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Water Scarcity and Water Management. A comparative analysis of different water availability and demand assessments

A Master's Thesis submitted for the degree of
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Abstract

Water availability remains one of the upmost crucial key factors for sustainable development. Integrated water resource management and water demand and availability assessments are important tools to adapt and mitigate water scarcity. Since the 1980s many different of these assessments were developed with different advantages and disadvantages. This paper aims to provide a comparative analysis of five different assessments, namely the Water Stress Index (WSI), Water Poverty Index (WPI), Availability to Consumption Ratio (AVCOR), Household Survey, and the Water Evaluation and Planning Model (WEAP). These five assessments are different approaches considering issues such as rather basic factors like availability and demand, to more holistic approaches acknowledging socio-economic aspects, information at a community level and a complex computer-based system with scenario options. Following the analysis of the assessments, the different approaches are evaluated based on five dimensions. These dimensions are (1) applicability after water-related natural disasters, (2) the consideration of water quality standards, (3) if it is IT-supported, and if it is used (4) in academia and (5) by policy makers. Firstly, the WSI, WPI, AVCOR and WEAP are applicable after natural disasters. WPI, Household Survey and WEAP acknowledge water quality standards. Only WEAP is seen as an IT supported assessment. In the dimension of academia and policy makers use, the WSI, WPI, Household Survey and WEAP were identified.

Key words: water demand and availability assessment, water evaluation and planning model, water stress index, water poverty index, water scarcity

Table of contents

List of abbreviations

AVCOR	Availability to Consumption Ratio
DHS	Demographic and Health Surveys
EU	European Union
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GWP	Global Water Partnership
JMP	Joint Monitoring Program
IWRM	Integrated Water Resource Management
LSMS	Living Standards Measurement Study
MDGs	Millennium Development Goals
MICS	Multiple Indicator Cluster Surveys
SDG	Sustainable Development Goal
SEI	Stockholm Environment Institute
UN	United Nations
UNICEF	United Nations Children and Education Fund
USAID	United States Agency for International Development
WASH	Water, sanitation, and hygiene
WEAP	Water Evaluation and Planning Model
WHO	World Health Organization
WPI	Water Poverty Index
WSI	Water Stress Index
WTA	Withdrawal-to-Availability Ratio
WWC	World Water Council

1 Introduction

1.1 Problem statement

Water is key for life on planet earth. It not only is essential for socio economic development but also to ensure sustainable and healthy eco-systems. There may be sufficient resources of fresh water, considering the fact only around 3% of Earth's water is fresh water and of that, only 1,2% are usable for drinking water. The abundance of water increased at almost twice the rate of population increase in the last century. This highlights the importance of managing water resources sustainably, with increasing demand of it in nearly all sectors. There may not be a global water scarcity yet, but there are already regions, which suffer from the consequences of water scarcity or of a lack in infrastructure and/or weak institutions. For example, weak infrastructure and institutions can have little capacity to enforce regulations, monitor river basins or water quality. The number of these regions are increasing. (FAO 2017/FAO & WWC 2015)

On average, agriculture accounts for 70 percent of the total global water usage. In addition, the sector contributes to water pollution, creating herewith even more severe issues. As water pollution increases, the availability of water resources decreases. By 2050, the Food and Agriculture Organization (FAO) of the United Nations (UN) estimates that 60 percent more food is needed to feed the growing population. The demand for water is therefore set to increase. (FAO 2017)

The target 6.5 of the Sustainable Development Goals (SDGs) states that, integrated water resources management at all levels shall be implemented, by 2030. The indicator used for this target is the degree of implementation of integrated water resources management. This goes in line with target 6.b to support and strengthen the participation of local communities in improving water and sanitation management using the indicator of the proportion local administrations with operational policies and procedures for water management. (UNESCO 2021)

In order to manage water sustainability, it is essential to know how much water is available and how much of it is used. The measures are important on local, regional, and national levels. There are several methods and assessments to measure the supply and demand of water. These different water indicators and assessments, however, suffer from numerous of limitations (Petit 2016). Therefore, this paper will compare and analyze different water demand and availability assessments as a base for water management.

Only by understanding these differences and possible advantages and disadvantages can water be managed sustainably.

1.2 State of the art

Research of the United Nations Food and Agriculture Organization (FAO) helps to understand the principle of water scarcity. It shows that water is a renewable resource, and it exists in a constant state flux in all phases. It can be solid, liquid or in gas form and is pushed by energy gradients. The conservation of mass governs the balance of water, meaning that the rate of in- and outflows of water is the same. However, one must understand the linkages between surface groundwater, surface water, soil moisture and the evapotranspiration process. Another important linkage is the connection between land areas in a river basin. Actions in one part of the hydrological systems have impacts on others. Accounting of water, i.e., the organization and management of physical volume and the quality of flows, is of high importance. Furthermore, it is important to consider economical aspects of water supply and demand and the distribution of water resources among users. (FAO 2012/FAO 2015/FAO 2017)

In order to evaluate the approaches, different working papers and articles are used. One of the accounting measures is the Water Evaluation and Planning Model (WEAP). This model uses a scenario-based option considering different conditions of input variables and was used by Amin et al. (2018) in a case study in the Upper Indus Basin in Northern Pakistan. The tool is broadly used in the allocation of water and water management and very useful for the evaluation of basin level water supply and demand. It provides a set of objects and procedures that helps to measure natural watersheds, reservoirs, and canals in difficult scenario-based circumstances. (Amin et al. 2018)

Another important work was published in 2016 by Damkjaer and Taylor. They measured water scarcity and the measurement of the usage and supply of water. In their paper they outline different measures, indicators, and index such as the Water Stress Index (WSI) and Withdrawal-to-Availability ratio (WTA). They further emerge holistic metrics, which consider more complex and detailed factors, and include social water stress index, physical and economic scarcity, and the water poverty index. As a conclusion, Damkjaer and Taylor argue that the measurement of water scarcity needs to be adapted in terms of physical redefinition as it ignores the subjective counting of the human environments and lacks in addressing the decision-making procedures sufficiently. (Damkjaer & Taylor, 2016)

Sullivan et al. (2003) researched on the Water Poverty Index. It is based on five categories (resources, access, capacity, use and environment) related to the availability of water. The index reveals a comparative ranking of states based on their domestic water poverty. However, the index faces some criticism, inter alia, on the exclusion of water precipitation. It also does not distinguish between rural and urban areas and presents some issues when it comes to calculating the population. (Sullivan et al. 2003)

Based on the Water Poverty Index by Sullivan et al. (2009), Stocker (2009) researched on the Availability/Consumption ratio (AVCOR), which takes hydrological data and socio-economics variables into account. This allows the AVCOR to create a comprehensive availability measurements per capita. The hydrological data includes external and internal renewable water resources such as precipitation values. The final ratio will then be weighted with the Gross Domestic Product (GDP) of the evaluated population group. (Stocker 2009, p. 3)

Some other researchers focused their work on water demand and availability especially on climate change. Among them are Masafu et al. (2016), Sarzaeim et al. (2017) and Chang et al. (2010) who researched how climate change influences environmental conditions for water. All the works are focusing on hydrological methods and models.

Conducting Household Surveys is another measure to calculate water demand. Nauges and Whittington (2010) published a paper on the estimation of water demand in developing countries, in which they outline the possible issues. Further, they outline several strategies on how to estimate water demand in least developed countries. In their paper they outline the differences among households such as those in middle and large cities, those living in slums and those who live in rural areas. However, there are issues in collecting the data. Data issues include the collection of data and individual circumstances and, for instance, the consequence of different households sharing the same waterpipe. (Nauges & Whittington 2010)

As Petit (2016) argues, the status of indicators as part of water management has been highly debated. There are many indicators and assessments on how to evaluate water demand and availability and water scarcity, as mentioned. According to the author, all these indicators and assessments have numerous limitations and lacks.

1.3 Objective of the paper

The objective of this paper is to reveal the differences, commonalities, advantages and disadvantages of different water demand and availability assessments “Water Stress Index”, “Water Poverty Index”, “Availability/Consumption Ratio”, “Household Survey” and “Water Evaluation and Planning Model”. The paper explains how the assessments are applied and how they work. It further takes into account the aspect of water scarcity and water management as the scientific discipline behind the assessments. Also, it will evaluate the different assessment based on the dimension of (1) applicability in water related disasters, (2) the consideration of water quality standards, (3) if the assessment is IT supported and if it is used by (4) academia and (5) by policymakers. It further gives recommendations in this regard.

Chapter 1, as the introduction chapter, will outline the problem of the paper. It touches on the importance of water and the role of water scarcity. It briefly describes how water scarcity evolved and is expected to develop in the future. This chapter also identifies the research questions and outline the methodology of the research. The second chapter defines the major terms of this paper to understand the essential concepts. These are water scarcity, integrated water resource management, what water demand and supply mean and why it is measured. It also describes water quality standards.

Chapter 3 provides the theoretical analysis of the different water demand and availability assessments “Water Stress Index”, “Water Poverty Index”, “Availability/Consumption Ratio”, “Household Survey” and “Water Evaluation and Planning Model”. The chapter begins with a short explanatory introduction and why the assessments were chosen. The analysis of each assessment will outline the history and evolution of the assessment, how it is applied, what its advantages and disadvantages are and who the target audience is. At the end of each assessment analysis an example of application, based on a case study, is outlined.

Based on chapter 3, the fourth chapter evaluates the assessments. Here the paper will evaluate the assessments based on five dimensions: (1) applicability in water-related disasters, (2) the consideration of water quality standards, (3) if the assessment is IT supported, (4) if the assessment is used by academia and (5) if the assessment is used by policymakers. The final fifth chapter summarizes all findings, and concisely answers the research questions. The sixth chapter outlines recommendations and limitations of this paper.

1.4 Research questions

In respect to the problem statement and the objective of the paper the following research questions are determined:

- What does Water Scarcity mean?
- What are the differences, commonalities, advantages and disadvantages of the water demand and availability assessments "Water Stress Index", "Water Poverty Index", "Availability/Consumption Ratio", "Household Survey" and "Water Evaluation and Planning Model"?
- How are these water availability and demand assessments applied?

1.5 Methodology

The fundamental basis of this thesis is the range of sources of literature used in this paper. This literature includes professional literature, booklets, newspaper articles and articles from scientific magazines and journals.

Keywords used for the research are, inter alia, water scarcity, integrated water resource management and water demand and availability. In regard to the analysis of the different assessments the titles of the assessments offer the best key word which are in the following, Water Stress Index, Water Poverty Index, Availability to Consumption Ratio, Household Survey and Water Evaluation and Planning Model. Prior the analysis of the respective literature, the literature was ordered by the importance for the particular topic. The outcomes of this literature review enable to answers the research questions of this paper. To understand the different assessments, literature including applied case studies are analyzed. This knowledge will support the analysis and evaluation of the different water demand availability assessments. The assessments will be evaluated in five dimensions. These dimensions seem to be important within the current political and scientific developments.

The secondary literature is derived from catalogues from libraries of the Technical University of Vienna, WU-University of Economics of Vienna and University of Vienna. Further, literature is collected in online data bases such as Emerald Insight, Ebsco, Scopus, Google Scholar, Sage and Springer Link. The data collections from the FAO of the UN and the World Water Council (WWC) also provide important information for this paper.

2 Definition of terms

This chapter identifies and explains the key terms and terminologies necessary to understand and answer the research questions. Most relevant is the importance of water and what is understood as water scarcity, followed by Integrated Water Resource Management. Furthermore, it outlines what demand and supply means, and why we measure it. Finally, this chapter presents what the water quality standards are.

