

THE ANALYSIS OF WATER AVAILABILITY INDICATORS AND ACCESS TO  
AVAILABLE WATER IN THE DEVELOPING, SEMI-ARID, RURAL SETTING

BY

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THESIS

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## ABSTRACT

In 2015, 663 million people did not have access to improved drinking water; the majority lived in the rural, water scarce regions of lesser developed nations. Global discussions of water scarcity had begun in the mid-1970's, and over the following 30 years, several water availability indicators evolved to try to understand this water availability quandary. This thesis provides an integrative literature review to identify and describe the current water availability indicators that are most commonly used to assess regional potable water resources around the world. It then assesses the adequacy of those indicators for use in the developing, semi-arid, rural regions of the globe with a focus on measuring community access to available water. One key finding is that existing indicators metrics focus solely on the physical availability of the water, but do not include metrics for quantity or quality or readily available access to it. This thesis also finds that while the base data collected for the indicators are at the spatial scale of country or region; these data are often arbitrarily applied to the local scale. This scalar variation is then found to create erroneous availability statistics. The resulting conclusion is that there is a need for an indicator, which more accurately represents access to water at the local level. Also discussed are the socio-economic issues of access that are missing from current indicators. For water access indicators to work at the local level, they must use data beyond water quantity and quality measured at the national or regional scale. Water access indicators need to be: easy to calculate, cost effective to implement, scalable to the micro-level, based on existing data, developed using a transparent process and, not least, must be easy to understand by all the stakeholders. Ideal indicators will use data and new technologies that include scalable tools that allow selection and use of appropriate water purification tactics.

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## ACRONYMS

BWR	Basic Water Requirement
FOA	Food and Agriculture Organization
JMP	Joint Monitoring Programme
MDG	Millennium Development Goals
SDG	Sustainable Development Goal
TARWR	Total Actual Renewable Water Resources
UN	United Nations
UNDESA	United Nations Department of Economic and Social Affairs
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations International Children's Emergency Fund
WHO	World Health Organization
WPI	Water Poverty Index
WRVI	Water Resources Vulnerability Index
WWAP	World Water Assessment Programme
WWDR	World Water Development Report

## CHAPTER 1: INTRODUCTION

Freshwater comprises just 2.5% of the total global water; 68.7% of this freshwater is in the form of ice and glaciers; 30.1% forms groundwater; and 1.2% forms surface water (Gleick, 1993). Global lakes account for some 20.9% of the surface water, with swamps and marshes accounting for 2.6%, and rivers just 0.5%. The accumulation of precipitation across the specific area will move as surface water into streams, rivers, lakes, and then percolate into the groundwater, and may then become available for extraction and use as a fresh water resource. Worldwide over 9,000 billion liters of fresh water are used daily (TheWorldCounts, 2017), an average of over 1,200 liters per person per day. The determination of just how users value this water as a resource is seen in its multidimensional, spatial and temporal characteristics, which include wide-ranging quantity and quality characteristics. The apparent disparity in water availability found within the same region has created a chasm in many developing and undeveloped nations. In turn, this rift often leads to water resource conflicts (Postel, 1997; Postel and Richter, 2003; Clanet and Ogilvie, 2009; Huho, 2012; Joshua et al., 2016).

Water is a central resource for the economy of every country, and also plays a vital role in the climate regulation of that county (Pielou, 1998). It is the management and protection of water resources, both freshwater, and saltwater, that is the basis of environmental protection for the world as a whole. Clean, fresh water is essential to human existence.

Existing water availability indicators used internationally to statistically represent water resources of a region or county fail to represent the actual quantities of readily available quality water. The dilemma of balancing water quantity and water quality by using the current

commonly used scientific water resource indicators could be overcome with the introduction of an optional indicator. The case study of Kenya illuminates, which included parameters should added in an optional indicator, one that supports both functional access and adequate supplies of water to rural homeowners in the developing, semi-arid regions of the world.

