in agriculture as poor financial profitability at high expenses, and this perception will not change until the issue is investigated and elaborated [42, 12-13, 18].

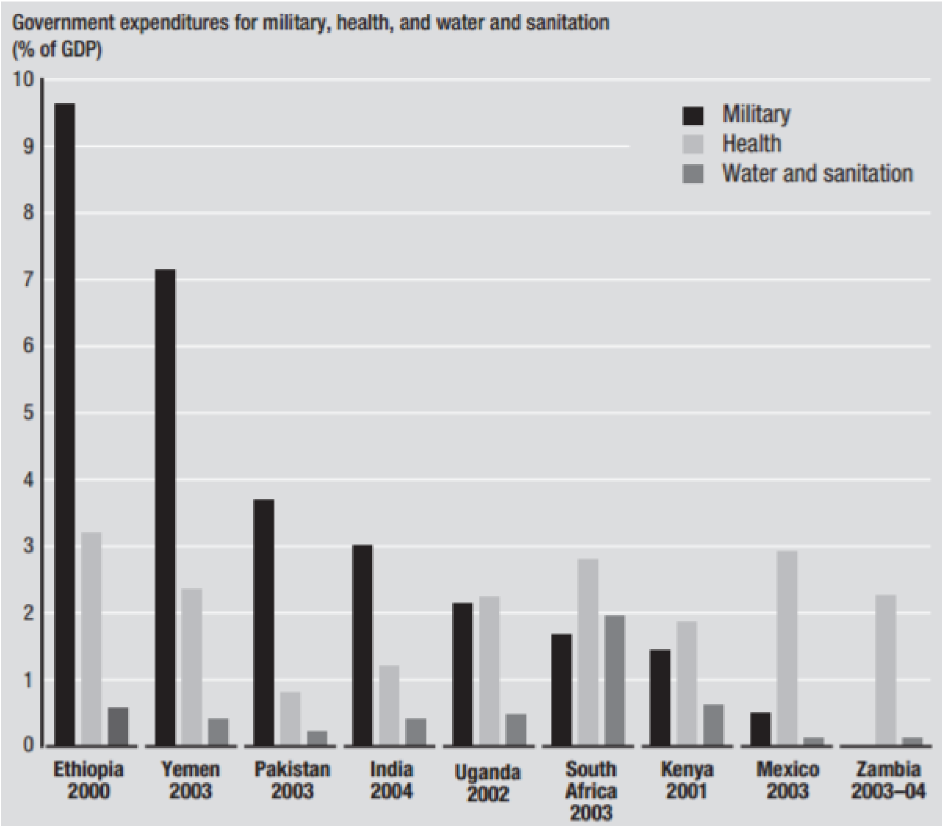

Figure 8. Government investment in water [3, 21].

Figure 8 above illustrates the share of government investment into water related sectors compared to other sectors. As can be seen from the figure, the countries' investments into water and sanitation sector is the lowest and in some cases almost 10 times less than their military budget. Therefore, it is important to find tools to convince authorities of the significance of investment in agriculture both on a local and a national scale [36, 419].

Some international organizations attempt to implement agricultural water management investment projects aiming to improve irrigation, apply new technologies and techniques. Examples of some obstacles faced by the projects or reasons for unsatisfactory results are agricultural water management practices being poorly adapted due to the lack of farmers' knowledge and failure to understand farmers' needs or local biophysical, socioeconomic or political conditions by researchers. There are cases when farmers cannot apply the technologies due to the physical inaccessibility of water resources or lack of information on ground water resources within their reach.

According to findings, the main problems and challenges that impede poverty eradication by implementation of agricultural water management projects are “lack of access to complementary productivity-boosting inputs and technologies, marketing constraints, institutional and organizational problems, water and land rights issues, and planning and implementation problems” [42, 60].

5 Conclusion

It is clear that water is the most vital and more importantly finite resource which plays a crucial role in every aspect of human life from survival (water for drinking purposes) to wealth (water used for agriculture and industry to ensure food security and increase the income and consequently boost the development). However, due to the population growth and water resources degradation, there is a need to preserve and to learn to manage the limited water resources.

A great number of scientists and researchers have attempted to develop guidelines and methods, firstly, to define the water scarce regions and, secondly, to recognize the reasons for water scarcity. They have aimed to obtain one single number (index) that could be easy to use as a tool to compare different regions and to determine the regions where actions are required to maintain and preserve utilizable water resources used to satisfy the current and future demand. However, as mentioned in chapter 3.3, no single index can provide reliable results; therefore, indexes shall be used jointly, and the objectives of index calculations shall be clearly and carefully defined.