2.1 Water scarcity and importance of water

The general definition of water scarcity is the missing availability of sufficient freshwater resources to meet the human and environmental demand of a given area (Petruzzello 2021/White 2014). Water scarcity is increasingly being recognized in many countries and considered as a growing concern. The term itself is regularly used by governments, media, non-governmental organizations, inter-governmental organizations, such as the UN, as well as in academia. Although the term is frequently used, there is no clear consensus on how water scarcity shall be defined and how it should be measured. There are many ways of measurements which can cause confusions. (White 2014)

In general, there are two types of water scarcity. First, the physical and second the economic scarcity. The physical scarcity, also called the absolute scarcity, is the result once a region's demand is more than the limited water resources can provide (Petruzzello 2021). Physical scarcity may result from anthropogenic influence such as desertification or water storage as well as from natural phenomena like aridity and drought. Often, these phenomena are coupled. For example, the overuse of water during a temporary period of drought (mostly in arid areas), often results in a process of desertification. Important is the distinction between these processes in the degree of permanency and reversibility. In the case of drought and overuse of water, Bond et al. highlight, that the impacts may be temporary, however impacts which result from aridity and desertification are often irreversible. (Bond et al. 2019)

According to the FAO approximately 1.2 billion people globally live-in areas which face physical scarcity. Many of them live in (semi) arid areas. The amount of affected people who suffer from physical water scarcity is expected to increase due to population growth and the increase in extreme and unpredictable weather patterns linked to climate change. (Petruzzello 2021)

Economic water scarcity arises from a lack of water infrastructure and the connected mismanagement of water resources. Here, the FAO predicts that more than 1.6 billion people experience economic water scarcity. Usually, areas have a sufficient supply of water to meet the human and environmental need which face economic water scarcity. However, because of poor water infrastructure, this results in polluted or unsanitary water quality standards for human usage. Often, this scarcity derives from an unregulated water supply for agriculture and/or the industry, resulting in a negative effect for the civil population. Once water resources become scarce, the authorities and governments may be forced to allocate water between industry, agriculture, municipal or environmental interests. A competition may arise. This leads to many issues as humanitarian crises and forced migration. (Petruzzello 2021)

Water pollution is a rising issue which is caused through released substances into water resources to a turning point where the substance reduces the water quality to a point where it is unusable for human usage and damages for ecosystems. Water can be differently polluted thorough domestic sewage, e.g., pathogens, plastics; toxic waste, e.g., from disposed wastewater from the industry; soil erosion or thermal pollution. Water pollution may exacerbate water scarcity even further. (Nathanson 2021a)

Regardless of the cause of the scarcity, water scarcity impacts humans and ecosystems on all continents. Regarding the seasonal aspect of scarcity, Mekonnen and Hoekstra (2016) found out that around four billion people live under conditions of water scarcity at least one month per year, as described in figure 1. This highlights the great impact of water scarcity on humans and nature.

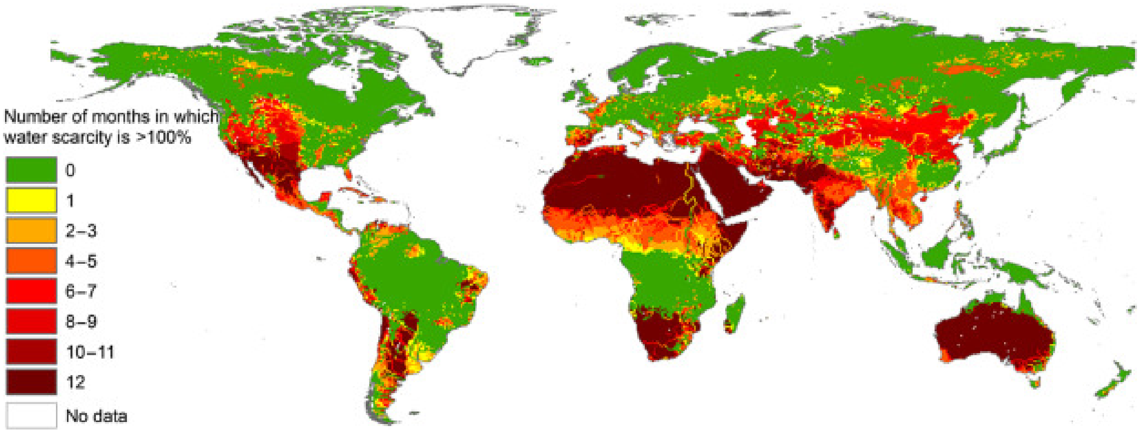

Figure 1: Global distribution of regions affected by water scarcity (Mekkonnen & Hoekstra 2016)

Water is the foundation of life and livelihoods and key to sustainable development. Only by implementing successful water management the achievement of the SDGs specifically SDG 6 “Ensure availability and sustainable management of water and sanitation for all” can be achieved. (UNESCO 2021)

Over the past 100 years the global freshwater usage has increased by a factor of six and keeps on growing by roughly one percentage since the 1980s. The increase in freshwater usage is the highest in countries with emerging economies and middle to lower income countries, due to the combination of growth in population, economy, and consumption. Figure 2 shows this trend and differentiates the withdrawals in reservoirs (evaporation from artificial lakes), municipalities, industries, and agriculture. (UNESCO 2021)

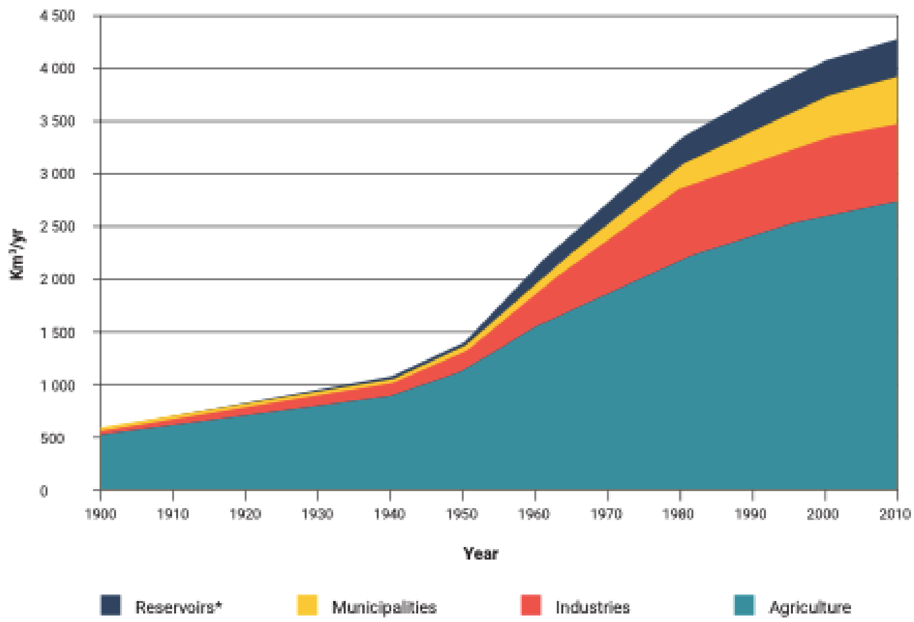

Figure 2: Global water withdrawals between 1900 and 2010 (AQUASTAT 2010)

Almost 70% of the global water withdrawal derives from agriculture and mostly from irrigation, water for livestock and aquaculture. This can increase up to 95% in developing countries. Industry accounts for almost one fifth of the consumption and municipalities are responsible for around 12%. The additional category of reservoirs was added to highlight that this water is not a water withdrawal per se but should be considered as an anthropogenic consumptive water use when artificial lakes are created through building a dam. (UNESCO 2021)

Different studies try to project future trends in water usage with different outcomes. The UN World Water Development Report 2021 highlights different scenarios ranging from demand increases between 20% to 55% by 2050. Further, it predicts that already 40% of the world population will face a water deficit under a business-as-usual scenario, by 2030. However, is it important to highlight that this remains uncertain, yet most authors agree that agriculture will face increasing competition when it comes to water withdrawal and allocation. The FAO estimates that the world will need around 60% more food by 2050 and irrigation efforts will increase more than 50%. (UNESCO 2021)

2.2 Integrated water resource management

The mentioned status quo in the previous chapter of water resources shows the need for improved and well-established water resource management. Integrated water resources management (IWRM) is a system approach in managing water, recognizing the need to manage the water cycle. It has been an international frame since 1990s. The Global Water Partnership (GWP), an international organization dedicated to promoting sustainable water resource management defines it as:

> *"a process which promotes the coordinated development and management of water, land and related resources in order to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems."* (GWP 2009)

In similar lines Pollard defines it as:

> *"simultaneously a philosophy, a process and an implementation strategy to achieve equitable access to and sustainable use of water resources by all stakeholders at catchment, regional and international levels, while maintaining the characteristics and integrity of water resources at the catchment scale within agreed limits."* (Pollard 2002)

However, there is no consensus on the definition and on how to implement IWRM (De Oliveira Vieira 2020, p. 1). IWRM should not be considered as a goal, but more as a guide to reach targets such as the efficiency in the use of water and other related natural resources, the equity in the allocation of water resources among different socioeconomic groups and social, economic, and environmental sustainability to protect water resources and associated ecosystems. (De Oliveira Vieira 2020, p. 4)

The UN Conference on Environment and Development in Rio De Janeiro in 1992, set off the concepts for IWRM and its first debates about the approach. It was then first introduced during the International Conference on Water and the Environment in Dublin in 1992, and led to the Dublin Principles, which are outlined later in this sub chapter. Two major organizations contributed to the concept of IWRM, firstly the already mentioned Global Water Partnership (GWP), which aims is to implement IWRM concepts at the operational levels and the World Water Council (WWC), which focuses on building awareness at political levels. (Vanham 2009, p. 1)

During the World Summit on Sustainable Development in Johannesburg in 2002 a plan for IWRM policies on national levels was made to achieve its goals. Hence, the GWP tried to identify indicators to measure the progress of IWRM by connecting the process indicators, outcome indicators and impact indicators with the UN's Millennium Development Goals (MDGs). Other organizations have also contributed and suggested indicators for the measurement of IWRM, inter alia, on governance, stakeholder participation and sustainable allocation of water resources (Petit 2016). Within the Agenda 2030 the SDG 6 includes a specific goal on IWRM. Under Target 6.5 the Agenda aims to implement integrated water resources management at all levels, including through transboundary cooperation as appropriate. This is measured through the degree of implementation and the proportion of transboundary basin area with an operational arrangement for water cooperation. (UN 2021)

The Dublin Principles, adopted during the International Conference on Water and Environment held in Dublin, state that IWRM indicates (1) an inter-sectoral approach, (2) the representation of all stakeholders, (3) the consideration of all physical aspects of the water resources and (4) the considerations of sustainability and the environment (ICWE 1992). They further recommend four principles to guide through the effort: Ecological, Institutional, Gender and Economic. (De Oliveira Vieira 2020, pp. 7-8)

Jønch-Clausen (2004) set up three pillars, in line with the Dublin Principles and the input of the GWP of IWRM. This helps to understand where to put in water demand and availability assessments within this framework, as visualized in figure 3 below. The framework consists out of three pillars: Economic Efficiency, Equity and Environmental Sustainability. The assessments can be found under "Management Instruments". They are based on the fact that the enabling environment was implemented, and institutions were working; these instruments help to address specific issues offering detailed methods to make rational evidence-based decisions. Assessments shall help to comprehend the interlinkages between water resources and its various users. Also, assessments help to calculate unpredictable events and how influence policies. This includes potential risks, vulnerability, social effects, ecosystems, the environment, and the economy. (De Oliveira Vieira 2020, pp. 8-10/Jønch-Clausen 2004)

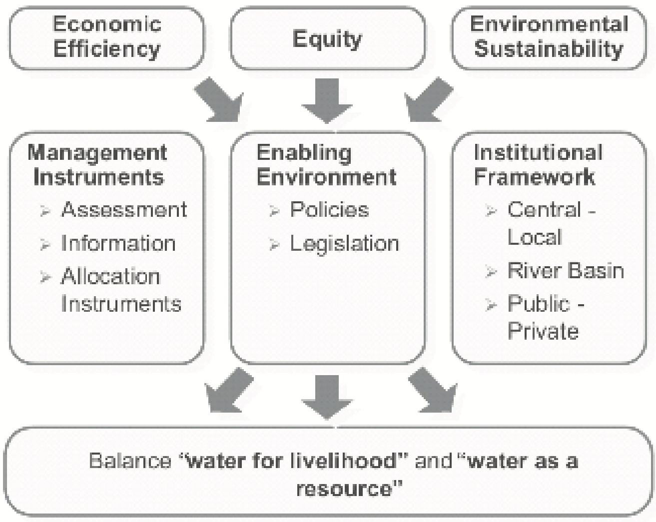

Figure 3: Three pillars of IWRM (Jønch-Clausen 2004)

2.3 What is water demand and supply?

Water demand and supply management is an important instrument of IWRM. It is also part of the three pillars of IWRM within the Management Instruments and supports efficiency in water management. Measuring demand and supply helps to improve supply and demand efficiency as an important strategy in IWRM practice. (De Oliveira Viera 2020, p. 10)

Several factors affect demand, and the calculation of water demand is complex. It cannot be directly correlated with household income as it has been done in the past (Parry-Jones 1999). As mentioned, there are several factors which influence demand:

- Gender, household income, occupation and assets, education, demographics
- Availability, reliability cost and convenience of existing services
- Household attitudes towards government sector policy and provider of services (Parry-Jones 1999)