### 1.1 AVAILABLE WATER: QUALITY AND QUANTITY

Available water resources that may be used by humans for their various domestic, agricultural, industrial, environmental and recreational needs are in most cases fresh water. Limited usage results as a function of the quality and the quantity of the available water. In developed countries, a drinking or potable, domestic water supply has to conform to very strictly imposed, regulatory quality standards. The ideal outcome would be for all nations to have the same standards of water quality, or at least a commonality in standards for regions of the world. Drinking water quality standards do exist in many developing nations. Most of these nations have guidelines or targets rather than requirements. In many parts of the world very few water standards have any legal basis or are subject to enforcement (Radcliff, 2003; UN, 2011). Health statistics show that it is the women and children of these communities that suffer the most from insufficient access to quality water (Ntouda et al., 2013; Mattioli et al., 2014; Pullan et al., 2014; Rodrigues et al., 2015; Pearson et al., 2016).

Assessing what constitutes good quality water versus contaminated drinking water is a contentious topic as standards around the world vary widely (Leiter et al., 2013). According to the definition set by the World Health Organization (WHO), safe drinking water implies that the water meets accepted drinking water quality standards and poses no significant threat to health. To be drinkable, the United Nations (UN) sets a level of 100% *Escherichia coli* (*E. coli*)

free for a water supply (Medema et al., 2003; WHO, 2011). This standard is often too difficult for most developing and undeveloped rural areas to achieve (Leiter et al., 2013). The quantity of water available to a nation's population is dependent upon the regional hydrology and hydrogeology; the prevailing environmental conditions; the infrastructure used to deliver the water resource; the governance of that resource; and the overall socio-economic situations of the region. The literature shows that water quantity is very often a fundamental driver of water quality (UNESCO, 2003a; UNESCO, 2003b; Molder, 2007; UNESCO, 2014). However, this is not always so. For example, excessive quantities occur in many regions of the world after heavy rains that bring flood conditions; this floodwater is of poor, deteriorating quality (Hrdinka et al., 2012).

There are numerous water availability indicators used around the world to assess water resource availability and sustainability (Döll et al., 2003; Koshida et al., 2015), and many countries define their own series of indicators. Indicator parameters include hydrology-based, climate-based, and water demand and supply data, illustrating the interdisciplinary nature of this topic.

## 1.2 ACCESS TO AVAILABLE WATER

Not all available water is accessible; water may be available from a well, or a river, but without a means of extraction it is not accessible. What is exactly meant by 'access' continues to be a hotly contested topic. It is a subject that impacts how the global water communities, from the academic community down through the water managers and then on down to the single domestic user, understand the problem of access. Consequently, this topic affects how solutions may be shaped to address issues of access. Ribot and Peluso (2013) present 'access'

as a heuristic concept, made up of many different factors: capital, maintenance, technology, governance, as well as cultural aspects. Each factor needs to be considered independently as well as with each other, as very often the factors conflict. Access should not be confused with the right of use of the water supply, nor to the want of fresh water (Ribot et al., 2003).

The United Nations defines access as a percentage of the population within 1 kilometer of an 'improved' water source. Access to safe drinking and sanitation water plays a critical role in the spread of communicable diseases (Wahome et al., 2014; Kiulia et. al., 2014; Mattioli et al., 2014 and 2015; Rodrigues et al., 2015). Research by Ntouda et al. (2013) showed that children under five years of age who do not have access to drinking water are 1.3 times more likely to have diarrhea than those living in a household with access to potable water.

## CHAPTER 2: METHODS

### 2.1. INTEGRATIVE LITERATURE REVIEW

An integrative literature review was carried out to identify the water availability indicators that have developed out of the global discussion of water resource issues (Torraco, 2005; Fink, 2009). The topic was further refined to isolate indicators that have an association to access of water resources. The basic premise of the analysis was that *it is the right of every human to have access to clean drinking water*. Using the Web of Science research database with the keywords 'water', 'availability', 'indicators', 'developing nations' and 'rural', and then 'Africa', and restricting the published date to be between 2000 to 2017, over 115 references were returned. Google Scholar was used to retrieve the full text when cross-referenced papers were not available from the Web of Science and for the 'gray' literature from inter-government agencies, such as the United Nations.