As mentioned earlier, water plays an important role in every aspect of human life that is why some researches have attempted to combine all possible water-related aspects in one index. However, such an approach has both benefits such as a possibility to review the water situation from multi-disciplinary perspectives and drawbacks such as an increased amount of processed data, give more space for error, leaving the choice and prioritization of index components at researcher’s discretion.

The other part of this thesis emphasized the importance of water for agriculture and food security and described the agricultural water management as one of the approaches to improve the water supply stability and enhancement of agriculture.

Agricultural water management includes a wide range of water-related aspects, most of which can be addressed, and measured by the AWPI approach. According to AWPI developers, the index could support the decision-making process both on a local and a national scale. However, in reality, I think that one single index value cannot provide the universal tool to understand the whole situation in the area.

As was discussed in chapter 3, such multidimensional index as AWPI requires a vast amount of input data, which, in many locations, could be unreliable, insufficient or simply unavailable, which, in turn, restricts the applicability and reliability of the results.

Indubitable is the fact that indexes can provide the value for overall understanding of agricultural water poverty issues. However, it requires very detailed, deliberate and properly designed approach to calculation and weight of each key component of the index and more importantly of each sub-component. As well as when it is aiming to evaluate the water poverty on farm level, it is important to take into account local distinct characteristics such as ecosystem, socioeconomic and political aspects. Furthermore, single value result might overshadow some aspects and extol the others.

As it was stated in chapter 4, in most developing countries (which experience severe scarcity, poverty and hunger, and require tremendous investments in, for example, agriculture and water infrastructure) government or local authorities are acting as a decision-makers. In order to convince the authorities of the necessity of investment and policy, a measurable value is required; here the indexes can play a vital role regardless of the accuracy of the actual calculations as a single value result is easy to comprehend and compare.

No one can claim that indexes are useless and unreliable, or oppositely, the only tools to measure water poverty. They can become a very valuable tool in good hands or completely inapplicable when misused. I can define several essential rules to keep in mind when it comes to index calculations: any index needs to be carefully and precisely designed depending on the objectives, based on reliable and sufficient amount of data, and the final result need to be interpreted by the experts.

6 References

1 Perlman HA. Uses of water, Water Encyclopedia [online]. [cited 2016 Oct 28]. Available from: http://www.waterencyclopedia.com/Tw-Z/Uses-of-Water.html.

2 Molle F and Mollinga P. Water poverty indicators: conceptual problems and policy issues. Water Policy 5. IWA Publishing; 2003. p. 529-544

3 Watkins K. Human development report 2006 Summary: Beyond scarcity: Power, poverty and the global water crisis. In: Ross-Larson B, Coquereaumont M, Trott C., editors. Human development report 2006 [online]. New York: Toppan Printing Company America Inc.; 2006 [cited 2016 Oct 15]. Available from: http://hdr.undp.org/sites/default/files/hdr_2006_summary_en.pdf.

4 Reed B, Reed B. Technical notes on drinking water, sanitation and hygiene in emergencies [online]. World Health Organization: Water, Engineering and Development Centre, Loughborough University; 2013 [cited 2016 Oct 17]. Available from: http://www.who.int/water_sanitation_health/publications/2011/WHO_TN_09_How_much_water_is_needed.pdf?ua=1.

5 The human right to water and sanitation, United Nations Department of Economics and Social Affairs [online]. 2014 [cited 2016 Oct 17]. Available from: http://www.un.org/waterforlifedecade/human_right_to_water.shtml.

6 Water quality, United Nations Department of Economics and Social Affairs [online]. 2014 [cited 2016 Oct 15]. Available from: http://www.un.org/waterforlifedecade/quality.shtml.

7 Fedotova T, Traubel S. WASH – access to water, sanitation and hygiene, World business council for sustainable development (wbcsd) [online]. [cited 2016 Oct 17] Available from: http://www.wbcsd.org/Clusters/Water/.

8 World Population Highlights 2007: Overview of World Population, Population Reference Bureau [online]. 2007 [cited 2016 Oct 28]. Available from: http://www.prb.org/Publications/Articles/2007/623WorldPop.aspx.

9 Zlotnik H. World population will increase by 2.5 billion by 2050; people over 60 to increase by more than 1 billion, United Nations [online]. Pop/952. 2007 March [cited 2016 Oct 28]. Available from: http://www.un.org/press/en/2007/pop952.doc.htm.