As Parry Jones (1999) highlights it is important to understand that demand is unique to each location, dynamic, dependency on alternatives, and willingness to pay. In his research paper, Sophocleous (2004) outlined nine major variables which have significant impact on the demand of water which were summarized by Richard Connor in 1999:

1. Population growth
2. Economic growth
3. Per capita energy consumption
4. Technological development
5. Land-use change, including urbanization
6. Rate of environmental degradation
7. Environmental awareness
8. Government programs
9. Climate change

These variables impact the water trend and its demand. All variables lead to an increase in water demand once the variable increases, except of technological development, environmental awareness, and government programs, which help to reduce the demand for water or increase water supply. Especially climate change and population growth, linked with economic growth, are major challenges regarding water supply. (Sophocleous 2004)

It may be also useful to divide water consumption into different categories. Firstly, there is domestic water use. This includes in-house use (cooking and drinking), out-house use (watering). Secondly, water consumption can be assigned to trade and industrial use, whereas industrial use includes factories and industries. The commercial part includes shops, offices and restaurants and the institutional part hospitals, educational and government buildings. The third part is the agricultural use for crops, livestock, and greenhouses. The fourth part is the public use for public parks, green areas, and infrastructure watering. The final fifth part are the losses, including distribution losses and consumer wastage. (Twort et al. 2000, p. 1)

Water supply is the system and infrastructure for collection, transmission, storage, treatment, and distribution of water. Water is distributed to private homes, commercial properties, industry and irrigation and this supply systems must meet the qualitative and quantitative requirements of each section. Especially these needs, including urban development, industrial growth, and environmental pollution decrease the quality of water. (Nathanson 2021b)

It is estimated that the world has a total of around 1.4 billion km^3 of water. It recycles and occurs in three states of solid, liquid and vapor. Two thirds of this freshwater occur in as part of permanent ice or snow in polar regions. Most of the freshwater occurs as groundwater, less in lakes, wetlands, and rivers (Sophocleous 2004). Less than one percent of the total amount is liquid fresh water. Surface water and groundwater are crucial in water supply, whereas groundwater accounts for the majority. In addition, the hydrologic cycle, or so-called water cycle, is the foundation for the earth's water supply as it supplies freshwater from rainfall over land. (Nathanson 2021b/Sophocleous 2004)

2.4 Water quality standards

The term "water quality standards" describes provisions of states, territories or laws that protects water and set achievements in the condition of water. The difference between standards and guidelines are from a legal perspective the bindingness and enforceability. Thus, standards provide a superior level of protection hence a failure in reaching a standard should result in legal action, whereas guidelines in the contrary provide voluntary targets. Therefore, the World Health Organization (WHO) says that states should implement legally binding national standards for drinking water quality. (Boyd 2006, pp. 7-8)

In general, the data for global water quality remains inadequate, as there is a lack of monitoring and reporting capacity. This accounts especially for the least developed countries. However, the following trends have been trends identified: almost all major rivers in Africa, Latin America and Asia experience a decrease in water quality due to nutrient loading and pathogen loading. On a global scale around 80% of industrial and municipal wastewater is released into the environment in an untreated state. This rate is much higher in least developed countries. The agricultural runoff, containing multiple chemicals, can be considered as one of the most prevalent challenges regarding water quality. (UNESCO 2021)

The WHO plays a crucial role in setting guidelines and standards in (drinking) water quality. With the publication of the Guidelines for Drinking-water Quality in 1958, the WHO published a normative, subsequently revised, guideline for countries to protect their water on a national and regional level. The guidelines include an assessment of health risks and a maximum concentration guideline for hazardous constituents. Many countries use this guideline in a direct or indirect way by setting national drinking water standards (WHO 2018a, pp. 1-2). Together with the publication "Developing Drinking-Water Quality Regulations and Standards", the WHO provides further information and guidance on how to implement quality guidelines. (WHO 2018b, p. 1)

As far as Europe is concerned, in December 2020, the European Parliament formally adopted the new Drinking Water Directive. The directive concerns the quality of water intended for human consumption and provides essential quality standards at EU level. It includes 48 microbiological, chemical and indicator parameters. This directive is based on the findings of the WHO's guidelines for drinking water. Since 2001, a commission has been in operation implementing the Water Framework Directive, which covers inland, transitional, and coastal surface and groundwaters. Many other directives followed, such as the Floods Directive, Groundwater directive, Environmental Quality Standards Directive, Marine Strategy Framework Directive, and programs for River Basin Management. (EC 2021)

This chapter underlines the importance of water and how much the world's population is or will face water scarcity. The FAO and the UN are key players to tackle water scarcity. The concept of IWRM can be a strong instrument to address water related issues. However, is much more research is needed to measure and implement it cohesively. In addition to the UN institutions, the GWP and the WWC are crucial players in working on IWRM. Regarding the water quality standards. the UN and the WHO play a leading role in setting these standards. Further, the chapter links the cruciality of water scarcity, water management tools, and quality standards to the assessment of water demand and availability.

3 Analysis of water demand and availability assessments

3.1 Introduction

This chapter analyzes the different water demand and availability assessments based on research and provides the theoretical framework of the assessments. The chapter investigates each assessment and outlines its development and history as well as how the assessment is applied including its rules and regulations. It highlights the possible advantages and disadvantages of the assessments and, if applicable, who is the target audience. At the end of each assessment-sub-chapter and case study, the paper will discuss how the assessment can be applied.

When in 1980s water scarcity evolved as a pressing issue, several indicators have been developed globally to assist in the understanding and assessment of water scarcity. Corresponding, the number of publications about water scarcity has strongly increased, as the issue rose more and more. From 1980s to 2000, many of these indicators were criticized due to their limitations and because they focus primarily on surface and groundwater and disregarding the importance of green water, which is water in soil from precipitation and temporary scarcities. By entering the new millennium, more detailed and complex assessments were created. This included aspects such as the quality of water or incorporation of green water. Another issue which arose was that the assessments were still too narrowed, even though water scarcity was more understood. Also, the more diverse and sophisticated approaches were mostly used by the research groups or institutions which developed the assessment. (Liu et al. 2017)

Figure 4 below visualizes the number of publications based on the keyword “water scarcity” from the database Scopus from 1980 to 2015. Further it differentiates between classical and simple with diverse and sophisticated approaches. This figure also highlights major indicators and assessments on the year they were created (Liu et al. 2017). Damkjaer and Taylor (2016) have identified more than 150 indicators.

The following assessments “Water Stress Index”, “Water Poverty Index”, “Availability/Consumption Ratio”, “Household Survey” and “Water Evaluation and Planning Model” are used in this paper as they provide a broad and diverse overview of different ways of approaching and measuring water availability and demand. The variation of the assessments provides a wide variety on the one hand of classical approaches, such as the Household Survey and the Falkenmark Water Stress Index, and on the other hand to more socio-economic aspects with the Water Poverty Index the Availability/Consumption Ratio, and even a more complex and holistic model such as the Water Evaluation and Planning Model.

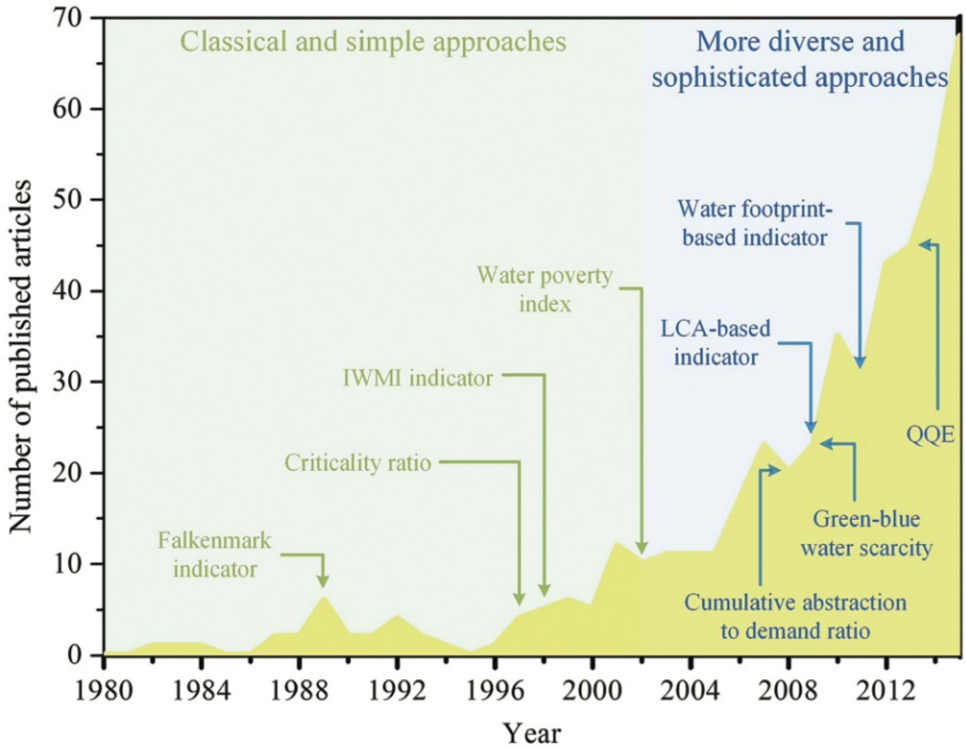

Figure 4: Number of publications based on the keyword "water scarcity" from Scopus as of 2016 (Liu et al. 2017)

3.2 Water Stress Index

3.2.1 History and evolution

The Water Stress Index (WSI), or so called Falkenmark Index (Falkenmark et al. 1989), is a simple yet widely used indicator (Matlock 2011, p. 1/Liu et al. 2017). The index was developed in the research paper "Macro-scale water scarcity requires micro-scale approaches. Aspects of vulnerability in semi-arid development", published in 1989 to show that water scarcity is a complicated problem when it affects countries which experience a fluctuation between dry and rainy seasons, i.e., semi-arid climate (Falkenmark et al. 1989). In their research Falkenmark et al. surveyed multiple countries and the water usage per capita in each economy was calculated. (Matlock 2011, p. 1)

Already in 1974 Falkenmark and Lindh proposed one of the first quantitative connections between population and freshwater at the Third World Population Conference in Bucharest. However, the explicit calculation of water scarcity started only in the 1980s, where the Water Stress Index has been established. This was caused due to the famines across the Sudano-Sahel area. The WSI was initially intended to provide an early warning system to provide information about strategies to adapt to possible droughts in combination with population growth. (Damkjaer & Taylor, 2016)

The WSI also serves as a base for other indicators. Rijsberman (2006) for example, highlights the Social Water Stress Index, which is a modification of the WSI with the United Nations Development Program's Human Development Index founded by Ohlsson in 1998.

3.2.2 Application

The WSI is the fraction of the total annual runoff available for human use (Matlock 2011, p. 1). It relates the total resources of freshwater with the total population of a specific area or country and indicates the pressure on this population. Falkenmark et al. (1989) established this indicator with the assumption of a minimum need of 100 liters per day per person. The volume of the available water per person is then calculated in m^3/person/year.

Damkjaer and Taylor (2016) outline that the WSI approach to water scarcity was initially developed bearing in mind the number of people, which compete to be sustained by a single flow unit of water of $10^6/m^3/year^{-1}$. Falkenmark et al. (1989) initially set the inverted WSI to 600 people which compete with one flow unit (~ 1.667 $m^3/capita^{-1}/year^{-1}$) as water stress. Originally it was set to 500 people, but Falkenmark did not want to exaggerate the situation and amended it to 600 people. The threshold for water scarcity was set to 1.000 people/flow unit (Damkjaer & Taylor 2016). The illustration below visualizes the different levels of water competition. Each cube indicates the flow of 1 million m^3 per year available in the water system. Each dot stands for 100 individuals depending on that water unit.

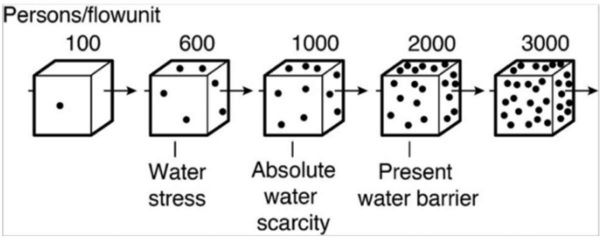

Figure 5: Levels of water competition in person/flow unit (Damkjaer & Taylor 2016)

Falkenmark et al. (1989) proposed the initial 500 m^3 of water per person and per year are comprised with around 10% domestic and industrial demand and 80-90 % for irrigation (Damkjaer & Taylor 2016). Based on the per capita usage, the water stress situation in an area can be then categorized in the following: no stress, stress, scarcity, and absolute scarcity (Matlock 2011, p. 1).