Analysis of the relevant literature for content was then undertaken, with a focus on water availability indicators that could be applied to the semi-arid regions of the world. The original purpose of each indicator, its data sources that derive the indicator parameter, the assumptions made about the environment of use of the indicator, and the limitations for use in the geographic region were all researched. Also considered was the ability of the identified indicators to described access to safe drinking water. The focus at this stage was to find a series of indicators that would represent access to available water.

An integrative literature review identified examples of local issues of access, and how users deal with the disinfection of the water for domestic use. Kenya was used as the case study location as it is a country with a long history of water resource development; therefore,

data was more readily available than most other countries with the same environment of interest. The water resource environment of Kenya was then used to discuss each of the shortlisted indicators.

Having described how these existing scientific indicators fall short of correctly describing access to available water, local level metrics, which are relatively easily acquired, are then presented. These are metrics that would help to define a better access to available, quality, drinking water indicator.

## CHAPTER 3: RESULTS AND DISCUSSION

### 3.1 HISTORY OF AVAILABLE WATER INDICATORS

The statistics we use to calculate global and regional available water resources have evolved out of the discussion of environmental and developmental concepts of global water problems. These discussions began in 1977 at the United Nation's Mar del Plata conference in Argentina (Worthington, 1977). Here it was declared that "...all peoples, whatever their stage of development and their social and economic conditions, have the right to have access to drinking water in quantities and of a quality equal to their basic needs." In 1992, the Earth Summit in Rio de Janeiro expanded this right to include ecological water needs and to safeguard the ecosystems (UN, 1992; Gleick, 1996). During the thirty years after the conference in Argentina, a select group of like-minded scientists and academics developed a series of indices that enabled them to identify and better define both the lack and excess of water resources of a study area. This set of water resource indices continues to be used to the present and provides common water availability metrics that allow for global discussion and analysis (UN, 2010).

At the United Nations (UN) Millennium Summit of 2000, held in New York City, the declaration: "to halve by 2015 the proportion of people who are unable to reach, or to afford, safe drinking water" and "to stop the unsustainable exploitation of water resources, by developing water management strategies at the regional, national and local levels, which promote both equitable access and adequate supplies" was made (UNESCO, 2013). The Millennium Declaration of 2000 was signed by 189 countries and adapted into eight Millennium

Development Goals (MDGs). The goals were time-bound with quantified targets, and specifically address extreme poverty around the world (WHO, 2015; UN, 2016).

In 2016, nearly a quarter of a century after suggesting these UN requirements, more than 1 billion people did not have access to clean drinking water (Gleick, 2016). Meeting the UN development goals can only happen if there is an expansion of improved water resources in the developing nations. This expansion will require the continued investment in water supply infrastructure, and the refinement of water metrics and the standardization and regulation of the supporting data that are behind the availability indicators (WHO, 2015; UN, 2016).

### 3.1.1 World Water Assessment Programme

The apparent disparity in water availability found between socioeconomic groups resulted in the formation of the World Water Assessment Programme (WWAP) in 2008, by the UN, and continues to the present. Assessing the ongoing condition of freshwater throughout the world is the focus of the WWAP; this assessment is founded on the county level statistics for available water resources, management, and usage available through the MDGs (UNESCO, 2013a and 2013b). According to WWAP, a sign of a developed nation is one, which has a well-developed water resource infrastructure, supplying sufficient quantities of quality water to both the rural and urban population to cover the demand. This appraisal of a country's water resources considers the organization of the water resource regarding the populations' needs, how a country deals with issues of water availability, as well as the efficiency and the effectiveness of their water delivery superstructure (UN, 2015). The cost of water supply to individual communities is also part of this country-wide appraisal, and access to available water is an essential element to understanding these costs (Holm, 2016). The WWAP sets out water

statistics in an annual report (UN, 2006 and 2015), using the UN database AQUASTATS. The Land and Water Division of the UN developed this database, and the Food and Agriculture Organization (FOA ) maintains it. One of the metrics in the database is Total Actual Renewable Water Resource (TARWR), which is used to define the quantity of potentially available water resources and is the basis for these cost calculations.