10 Paulson LD. What is water scarcity?, RWL Water [online]. 2015 Feb [cited 2016 Oct 29]. Available from: https://www.rwlwater.com/what-is-water-scarcity/.

11 How do you define safe water?, USGS [online]. 2016 Nov [cited 2017 Feb 2]. Available from: https://www2.usgs.gov/faq/categories/9814/2864.

12 Safe water, Business Dictionary [online]. [cited 2017 Feb 2]. Available from: http://www.businessdictionary.com/definition/safe-water.html.

13 Water stress index, California water sustainability: Sustainability indicator framework to support water decisions [online]. Davis: University of California. [cited

2016 Nov 12]. Available from: https://indicators.ucdavis.edu/water/indicators/water-stress-index.

14 Schulte P. Defining Water Scarcity, Water Stress, and Water Risk: It's Not Just Semantics [online]. Pacific Institute, Insights. 2014 Feb [cited 2016 Nov 12]. Available from: http://pacinst.org/water-definitions/.

15 Water scarcity, ScienceDaily [online]. [cited 2016 Nov 12]. Available from: https://www.sciencedaily.com/terms/water_scarcity.htm.

16 Living-water Ltd. What is the difference between water stress and water scarcity?, Living-water [online]. 2016 June [cited 2016 Nov 12]. Available from: https://www.living-water.co.uk/blog/difference-betweenwater-stress-water-scarcity/.

17 Coping with water scarcity: An action framework for agriculture and food security [online]. Rome: FAO; 2012 [cited 2016 Nov 12]. Available from: http://www.fao.org/docrep/016/i3015e/i3015e.pdf.

18 Reig P, Maddocks A, Gassert F. World's 36 most water-stressed countries, World resources institute [online]. 2013 Dec [cited 2016 Nov 22]. Available from: http://www.wri.org/blog/2013/12/world%E2%80%99s-36-most-water-stressed-countries.

19 Luo T, Young R, Reig P. Aqueduct projected water stress country rankings. Technical note [online]. Washington: World Resources Institute; 2015 Aug [cited 2016 Nov 22]. Available from: http://www.wri.org/sites/default/files/aqueduct-water-stress-country-rankings-technical-note.pdf.

20 Oxford living dictionaries [online]. Oxford University Press. [cited 2016 Dec 1]. Available from: https://en.oxforddictionaries.com/definition/indicator.

21 The Free Dictionary [online]. Farlex. [cited 2016 Dec 1]. Available from: http://www.thefreedictionary.com/indicator.

22 Cambridge Dictionary [online]. Cambridge University Press. [cited 2016 Dec 1]. Available from: http://dictionary.cambridge.org/dictionary/english/index.

23 Assimacopoulos D. Indicators and Indices for decision making in water resources management, Water Strategy Man [online]. 2004 Jan-Mar; Issue 4 [cited 2016 Dec 1]. Available from: http://environ.chemeng.ntua.gr/WSM/Newsletters/Issue4/Indicators.htm.

24 Assimacopoulos D. Appendix, Indicators and Indices for decision making in water resources management, Water Strategy Man [online]. 2004 Jan-Mar; Issue 4 [cited 2016 Nov 30]. Available from: http://environ.chemeng.ntua.gr/WSM/Newsletters/Issue4/Indicators_Appendix.htm#Index of water scarcity.

25 White C. Understanding water scarcity: Definitions and measurements, Global Water Forum [online]. 2012 May [cited 2016 Nov 30]. Available from: http://www.iwmi.cgiar.org/News_Room/pdf/Understanding_water_scarcity.pdf?galog=no.

26 Rijsberman FR. Water scarcity: Fact or fiction? Agricultural Water Management. 2006 Feb; Volume 80, Issue 1-3: 5-22.

27 Brown A, Matlock MD. A Review of Water Scarcity Indices and Methodolgies. The Sustainability Consortium. University of Arkansas; 2011 Apr, White Paper #106.

28 Pedro-Monzonís M, Solera A, Ferrer J, Estrela T, Paredes-Arquiola J. A review of water scarcity and drought indexes in water resources planning and management. Journal of Hydrology. 2015 Aug; Volume 527: 482-493.

29 Sullivan C. Calculating a Water Poverty Index. World Development. 2002; Volume 30 No. 7: 1195-1210.

30 Lawrence P, Meigh J, Sullivan C. The Water Poverty Index: an International Comparison. Staffordshire: Keele University; 2002 Oct.