Table 1: Water barrier differentiation by Falkenmark (Author's illustration based on Falkenmark et al. 1989)

Index (m^3 water per capita)	Category/Condition
> 1.700	No Stress
1.000 – 1.700	Stress
600 – 1.000	Scarcity
< 600	Absolute Scarcity

If water availability is lower than 600 m^3 per capita and year the population in an area faces absolute water scarcity. Has this area an availability of more than 1.700 m^3 it faces no water stress at all. The proposed 1.700 m^3 of renewable water resources as the threshold, are based on the estimates of water requirements in households, agriculture, industry, energy sector and need of the environment (Damkjaer & Taylor 2016). Table 1 above visualizes these differentiations.

3.2.3 Advantages/Disadvantages

The advantage of the WSI is the simplicity and ease to apply this assessment, as data is readily available, and its meaning is intuitive and simple to understand (Rijsberman 2006). As already mentioned in the introduction assessments and indicators founded in the 1980s have a rather classical and simple approach, thus they experience criticism for their limitations.

The index does not consider regional differences in the availability of water, as it measures the scarcity on a country level (White 2014). The method also fails in considering whether those water resources are accessible if the resource of freshwater of a country is not yet accessed underground water. It further ignores freshwater supply through desalination plants, which increase the water availability. Also, it does not take into the account the temporal variability or variation of water consumption of different countries and regions. One country may have a way higher or different threshold consumption and another one and very little average consumption, due to culture, economic growth, technological developments lifestyle, or climate conditions (Liu et al.

2017/Matlock 2011, p. 1/White 2014). Matlock (2011, p. 1) further argues that this assessment may under-measure the impact of smaller populations. Another major disadvantage of the Falkenmark Index is that it excludes the quality of the water (Liu et al. 2017). For example, water may be stored up in the underground but may be heavily polluted. (White 2014)

3.2.4 Main target audience

The Falkenmark Indicator or WSI is supposed to be used for entire countries and regions to cover an area (Liu et al. 2017/Matlock 2011, p. 1). Matlock (2011) further argues that the WSI is usually used where data is readily available and that the results of the WSI are easy to understand and intuitive. Large organizations and leading environmental programs use the Water Stress Index, namely the Intergovernmental Panel on Climate Change in their reports. (Nobel Foundation 2007)

3.2.5 Example of application

As mentioned, the WSI or Falkenmark indicator be used for any area or country. Once information as the size of population and water availability is collected, the indicator can account how much water stress there is. For example, the European Environment Agency published an annual water availability per person map of Europe and parts of Asia (figure 6) to visualize the water availability between 1971 and 2000 and a projected map between the years 2070 and 2099. Based on this map, one can see where water stress areas are. (EEA 2011)

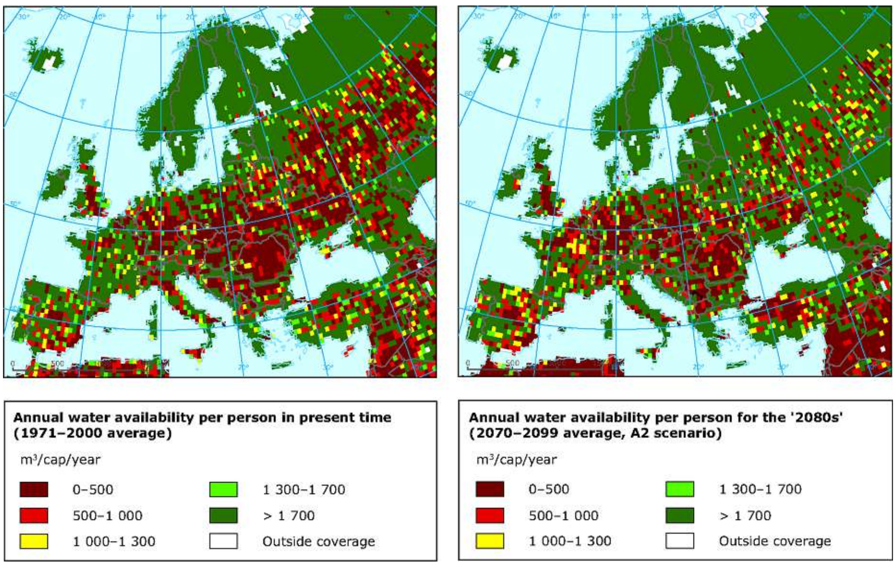

Figure 6: Annual water availability per person (Falkenmark indicator) (EEA 2011)

3.3 Water Poverty Index

3.3.1 History and evolution

The Water Poverty Index (WPI) was originally proposed by Lawrence, Meigh and Sullivan in 2002 (Damkjaer & Taylor 2016/Lawrence et al. 2002/Sullivan 2003). They took the outcomes of the Dublin Conference in 1991, which concluded that effective management of water resources shall be approached with a holistic approach linking social and economic aspects while protecting the natural ecosystem, to establish this index (Matlock 2011, p. 9). As it is stated in the initial research paper:

> *"the purpose of the Water Poverty Index is to express an interdisciplinary measure which links household welfare with water availability and indicates the degree to which water scarcity impacts on human populations"* (Sullivan et al. 2003)

In the initial research paper 147 assessed countries were ranked according to their water poverty (Sullivan et al. 2003). The index was established from a need to develop the use of indicators which examine poverty in different dimensions. This includes areas like food, gender, health, sanitation, and development. It emphasizes the vital connections between water availability and poverty reduction. Sullivan et al. (2003) argues that the WPI is a holistic approach towards the representation of conditions which contribute to water stress on a household and community level. The index pursues to strengthen the participation of poor people in water resource planning and to assist the policy and decision makers in the priority setting within the water sector (Damkjaer & Taylor 2016). Furthermore, it aims to reflect both the physical availability of water, how far the population is served by the water resource and if the ecological integrity is maintained (Rijsberman 2006). Meaning that it differentiates between populations which are water poor and are subject to physical water scarcity and populations with little income, whose supply of water is caused due to economic water scarcity (Stocker 2009, p. 17). Cho et al (2009, p. 258) highlights the potential to determine the linkages between water poverty and other socioeconomic indicators. Cho and Ogwang (2014) define the WPI as

> *„The Water Poverty Index (WPI) is a mathematical data-driven tool for gauging the degree of water-related poverty in a community, region, or country. Several approaches to the development of such an index have been tested, and the five-component WPI developed by Sullivan and her associates is now widely*

accepted, although refinements for more cost-effective application continue.“ (Cho & Ogwang 2014)

Sullivan describes four ways to approach and construct the WPI. The first way, and probably the best-known approach which will also be the focus of this paper, is the composite index approach. Here, Sullivan conceptualized the WPI in three components. Firstly, the water availability, secondly, the access to safe water and sanitation, and thirdly the time factor, which includes the effort to collect domestic water (Cho et al. 2009, p. 258/Sullivan 2002). This was then extended to five components (resources, access, capacity, use and environment) which allowed a more comprehensive composite of the WPI (Cho et al. 2009, p. 258). The following application chapter will outline these components in more detail.

The second method is the gap method. This method considers how much water provision and use deviates from the standard which was predetermined. The standard or basis can be dependent on the ecosystem health, community well-being, human health, and economic welfare. These components set the qualitative or quantitative basis/standard value and are then compared to the current empirical data.

The third method is the matrix approach. This approach helps to keep the WPI easy to understand and combines human welfare and water stress in a two-dimensional matrix. It uses availability and access on one axis and capacity and use on the other to have a quadrant. Figure 7 below illustrates how this can look like.

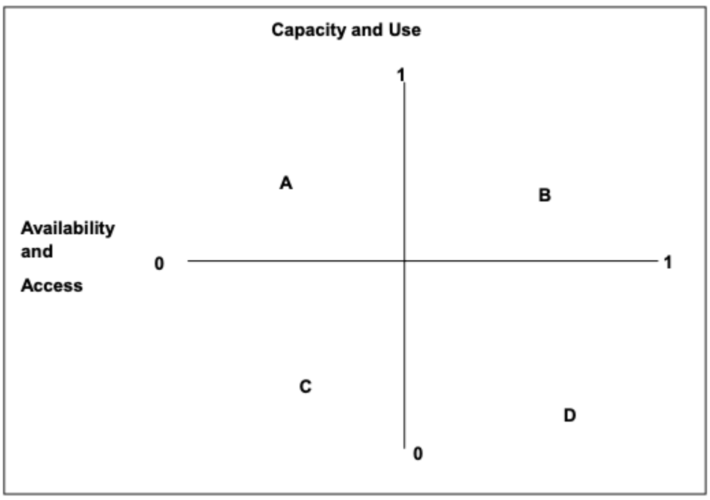

Figure 7: WPI matrix approach (Lawrence et al. 2002)

The fourth approach is a time approach. Time is used as a factor for the purpose of assessing water poverty. The approach follows the principle of how much time is needed per capita to collect a certain amount of water. This value can be then compared to wages and labor time. However, this approach has many weaknesses like the non-consideration of the ecosystem. (Sullivan 2002)

3.3.2 Application

The WPI suggest a relationship between the physical axes of water availability, how easy it is to abstract and the level of welfare of the community. The WPI considers five factors and is seen as a more composite approach (Liu et al. 2017):

1. Resources or water availability
2. Access to water for human use
3. Effectiveness of people's ability to manage water
4. Water use for different purposes
5. Environmental integrity related to water and of ecosystem goods and services from aquatic habitats in the area

Each factor consists of sub-components which provide the data for the factor and are put into relation to each other. Table 2 below visualizes the components and their respective indices. The WPI is then calculated with the weighted average of the five components. The WPI results is between 0 and 100, representing the lowest and the highest level of water poverty. (Liu et al. 2017/Sullivan 2003)

These indicators are then weighted and integrated in an equation, as Damkjaer and Taylor (2016) express in in their research paper:

$$WPI = \frac{\sum_{i=1}^{N} w_i X_i}{\sum_{i=1}^{N} w_i}$$

X_i refers to the respective indicator *i* of the WPI and w_i is the weight which is applied to that indicator *i*. Each indicator consists of several variables. The researchers emphasize that the first component of water availability and resources is derived from the WSI and thus brings along the already mentioned issues. (Damkjaer & Taylor 2016)

Table 2: Contents of the Water Poverty Index (Author's illustration based on Lawrence et al. 2002)

Resources	- internal freshwater flows - external inflows - population
Access	- % population with access to clean water - % population with access to sanitation - % population with access to irrigation adjusted by per capita water resources
Capacity	- ppp per capita income - under-five mortality rates - education enrolment rates - Gini coefficients of income distribution
Use	- domestic water use in litres per day - share of water use by industry and agriculture adjusted by the sector's share of GDP
Environment	indices of: - water quality - water stress (pollution) - environmental regulation and management - informational capacity - biodiversity based on threatened species

There are also criticisms for each category. Stocker (2009) argues that the differences and variations in water resource availability are essential. Especially with the implementation and estimation of precipitation, as it is not considered in the WPI. There is also a need in the WPI to distinguish between urban and rural population areas. For the component access, it can be argued that all these indicators correlate with the GDP and may not be separated. In the area of capacity, Stocker (2009) mentions issues that arise with the indicators which deal with education, capita income and mortality rate as they are based on the UN Development Programs Human Development Report.

The Gini Coefficient can be used for the national assessment, however, is it not required for a localized assessment. In the area of use the base figure of 50 liters per day for developing countries can be criticized as well as the fact that the indicator does not account for the loss of water transfer. For the environment component Stocker argues that with indicators such as water quality and regulation and management capacity the index overcomplicates itself. (Stocker 2009, pp. 22-27)

Cho et al. (2009) even tried to simplify the WPI from the conceptualization of Lawrence et al. of 2000, whereas they focused on principal sub-indexes and the respective weighting. Their results showed that it is questionable to assign equal weights to the five sub-indexes. Their research findings showed that the WPI can be simplified with three sub-indexes, namely access, capacity, and environment. These sub-indexes are unequally weighted. The researchers go even further and argue that the WPI can be so far simplified that it has only two sub-indexes (capacity and environment) with the same weights which would be even more practical. (Cho et al. 2009, p. 266)

3.3.3 Advantages/Disadvantages

The WPI has also different advantages and disadvantages. A mayor advantage is its comprehensiveness (Rijsberman 2006). Disadvantages of the WPI are further its complexity and lack of intuitive understanding. Moreover, it lacks in information for some of the factors which are needed to set up the indicator on a bigger scale (Rijsberman 2006). Stocker (2009, pp. 24-27) identifies various issues within the index and argues that it may be even too comprehensive and make itself too complicated.

Another issue which arose with the WPI is the aspect of standardized weights which are applied to each of the variables/components. These weighting factors are crucial for the index. The problem is how the basis of it can be elaborated, and how far the assumptions of these weights are true for communities, ecosystems, cultures, and economies. (Matlock 2011, p. 9)

3.3.4 Main target audience

One target audience are policy and decision makers in the field of water resource management. It should assist people in their decisions, so researchers found that this indicator is a more political than statistical indicator. The WPI should help governments, authorities and people dealing with the formulation of water policies to receive an overview of the connection between economical and physical water poverty. (Damkjaer & Taylor 2016)

As the WPI is addressed to measure the water poverty on a community and household level, it has been mostly applied so far at the community level in a few countries (Damkjaer & Taylor 2016/Rijsberman 2006). It may be also used for a community, regional, national, and international comparison of water circumstances, which however contradicts some researchers' opinions with rising issues about the standardized weighting. (Cho et al. 2009, p. 258)

3.3.5 Example of application

As mentioned, Lawrence et al. in 2002 ranked 147 countries regarding their water poverty. Most of the countries in the top half are either developed or richer developing countries. According to this study were Finland (WPI = 78) and Canada (WPI = 77,7) the first and second ranked countries. Haiti (WPI = 35,1) and Niger (WPI 35,2) were the last and second last countries. These also count as less developed countries. Exceptions are Guyana (WPI = 75,8) and Suriname (WPI = 74,9), as non-developed countries, with a high score. (Cho et al. 2009, p. 258/Lawrence et al. 2002). In the following figure 8 provides an overview of the findings of the study.

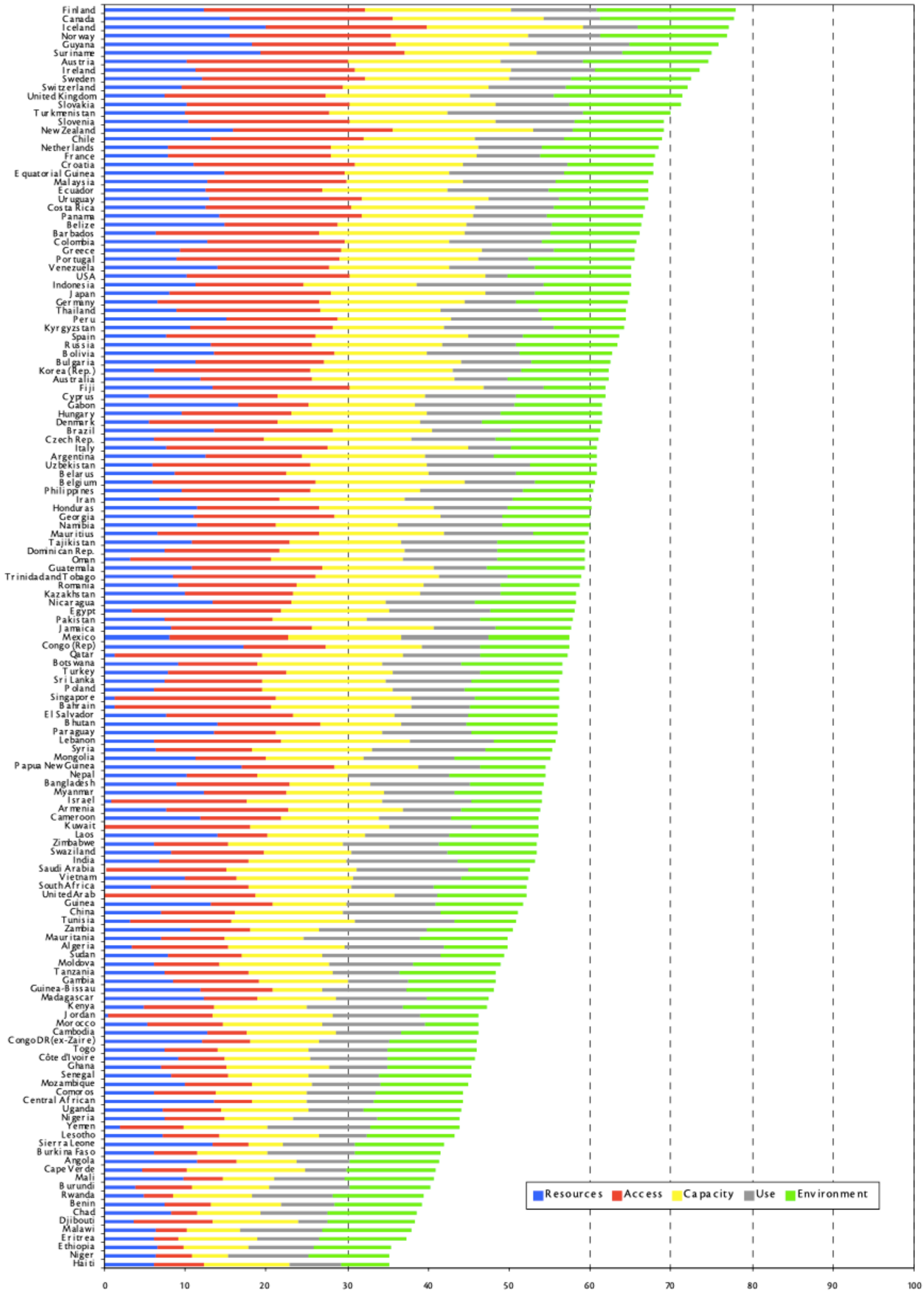

Figure 8: National values for the Water Poverty Index (Lawrence et al. 2002, p. 11)

3.4 Availability/Consumption Ratio

3.4.1 History and evolution

The universal and fixed water demand presumption, which is embedded for example in the Water Stress Index, was questioned by water resource assessments which especially investigated the freshwater resources. These assessments incorporated demand on a spatial and cross-sectoral level. Domestic, industrial and agriculture sources have been identified as the three main consumer sectors of water (Damkjaer & Taylor 2017). A major analysis on the supply and demand approach has been done by a research team in the State Hydrological Institute in St. Petersburg, Russia. The team was led by Professor Shiklomanov and investigated national annual renewable water availability with assessments of national water demand in the three sectors of domestic, industrial and agriculture (Rijsberman 2006). The most common equation for this approach is: $\frac{\sum D\ I\ A}{Q}$ whereas *D* stands or domestic, *I* for industrial, *A* for agriculture and *Q* for the quantity supply. (Damkjaer & Taylor 2017)

The availability and consumption ratio occurs in different forms and under different names. The factor of availability usually consists of the available renewable water resources. Water use can typically refer to either water consumption or water withdrawals, which differentiates the different assessments. Water consumptions measures the amount of water which is taken out of lakes, groundwater, rivers, or atmospheric evaporated water. Whereas water withdrawal concerns the amount of water which is withdrawn from lakes, groundwater or rivers including parts which are returned through leakage or return flows. (Liu et al. 2017)

Different names found in the literature for similar water available-use ratios or availability to consumption ratio were, inter alia, “the ratio of water withdrawals for human use to total renewable water resources”, “Water Use to Availability Ratio”, “Withdrawal-to-availability ratio (WTA)”, “Water Resources Vulnerability Index”, or “Criticality Ratio”. These similar ratios suggest that a country faces scarce water if its annual water withdrawals are between 20% (0,2) and 40% (0,4) of annual supply. A country faces severe water scarcity if the withdrawal exceeds 40% of the supply. (Damkjaer & Taylor 2017/Liu et al. 2017/Rijsberman 2006)

However as mentioned in the introduction chapter this paper will focus mainly on the “Availability/Consumption Ratio” (AVCOR), which was developed by Stocker in 2009. Stocker based this approach on the Water Poverty Index to incorporate hydrological data and socio-economic variables. Based on the literature research on Scopus, a database of abstracts and citation for literature, no more research has been done on the AVCOR and this assessment seems to be a rather unknown assessment method.

3.4.2 Application

Stocker approached the AVCOR with an integrated approach to include parameters and data into this new index. Figure 9 below visualizes the different parameters used in the index. The part of population and area, as the foundation with the data of availability and consumption. (Stocker 2009, p. 28)

General parameters about population and the area are central to the index. This data defines the system area and its boundaries which is the basis of the index. In her research, Stocker used several data resources for this. As an example, FAO's Aquastat data provides useful information for this section. For the categorization of income, data from the World Bank's example is useful. (Stocker 2009, pp. 28-30)

The next parameters are dealing with the water availability within the defined system area. The index attributes the water availability to two sources (internal renewable water resources and total renewable water resources) as defined by the Asia Development Bank. Stocker (2009) outlines several resources but highlights the option of single usages of the parameters. The system input of freshwater resources can be integrated through either internal and external water flows, the precipitation values in each time or the total discharge from a river or different water resource of the area.

Stocker argues that areas with no external water input may focus on precipitation, large areas on the external water flow and small areas next to a river use the calculated discharge. For drinking water an assumption between 0 and 20 percent is made. The index is then calculated in the respective area with calculations on precipitation input, calculation on system input, and on runoff. (Stocker 2009, pp. 32-41)

The differentiation between the rural and urban level on the consumption of water is crucial. This should distinguish between the population which is affected by water scarcity. Stocker leaves it to the applicant of the index to decide who accounts for which population group. Relevant factors for the consumption are the average domestic water consumption with a loss coefficient, which is estimated at around 25%. This is accumulated as consumption pattern. Important to mention here is that this factor may be more important in some cases, and data may be extracted from different statistical offices. The second bigger part is the use for agriculture which consists of the area used for agriculture, with data from the FAO and the water withdrawal from that sector. (Stocker 2009, pp. 41-47)

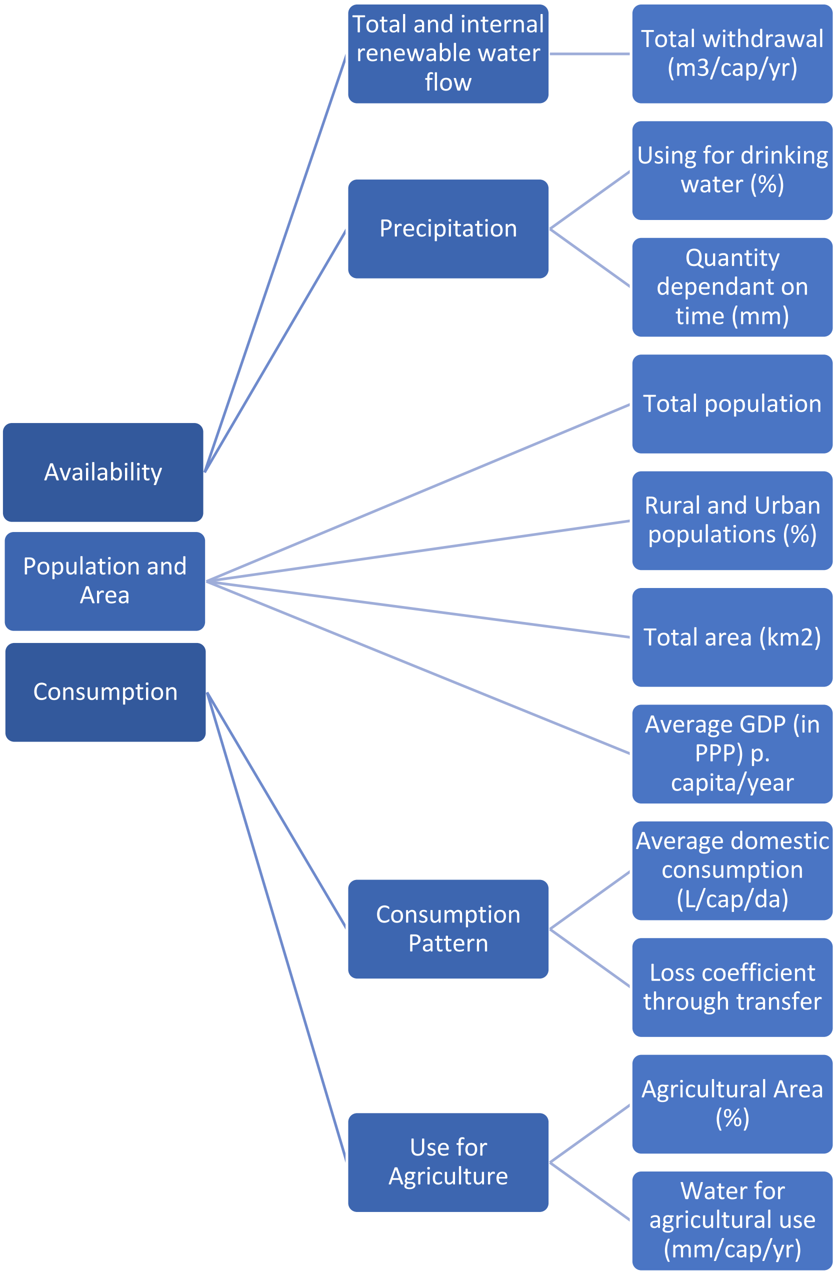

Figure 9: Flow chart of parameter in the AVCOR (Author's illustration based on Stocker 2009, p. 31)