31 Meigh J, Sullivan C. Using the Water Poverty Index to monitor progress in the water sector. CEN Wallingford. Department for International Development.

32 Sullivan CA, Meigh JR, Giacomello AM, Fediw T, Lawrence P, Samad M, Mlote S, Hutton C, Allan JA, Schulze RE, Dlamini DJM, Cosgrove W, Delli Priscoli J, Gleick P, Smout I, Cobbing J, Calow R, Hunt C, Hussain A, Acreman MC, King J, Malomo S, Tate EL, O'Regan D, Milner S, Steyl I. The Water Poverty Index: Development and application at the community scale. Natural Resources Forum 27. 2003: 189-199.

33 Mlote SDM, Sullivan C, Meigh J. Water Poverty Index: a Tool for Integrated Water Management. 3rd WaterNet/Warfsa Symposium 'Water Demand Management for Sustainable Development'. 2002 Oct.

34 Cho DI, Ogwang T, Opio C. Simplifying the Water Poverty Index. Springer Science+Business Media B.V.; 2009.

35 Fenwick C. Identifying the Water Poor: an Indicator Approach to Assessing Water Poverty in Rural Mexico. Thesis. University College London; 2010.

36 Forouzani M, Karami E. Agricultural water poverty index and sustainability. Shiraz: Shiraz University; 2010 Oct.

37 Atapattu S, Barron J, Bindraban P, Bunting SW, Coates D, Descheemaeker K, Eriyagama N, Finlayson M, Gordon L, Khaka E, Lloyd GJ, Molden D, Muthuri C, Nguyen-Khoa S, Peden D, Pert P, Sinclair F, Solowey E, Sanford L, Stentiford D, Thiombiano L. Ecosystems for water and food security [online]. Colombo: International Water Management Institute; 2011 [cited 2016 Dec 9]. Available from: http://www.iwmi.cgiar.org/Issues/Ecosystems/PDF/Background_Document-Ecosystems_for_Water_and_Food_Security_2011_UNEP-IWMI.pdf?galog=no, 2011.

38 Water and food security. United Nations Department of Economics and Social Affairs [online]. 2014 [cited 2016 Dec 9]. Available from: http://www.un.org/waterforlifedecade/food_security.shtml.

39 Forouzani M, Karami E. Looking at Food Security through the Agricultural water poverty Index. Conference on International Research on Food Security, Natural Resource Management and Rural Development. Prague; 2014 Sep.

40 Coping with water scarcity: challenge of the twenty-first century [online]. World water day; 2007 [cited 2016 Dec 14]. Available from: http://www.fao.org/nr/water/docs/escarcity.pdf.

41 Water for Food: Innovative water management technologies for food security and poverty alleviation. United Nations Conference on Trade and Development [online]. 2011; 4 [cited 2016 Dec 14]. Available from: http://unctad.org/en/docs/dtlstict2011d2_en.pdf.

42 Koppen B, Namara R, Safilios-Rothschild C. Reducing Poverty through Investments in Agricultural Water Management: Poverty and Gender Issues and Synthesis of Sub-Saharan Africa, Case Study Reports. Working Paper 101. International Water Management Institute; 2005 Aug.

43 Hussain I, Giordano M, Hanjra MA. Agricultural Water and Poverty Linkages: Case Studies on Large and Small Systems. Water for All.

44 Coping with water scarcity in agriculture: A global framework for action in changing climate. Food and Agricultural Organization of the United Nations [online]. 2016 [cited 2016 Dec 10]. Available from: http://www.fao.org/3/a-i6459e.pdf.

45 Namara RE, Hanjra MA, Castillo GE, Ravnborg HM, Smith L, Koppen B. Agricultural water management and poverty linkages. Agricultural Water Management. 2010 Apr; Volume 97 Issue 4: 520-527.

46 Water Management. Food and Agricultural Organization of the United Nations [online]. [cited 2016 Dec 10]. Available from: http://www.fao.org/land-water/water/water-management/en/.

47 FAO's "Global framework for action on water scarcity". Asia-Water: Water & Food Security Network [online]. 2015 Aug [cited 2016 Dec 13]. Available from: http://www.asia-water.org/economic-food-and-water-security-all/413-fao-s-global-framework-for-action-on-water-scarcity.

48 Hagos F, Jayasinghe, Gayathri, Awulachew, Loulseged SB, Denekew M, Denekew A. Poverty Impacts of Agricultural Water Management Technologies in Ethiopia. International Water Management Institute (IWMI) Sub Regional Office for the Nile.