If the final AVCOR figure is less than 1, it suggests that there is water scarcity for the individuals. If it equals 1 the availability is equal to the consumption. If it is higher there is no water scarcity. The final AVCOR ratio will be then weighted with the GDP (in PPP/cap/year) converted into U.S. Dollars, as provided by the World Bank Atlas method. The GDP should be corrected regarding the difference between rural and urban population. If the corrected GDP is lower than the AVCOR, a country and its population face eventual water scarcity. A GDP may be lower for income weak countries. The higher the difference, the more capable a country is to adapt to water unavailability. Further the ratio differentiates between income categories low-, low-middle-, upper-middle-, and high-income countries. (Stocker 2009, p. 30, pp. 47-50)

3.4.3 Advantages/Disadvantages

Liu et al. (2017) highlights that a major disadvantage of the availability/consumption ratio is that the consumption is normally lower than the withdrawal, which results in an improbable assessment of water scarcity. Therefore, it depends on how the consumption, or water usage is measured in the ratio. Another important aspect is that it does not differentiate how much of the consumed water can potentially be recycled through return flows. Also, it disregards how much a society may adapt to the situation of water scarcity. (Rijsberman 2006)

In regard to the threshold at 40% for water scarcity, one must take into consideration the issues of consumption and regional differences depending on natural, social-economic and technical conditions (Liu et al. 2017). Stocker argues that the AVCOR avoids unnecessary assumptions, as mentioned in the WPI. (Stocker 2009, p. 79)

3.4.4 Main target audience

The index is applicable in every area depending on the size of the system border. The researcher finds the AVCOR a

> *"useful tool on which policymakers may base their decisions pertaining to water allocation and water resource management in order to alleviate water stress and poverty to specific population groups"* (Stocker 2009, p. 3)

This highlights that this assessment can be used to make decisions in water resource management for policy makers. Further, the availability to consumption ratio assesses water scarcity on a spatial or global scale with high spatial resolutions. (Liu et al. 2017)

3.4.5 Example of application

In her research paper, Stocker (2009) researched a case study around the Asia-Pacific region, using Australia as a case study with additional application of the index for selected countries in Asia. Figure 10 below shows the case study of Australia. The results are divided according to Australia's different states. The figure compares it also to the corrected GDP. Here, the majority of Australian states face water scarcity, but the difference to the GDP shows that all states have a capacity to adapt to water scarcity. Only three states (Australian Capital Territory, Queensland, and Victoria) face no water scarcity. (Stocker 2009, p. 60)

State	AVCOR (Average)	Corrected by GDP (Average)
Tasmania	0.66	2.00
South Australia	0.69	1.81
Western Australia	0.62	2.16
Northern Territory	0.64	1.97
Queensland	3.47	10.93
New South Wales	0.74	2.27
Victoria	2.36	6.75
Australian Capital Territory	1.17	3.56

Figure 10: AVCOR index and GDP for the Australian states (Stocker 2009, p. 60)

3.5 Household Survey

3.5.1 History and evolution

Household Surveys are one of the most important data sources for different demographic and socioeconomic statistics (Khan et al. 2017, p. 2). They are even more important in countries with less capacities, administrative systems, and access to information (Development Initiatives 2017). These surveys can be done on many different topics. Also, many different topics can be covered by one Household Survey, a so called “multi-topic-survey”. (Grosh & Glewwe, 2000, p. 5)

The first systematic collection of information from households began over 200 years ago. In the late 18th century, the first data collection happened in England on family budgets. In the following decades, data collection started in other countries like Belgium, the United States and Prussia with a focus on the poor. By the mid 19th century generalizations of these surveys began and in the 1920s the statistical theory was founded, which now supports the modern survey methods. After World War 2, these surveys started to be established on a nationwide scale, including developing countries. With the support of computers, the collection and analysis of data expanded rapidly in developed and developing countries. (Grosh & Glewwe 2000, p. 5)

Since the 1970s several major international programs have been set up to promote the collection of data through Household Surveys (Grosh & Glewwe 2000, p. 6). In general, there are three major international Household Survey programs.

First, the Multiple Indicator Cluster Surveys (MICS) was developed by the UN Children's Fund (UNICEF) as an international Household Survey program in the 1990s. In order to monitor the 1990 World Summit for Children goals, MICS was created. Since then, around 300 surveys have been conducted in more than 100 countries. In addition to UNICEF, other UN agencies and partners support and finance the MICS. MICS are carried out usually by national governments with support from the UNICEF teams and in rounds of which six have happened so far since the mid 90s. UNICEF and the WHO have also established a Joint Monitoring Program (JMP) on Water Supply and Sanitation. The JMP established a global database for research and benchmarking (Batram et al. 2014/Development Initiatives 2017)

The second major program is the Demographic and Health Surveys (DHS). It is a more national focused Household Survey, carried out usually every five years, and developed by the United States Agency for International Development (USAID) in the 1980s. The program was based on the World Fertility Survey and Contraceptive Prevalence Surveys in the 1970s and since then, in less than 100 countries over 300 surveys have been done. The DHS is mainly funded and supported by the government of the United States of America. (Development Initiatives 2017)

The third program is the Living Standards Measurement Study (LSMS) which was developed by the World Bank's Development Research Group in the 1980s. As part of the World Bank's Survey Group, it has conducted over 100 surveys in around 40 countries. The LSMS is funded and implemented by national statistical offices in cooperation with the World Bank. LSMS, also known as "Household Income and Expenditure Surveys", is customized to satisfy the need of the respective country. A new component of the LSMS focuses on agriculture, which is also important for the assessment of water (Development Initiatives 2017). The LSMS questionnaires always record information on a variety of dimensions, including housing, water and sanitation, water sources. (Grosh & Glewwe 2000, p. 12, p. 29)

A typical Household Survey collects data on a national sample of households. The sample sizes vary and depend on the purpose of the survey, and the size of the population. Sample sizes of 10.000 are recently carried out, which would correlate to a sampling fraction of 1:500. (Deaton 2018, p. 10)

During the time of the MDGs the WHO and UNICEF's JMP for Water Supply and Sanitation set global standards for monitoring the progress on water, sanitation, and hygiene (WASH) (Khan et al. 2017, p. 2). This included a categorization of drinking water and sanitation coverage according to the use of different types of usage as drinking water sanitation and/or hygiene. The JMP provided core questions on water, sanitation, and hygiene (WASH). An example of these questions is the following (Batram et al. 2014):

- What is the main source of drinking water for members of your household?
- Where is that water source located?
- How long does it take to go there, get water, and come back?
- Who usually goes to this source to collect the water for your household?
- Do you do anything to the water to make it safer to drink?
- What do you usually do to make the water safer to drink?

The final assessment of the MDGs showed that 84% of data on WASH came from Household Surveys. (Khan et al. 2017, p. 2)

3.5.2 Application

To assess water demand, a quantitative Household Survey offers the information of water access related to an entire region or country. Important for the Household Survey is that a representative sample of population is collected and that clear definitions are established. (Roger 2010, p. 68)

National representative Household Surveys are undertaken on a regular basis in over 100 countries. They are usually conducted by national statistic offices with support of international organizations. They usually undertake DHS, MICS or LSMS. A decision is made by national governments in consultations with the World Bank, USAID, or UNICEF. To conduct surveys such as a DHS or MICS, countries are divided into several primary sampling units. Within these units randomly selected households are surveyed. Stratification on demography and geography are also made. Usually, one person of each household is then questioned with an interview lasting around one hour. Depending on the program of the survey, usually only a small part of the core questions is dedicated to water and sanitation. (Bartram et al. 2014)

An important factor of the Household Survey is the shift from provider to user orientation. The JMP found out in several studies that national data and data from Household Surveys can differ a lot. However, it is difficult to generalize this assumption. (Bartram et al. 2014)

3.5.3 Advantages/Disadvantages

To properly represent the population, Household Surveys need accurate and up-to-date census information about the researched population. Census data is not available in every country and rely on biased information for sampling. Also, do some DHS and MICS represent only a selected subnational or regional area, thus creating limitations when it comes to compare the data. (Development Initiatives 2017)

Another disadvantage of Household Surveys is the time factor. The analysis of the data can take up to years after the survey has been completed. This may cause outdated data related to the respective researched area (Development Initiatives 2017). Also, do Household Surveys include only household data, meaning that homeless and rough sleeping people, refugees, internally displaced persons, nomads and people in prisons or orphanages are excluded. (Development Initiatives 2017)

Roger (2010, pp. 158-159) highlights several advantages and disadvantages of the Household Survey for assessing water demand. He underlines possible not qualitative results, and lacking background information, such as potentials failures in the sampling method. Also, the Household Survey includes the risk of poor-quality responses, which may depend on the interviewee or the interviewer. This means that well trained staff is needed. Further, Roger emphasizes the key advantage of the Household Survey, as it can provide the most detailed information of a household. Specifically, for demand and supply information of consumption can be made and compared, such as the willingness to pay and resulting adaption of water supply. (Roger 2010, pp. 163-166)

Nauges and Whittington (2010) highlight issues in the collection of data and summarize them in seven key points:

1. Surveys should be conducted in more than one region to ensure cross sectional comparison
2. All possible water resources of a household should be elaborated, not only the ones which are being used by that household
3. For households which have no connection to a water pipe, information of the person collecting water should be gathered

4. The household's knowledge about consumption and expenditure should be collected
5. Seasonality of water demand must be regarded
6. Permanent and non-permanent household members should be included in a Household Survey
7. The date of access to water infrastructure by the user shall be collected, to collect knowledge whether the acquisition of new infrastructure influences the water use

3.5.4 Main target audience

The main target audience for the Household Survey are various international organizations such as the UN and its institutions, the WHO, or the World Bank. These international institutions support the national governments and their national statistic offices with technical and financial support. The Household Surveys are used for a regional or national assessment of the water demand. (Batram et al. 2014)

3.5.5 Example of application

As an example for the Household Survey a research from Basani et al. in 2010 on the determinants of water connection and water consumption in Cambodia will be given in this chapter. The researchers used cross-sectoral household level data from seven provincial towns and one district in Cambodia. In each surveyed location, 50 urban households were randomly selected and questioned through a Household Survey. Each household was either served by a public or private utility.

In total, 451 connected households and 375 not connected households responded. A catalogue of 186 questions included 200 variables. These variables include information on demographics, water service provider, cost of service and connection, quality of water and number of household members. Water consumption was a key dependent variable and showed that the sample average monthly consumptions are 72 liters per day of the connected household. This result is comparable to the average consumption per person of the urban and peri-urban population used by the World Bank for economic analyses. The results showed also that number of households with no access to water infrastructure can be reduced by decreasing the price of the connection fee. (Basani et al. 2010)

3.6 Water Evaluation and Planning Model

3.6.1 History and evolution

The Water Evaluation and Planning Model (WEAP) is a software tool for integrated water resources planning and was developed in 1988 by the Tellus Institute and Stockholm Environment Institute's (SEI) US Center with many contributions from various researchers. Since the beginning, WEAP is constantly developed and supported by the SEI and the Boston center (SEI-Boston). Many organizations have contributed funding for the development of WEAP, such as the UN, World Bank, USAID, the EU Global Water Initiative, and various national governmental departments around the globe. Since its launch it has been applied in water assessments of multiple countries all round the world. (SEI 2021)

As the SEI highlights on their website, was it developed:

> *"with the aim to be a flexible, integrated, and transparent planning tool for evaluating the sustainability of current water demand and supply patterns and exploring alternative long-range scenarios."* (SEI 2021)

It is a user-friendly software tool with an integrated approach to water resources planning. WEAP tries to assist rather than substitute for planners. WEAP incorporates an integrated approach to water development considering the demand-side management, ecosystem protection and its preservation and quality of water. It puts water use and water supply topics on an equal approach and compares their different influences. WEAP also simulates both the natural and engineered components of water systems. For example, natural components are runoffs, baseflows and engineered components are anthropogenic impacts like reservoirs and groundwater pumping. (SEI 2021)

Raskin et al. in 1992 were the first applying WEAP to a study on the Aral Sea. The first version of WEAP had however several limitations, such as an allocation scheme that treated rivers independently, prioritized demands on upstream over downstream sites, and in surface water allocations the least priority was given to demand sites which preferred groundwater to surface water. A new update of the version "WEAP21" introduced relevant developments with a modern graphic user interface. It also introduced an algorithm to solve issues with water allocations and integrated hydrologic sub-modules which considered the rainfall runoff, an alluvial groundwater model and a stream water quality model. (Yates et al. 2005)

3.6.2 Application

WEAP is a computer-based system. WEAP offers various tools, such as a "water balance database" to maintain information around water demand and supply. A "scenario generation tool", which simulates various details about for example the water demand, supply, streamflow, storage, water quality etc. And a "policy analysis tool" to evaluate water development and management options and the different uses of systems for water SEI 2021). The following chapter will try to summarize how WEAP works and is applied. Due to WEAP's complexity and the limitation of this paper, chapter 3.6 will only briefly touch on WEAP.

Generally, the application of WEAP include the following steps as outlined in the WEAP Handbook provided by the SEI (SEI 2021).

- *"Study definition:* The time frame, spatial boundaries, system components, and configuration of the problem are established.
- *Current accounts:* A snapshot of actual water demand, pollution loads, resources and supplies for the system are developed. This can be viewed as a calibration step in the development of an application.
- *Scenarios:* A set of alternative assumptions about future impacts of policies, costs, and climate, for example, on water demand, supply, hydrology, and pollution can be explored. (Possible scenario opportunities are presented in the next section.)
- *Evaluation:* The scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables." (SEI 2021)

The basic principle of WEAP for a water balance can be variously applied as on municipal and agricultural systems, individual watersheds, and transboundary river basin systems. The program can simulate various natural and engineered components (e.g. of these water systems. These simulations can be of natural hydrological processes for water availability assessments or simulations of anthropogenic activities for the human impact of the water use by assessing the consumption and demand. (SEI 2021) These simulations are constructed as a set of scenarios which can be assessed over the period of a day, a week, a month, a season or yearly up to 100 years. (Yates et al. 2005)

The user enters different information into the system. These are the various supply sources (e.g., groundwater, reservoirs, desalination plants, rivers, creeks etc.), the withdrawal, transmission, and wastewater facilities, the water demands, how much pollution is generated and what the ecosystem requires. The inserted data can be easily customized to adapt to the data availability of a particular system. (SEI 2021)

Usually, the model within WEAP is done by making the program to simulate a recent “baseline” year, or so called “Current Accounts”. Within this baseline year the water availability and demand are defined. This year is then used to simulate different scenarios to assess how different developments impacted the observed area and which management option there might be (Arranz & McCartney 2007, p. 2). These scenarios analyses are central to WEAP and are realistic “what if” questions. These “what if” questions can look as listed in the following (SEI 2021):

- What if population growth and economic development patterns change?
- What if groundwater is more fully exploited?
- What if water conservation is introduced?
- What if ecosystem requirements are tightened?
- What if a water recycling program is implemented?
- What if a more efficient irrigation technique is implemented?
- What if the mix of agricultural crops changes?
- What if climate change alters demand and supplies?

WEAP includes a geo-information-system (GIS) based graphical interface which helps to construct, view, and modify the overserved area in a map format. This happens via “drag and drop” elements added to the system (SEI 2021). Figure 11 visualizes a sample screen from WEAP.

This GIS tools can configure water systems and system elements (like rivers, wastewater treatments plants etc.) can be positioned. The map can be extended by adding other GIS vector or raster to visualize different backgrounds. (SEI 2021)

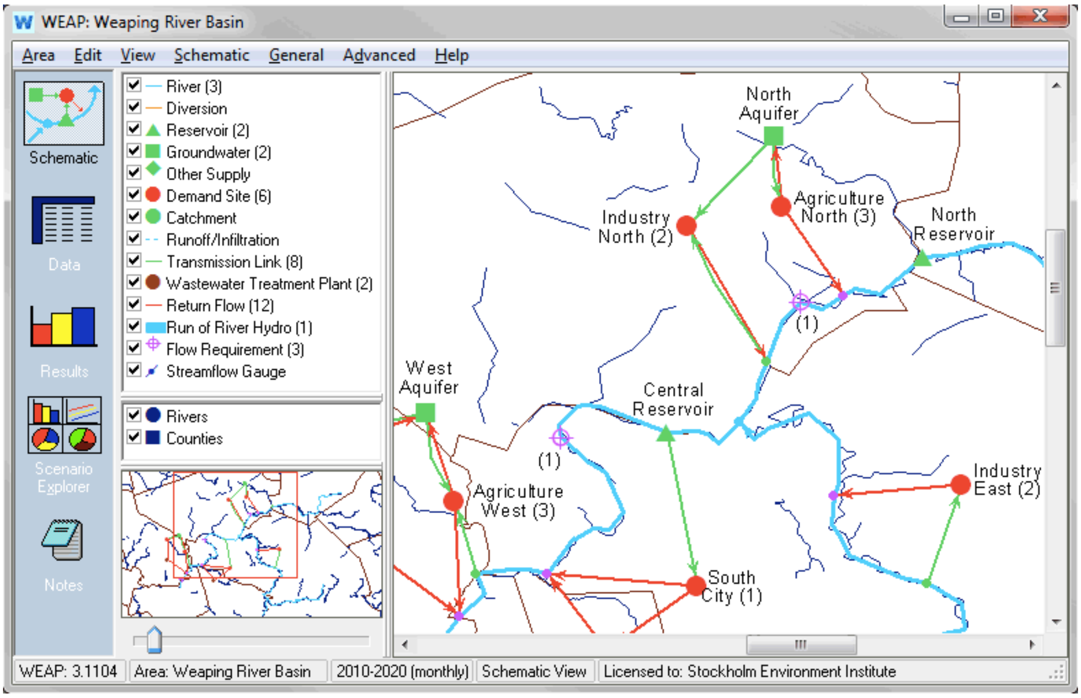

Figure 11: Sample screen of WEAP (SEI 2021)

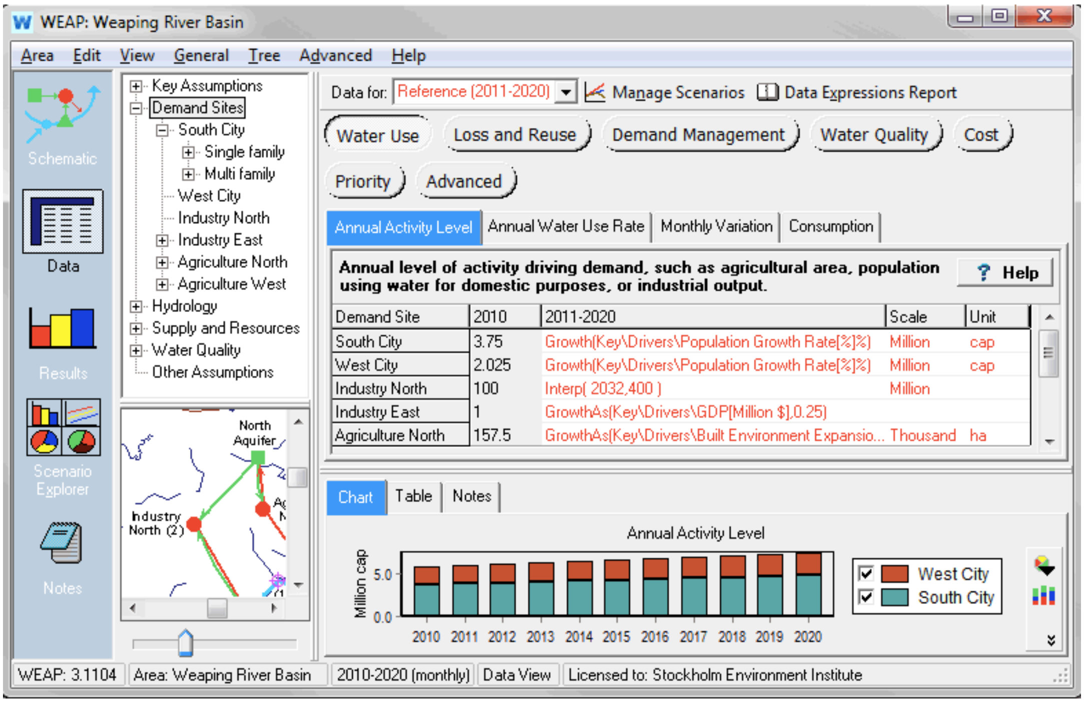

Figure 12: Model building in WEAP (SEI 2021)

Once the schematic mapping is done, data can be entered. The data model building tools create variables and relationships (see figure 12), assumptions and projections by also using mathematical expressions. Excel is used here to im- and export data. The results are offered in many ways. WEAP can display detailed results in graphs, tables and on the map with animated viewing options. Further, on the left side of the screen the scenario explorer is used for the already mentioned scenarios.

3.6.3 Advantages/Disadvantages

As of its complexity and the therefore evolved operating rules for individual water resource planning, applicants of WEAP need intense training on how to use the program. These trainings are offered on regular basis by the SEI (SEI 2021/Yates et al. 2005). However, once trained and introduced to the program, WEAP appears to be a very useful, easy to use and adaptive program. (Yates et al. 2005)

Other advantages of WEAP are its graphical user interface, an informative user manual, a built-in calibration tool and it is free for NGOs and governments of developing countries. On the other hand, is WEAP is not applicable for detailed design and the data needs to be imported. Also, the program cannot model reservoir water quality. (SEI 2021)

3.6.4 Main target audience

WEAP is widely used for studies and research on climate change adaption and has been used by multiple researchers and planners of various organizations (SEI 2021). As it offers alternative development and management options is a very useful tool for policy- and decision makers.

3.6.5 Example of application

As an example for the WEAP the Small Reservoirs Project can be mentioned. The full title of the project is "Planning and evaluating ensembles of small, multi-purpose reservoirs for the improvement of smallholder livelihoods and food security: tools and procedures." The projects include three water systems, namely the Sao Francisco River Basin in Brazil, the Volta River Basin in Ghana, and the Limpopo River Basin in Southern Africa. The project looked at planning and evaluating small, multi-purpose reservoirs for the improvement of food security and the livelihood of smallholders. Small multi-purpose reservoirs are crucial for rural communities in Africa and Latin America for their household, livestock, and irrigation (SEI 2021). The duration of the project lasted four years. The project collected socio-economic, institutional, ecological, health, and physical data of the areas. WEAP was used as the water use modeling program in the basins. Other selected applications can be found on the website of WEAP21. (Small Reservoirs Project 2021)

4 Evaluation of assessments

4.1 Introduction

Based on the in-depth research of the scientific literature, it was determined that no evaluation of this type had been conducted to date. However, some researchers have provided overviews of different assessments. Found and used in this paper are Matlock (2011), Liu et al. (2017), Damkjaer and Taylor (2016), Petit (2016), and Rijsberman (2005).

Therefore, against the background of this theoretical discussion of the assessment tools mentioned above, the following five dimensions were developed. They seem to be relevant for the evaluation of the presented assessments with regards to current scientific but also political developments around water scarcity. The dimensions are the following:

1. Applicability in natural disasters
2. Consideration of water quality standards
3. IT-support
4. Academia Use
5. Policy makers use

Chapter 4.2 discusses each dimension concerning the analyzed assessments. Based on theoretical findings, evaluations of the assessments will be made, whereas chapter 4.26 will provide an overview.

4.2 Dimensions

4.2.1 Applicability in crises situations

The first dimension will evaluate whether and how the analyzed assessments can be applied after water-related natural disasters. Between 2001 and 2018 almost 75% of all natural-disasters were water-related. 5% of natural disasters were droughts. Water-related disasters can be floods, landslides, tsunamis, storms, heat waves, cold spells, droughts, and water borne disease outbreaks. They can have direct (e.g. infrastructure) and indirect impacts (e.g. loss in livelihood). Disaster risk reduction strategies are now globally in focus (UN Water 2021).

The assessments are evaluated based on how easy and fast they can be applied to areas which have been affected by water-related natural disasters. The evaluation is based on the analyzed literature used for each assessment.

The first assessment, the WSI, is a simple and fast applicable assessment. After an area is hit by a water-related natural disaster and water supply and demand are changed, the WSI can be rapidly applied to evaluate an area under the new circumstances once information about the new water situation is available. The WPI is recognized to be in a similar situation as the WSI. It may be more complex to gather all the information needed, but the WPI offers flexibility related to which exact indicators are used in the final calculation. Additionally, water-related natural disasters do not affect all factors of the WPI. Thus, it is applicable after a natural disaster. In similar lines as the WPI, the AVCOR is seen as an assessment which can be applied after natural disasters. Here, access to information about the changed circumstances of water demand and supply is also key to calculate the AVCOR.

Household Surveys are a long ongoing process and complicated to perform. Because of the much work involved and the interview-based process, Household Surveys are not considered to be quickly applicable after water-related natural disasters. Of course, one can argue that Household Surveys might bring a first insight of the current water status, however, is it difficult to apply few brief Household Surveys on a large scale for an entire area. Due to its complexity and computer-based system WEAP is probably the best assessment to be applied after natural disasters. Also, it can provide future scenarios how situations can evolve and what is needed to mitigate the effects of the disaster.

4.2.2 Consideration of water quality standards

The dimension "consideration of water quality standards", evaluates whether an assessment acknowledges the aspect of the water quality. As outlined in chapter 2, there are water quality guidelines and standards all around the globe. These standards are crucial in the aspect of sustainable water management. Already highlighted by Liu et al. (2017) the easy approach of the WSI brings along a major downside as it excludes the quality of water. Therefore, it is not seen as an assessment which considers water quality standards.

The WPI consists of five factors. The fifth factor of environmental integrity deals with not only the protection of the environment but also the quality of water. Based on this, the WPI is considered to regard water quality standards. Although the AVCOR is based on the WPI, it does not consider the quality of water in its approach. It primarily looks at the

total and internal renewable water flow and the precipitation. However, it does not mention the aspect of water quality standards in its calculation and is hence not considered as an assessment which recognizes water quality standards.
Household Surveys can include and exclude the aspect of water quality. Depending on the type of survey and how much they are designed on a multi topic level they are, they can include aspects of water quality. As most of the surveys are done in developing countries it is assumed that most of the conducted surveys include questions around water quality. Consequently, are Household Surveys considered to be assessments including water quality standards. The WEAP approach specifically includes the status of water quality in the section of “current accounts”. This section is used to create baselines years on which the scenarios are based. For this reason, it is also seen to consider quality standards.

4.2.3 IT-support

The dimension of IT support should evaluate if an assessment is based on a computer system or is supported via IT. Hence, most applications are now computer supported and there may be different argumentation of what it means to be IT supported. Based on the analyzes of the assessments this section will discuss whether an assessment is IT supported or not.

The WSI is identified through its simplicity and the setting of threshold in regard to population and the availability of water. Thus, it sets thresholds and does not require any further support of IT. Hence, it is not considered as an IT supported assessment. Much information for the WPI is derived via computers and IT systems. As it considers many different factors with socio-economic backgrounds, the WPI is a complex assessment. However, is there no IT system which collects and summarizes all the data. The AVCOR can be seen in similar lines as the WPI and WSI. It certainly derives information for its calculation from IT systems but has no computer system itself to be calculated. Only Stocker (2009) outlines in her research an excel sheet for the calculation. Thus, it is not considered as an IT supported assessment. Household surveys have a long history and have been existing even before the age of computers. The collection of household data is mostly done via interviews with pencil and paper. The analysis is certainly done via statistical programs. However, based on the research of this paper, there is no specific Household Survey program, and it is therefore also not considered as an IT supported system.

WEAP seems to be, out the five analyzed assessments, the most obvious IT supported tool. WEAP is solely available via a Windows based application. The tool itself is user friendly and scenarios can be made within a very short time frame. Thus, WEAP is considered as an IT supported tool.

4.2.4 *Academia use*

In order to evaluate the usage in academia of the respective assessments, the platform Scopus[1] will be used. Scopus is one of the largest abstracts and citation database of peer-reviewed literature. Here, search terms for each assessment will be used to search for the total document results. The search was done within article title, abstract and keywords in May 2021. Table 3 below shows the different assessments with their respective search terms used in Scopus and the total number of documents.

Table 3: Number of documents for each assessment in Scopus (Author's illustration 2021)

Assessment	Search terms	Total # of documents
WSI	"Water Stress Index" and "Falkenmark Index"	914
WPI	"Water Poverty Index"	113
AVCOR	"Availability to consumption ratio" and "AVCOR"	0
Household Survey	"Household Survey" and "Water"	1414
WEAP	"Water evaluation and planning model" or "WEAP"	407

The term "water" was added to the search for the Household Survey. Running a search only on "Household Survey" would have given a result over 17.000 results and would have included all other different Household Surveys. Due to the limitation of this paper, the term "water" is considered to limit the search on Household Surveys about water.

Zero documents have been found for the AVCOR. The reason for this is that the AVCOR founded by Stocker in 2009, is not commonly used anywhere but by the researcher. However, it must be mentioned that the AVCOR is a variation of a common ratio comparing the availability and the consumption. If search terms were added like "Withdrawal-to-availability ratio", "Water Resources Vulnerability Index", or "Criticality

[1] Retrieved from www.scopus.com

Ratio", as mentioned in chapter 3.4.1, the total number of documents is around a mid-four-digit number. Thus, all assessments, but the AVCOR, are considered to be used in academia.

4.2.5 Policymakers use

The dimension of policymakers use considers whether an assessment is usable for policy and decision makers or not. Especially, the information and result derived from the water demand and availability assessment will be the key factor. To say if an assessment is used by policy makers, the theoretical research based on the literature will therefore provide this information.

The WSI is a very broadly and widely used indicator. Due to its simplicity and broad application area, it can be used by policy makers. As the Nobel Foundation in 2007 outlines, even the Intergovernmental Panel on Climate Change uses this indicator with regards to the thresholds for water scarcity. Therefore, the WSI is considered as an assessment which is used by policy and decision makers. The WPI is especially made for policy and decision makers as outlined by researchers as Damkjaer and Taylor in 2016. As it is based on the outcomes of the Dublin Conference it connects water management with social and economic aspects, especially about poverty reduction, and is therefore very useful for water politics and decisions.

The AVCOR, developed by Stocker in 2009, highlights various times its capability and usefulness for policy and decision makers. As a developed index of the WPI in combination with a simple availability and consumption ratio, it provides useful information for water allocation and water resource management for water stress. However, as it is not used by any other institution the AVCOR is not considered as an assessment used by policy makers.

The Household Surveys under the topic of water provide direct information from a community and household level. Due to the flexibility of what a Household Survey can cover (demand, availability, quality, willingness-to-pay, etc.), policy and decision makers will receive a broad overview of what policy implications are needed. Further, as of the support of various international organizations (e.g. World Bank, UN, etc.) it is therefore also considered as an assessment used by policy and decision makers.

WEAP as a complex computer-based tool, is also seen to be used by policy and decision makers. The SEI offers its application free of charge to NGOs, research and university institutes and governments of developing countries. The scenario tool offers developments of a water system and what managements options there are. Thus, it is also considered as an assessment for policy and decisions makers.

Due to the limitation of this paper, only the information derived from the literature will be used in the evaluation, however there is potential for empirical research in cooperation with governments.

4.2.6 Overview of dimensions

Table 4 below summarizes all the different findings of the assessment in the respective dimension. The "x" marks if an assessment fulfils the defined criteria for each dimension. The evaluation of the assessment in the different dimensions, which are in this paper considered to be important for the assessments, based on current political and scientific developments, also underlines the differences and commonalities of the assessments. After water related natural disasters, the assessments WSI, WPI, AVCOR and WEAP may be applied. In the dimension, whether water quality standards are considered the WPI, Household Surveys and WEAP stand out. Only WEAP is considered in this paper as an IT supported assessment. All assessments (WSI, WPI, Household Surveys and WEAP), except AVCOR, are considered in this paper to be used in academia, based on the Scopus research, and to be used by policy and decision makers.

Table 4: Overview of the dimensions and assessments (Author's illustration 2021)

	Natural disasters	Water quality	IT support	Academia use	Policy maker use
WSI	x			x	x
WPI	x	x		x	x
AVCOR	x				
Household		x		x	x
WEAP	x	x	x	x	x

5 Summary

Sustainable and integrated water resource management is key for adapting the issue of water scarcity. More and more regions on planet earth suffer from water scarcity. Several UN institutions strongly empathize the increase of water consumption in the future for agriculture and industry and predict that by 2030 almost 40% of the world's population will face water difficulties with water. To tackle these issues, it is important to understand what water scarcity means, how much water is available and how much water is used. Further, water is a key indicator for various other sectors and crucial for the development of a country. Thus, the knowledge around water demand and availability assessments is a strong contributor to mitigate and understand the issue.

Since the 1980s, when water scarcity became a more and more highly discussed issue, the number of water demand and availability assessments has strongly increased. At the beginning, many of these assessments were criticized due to their limitations. Since the new millennium, many of these assessments became more detailed and complex. Since then, integrated water resource management should help to better manage and sustain water resources. The diversity of the examined water demand and availability assessment in this paper illustrates the breadth of the topic of water scarcity. It must therefore be addressed with many different procedures to be applied in specific settings. Hence, a broad variety of different water demand and availability assessments were chosen in this paper.

The first examined assessment, the WSI, is a traditional approach and was one of the first major assessments in calculating thresholds for water scarcity. It investigates how many people compete with a certain amount of water. Based on four conditions (no stress, stress, scarcity, and absolute scarcity), the status of water scarcity within an area was defined. Its advantage is its simplicity and simple approach. Its disadvantage comes along with the ease, as it is a non-comprehensive tool which disregards for example the quality of water, cultural, economic, and geographical differences.

The WPI offers a holistic approach towards water scarcity and considers socio-economic aspects and focuses especially on the aspect of poverty. At the same time, it looks at the physical scarcity, the population as a user and the ecological integrity. The WPI considers five main factors (resources, access, capacity, use, and environment), which are weighted in an equation for the result. Its major advantage is its comprehensiveness and its interdisciplinary approach. On the other hand, its downsides are the difficulties with the assignment of weights on these factors.

The AVCOR, as a rather unknown assessment, is based on the WPI. Following a holistic approach, the founder of the assessment tries to improve the WPI. It does so by considering different parameters on the availability and consumption side, together with general parameters about population and area. A major downside of the AVCOR is that the data input is very flexible. This means that the user of the AVCOR can decide which parameters to include and use to differentiate between urban and rural population. The AVCOR does not account water usage of the industry.

The Household Survey is a classical approach with a long-lasting history. This assessment method approaches water scarcity on a community level with direct information from households by conducting surveys on a large scale. Household Surveys are very flexible and can be "multi-topic-surveys". Most of the large Household Surveys are done in cooperation with various UN Institutions and the World Bank to ensure a high-quality survey. A disadvantage of the Household Survey is the time factor, as much time is needed to conduct and analyze a survey.

The WEAP software tool is a comprehensive approach to water resource planning. It compares the status of a water system with a baseline year, can simulate various scenarios with many different possibilities of data input (natural and anthropogenic). The schematic of a water system can be easily created through a GIS data map. Since its development, WEAP has constantly improved and developed with the support of various international organizations and researchers. The advantages of WEAP are certainly its complexity and the scenario function. WEAP is also offered for free to scholars, NGOs and governments in developing countries.

6 Recommendations

This paper highlights the importance of water and the cruciality of this natural resource. It further underlines that water scarcity is already an issue in many parts of the world and will constantly increase in the future. Because of this and the dependency of water for the sustainable development of a country and/or region it necessary to continue researching on how to approach, calculate and measure water scarcity.

Due to the many different assessments and indicators, which have been created over few decades, the paper suggests to further research on and streamline these assessments which are holistic and easy to understand for the user and policy makers. This is also highlighted by Liu et al.'s (2017) research. Easy understanding for policy makers should be also one of the key aspects as this provides the basis for more effective legislation around water resource management. Regarding the different nature of the assessments, more research is needed to also differentiate the target audience and express who and in what area should which assessment be used. This study also underlines the importance for further research of assessment applicability after water related natural disaster which would contribute to a disaster risk reduction approach. Further, it is recommended to develop IT systems for water resource assessments, as they offer quick and complex approaches to understand current situations and possible future scenarios. However, these IT systems must be affordable for everyone.

Based on this research the analysis showed that there is further demand for empirical research around the differences of water demand and availability assessments. Depending on the dimension and the assessments, this could be done via expert interviews with representatives of governments and researcher in the field of water management. The overall goal of this empirical research should be standard setting of what demands of the assessments are and how they can be improved. The result of this paper sets a base for further research in the field of water demand and availability assessments. This study represents the starting point and is intended to provide implications for practice and to stimulate further research efforts.

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List of figures

List of tables