### 3.1.2 Database AQUASTATS-TARWR metric

TARWR also includes a measurement of the water quality and wastewater aspect of the resource. Calculated values for the seasonal, annual and long-term TARWR for each participating country are made at the state spatial level. The statistics are stored in the AQUASTATS database by country and include water uses, agricultural management, and many other water resource topics. The data is gathered and compiled annually by the World Health Organization (WHO) and the United Nations International Children's Emergency Fund (UNICEF) from routine censuses and household surveys sent out every 3-4 years. In the questionnaire, the householders are asked about their basic drinking water source type, whether it is improved or not, and whether the source is on the premises (UN, 2016). Not accounted for in the surveys are issues of continuity, broken hand pumps or public standpipes, as well as seasonality of supply, as in the case of reservoirs and shallow ground water wells.

Worthy of note is that the majority of the consumers surveyed are illiterate, so the surveys are primarily verbal questionnaires, with interpreted responses. The qualitative responses to the surveys are then coded, and the results analyzed. This method of surveying introduces several degrees of biases to the analyzed data as the users' judgment as to the quality of the water available to them is subjective (Montello et al., 2013). When surveys are

not available, administrative records are used. However, data from these surveys have been found to be far more reliable than administrative records as the basis of the data is actual use of sources, and households provided information on the facilities utilized rather than the mere presence of the sources (UN, 2016). The frequency of the surveys has been found to be sufficient to determine actual changes in access to safe drinking water. The quality of water in each census area is known from microbiological and chemical laboratory testing. However, the number of samples taken is very restricted due to cost and practicality (UN, 2016). The laboratory and survey results are combined, and the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation (JMP) estimates basic access for each country by fitting a regression line to the series of data points from the study region. For global comparison of this data, adjusting these national estimates occurs (UN-Water, 2016).

TARWR is a measure of cubic meters per capita per year ( $m^3/cap/yr$ ) and has four focus components: context, function, governance, and performance. Context refers to the water storage quantities and is an estimate of the surface and groundwater reservoir capacities. Run-off, infiltrating water and evapotranspiration rates are components of the reservoir capacity. Function refers to the quantity of water used; and includes social, economic and environmental components. Deriving an indication of a region's water scarcity can be achieved by considering both the context and function values of that shortage. A third element of the TARWR is governance, which is the management of the resource. Governance will include the standards and procedures for data gathering. Performance is the fourth component; this is a combined measure of the quality and quantity of the resource and will be a function of the methods of sampling, testing, and reporting. Table 1 outlines the parameters associated with each

component of TARWR. These listed TARWR metrics do not specifically address the critical metric: access.

**Table 1:** AQUASTATS TARWR measures and associated indicators.

<b>TARWR focus component</b>	<b>parameter measured, m<sup>3</sup>/capita/yr</b>
context	water storage
function	water use
governance	management of resource
performance	quantity and quality

Molden (2007) points out that issues arise when applying this statistic on the global scale as there are known discrepancies in data for the same variable from different nations. These discrepancies arise as the result of differences in definitions and methodology in monitoring processes and data reporting. The comparison of the data is also an issue: the country size, climate, and development level for the study regions are not considered. The scale of the information is that of the country rather than a watershed, and there are often difficulties in obtaining a full-time series of the data, giving rise to further discrepancies when comparing data across political boundaries.

### 3.1.3 Interpretation of Water Resource Statistics

The global interpretation of the water resource statistics is, therefore, very generalized. A nation that has high, or moderately good, water availability statistics is often seen as having a population with good access to that water. Conversely, a nation with a low water resource statistic is represented as having poor access to the water. However, inconsistencies arise when applying these high-level statistics at the micro-level, in which case access and technologies

influencing water availability conditions do not adequately represent the rural settings. Also to consider are the inconsistencies in water availability between the less affluent rural dwellers and the more affluent urban dwellers within the same (WHO, 2014a).

### 3.2 KENYA- A CASE STUDY

A regional case study uses Kenya to explore the application of the water availability indicators. This nation exemplifies the range of water resource issues experienced in so many regions of the world and is a land that has a well-developed history of water resource governance and data that are more readily obtainable than other developing nations.

In 2015, Kenya had a population of 48.2 million (world population review, 2015). Combined with a population growth rate of 2.5% per year a heavy burden is being placed on the country's sustainable natural resources, including fresh water for domestic use. These are resources that are unevenly distributed compared to other regions of the world (UN-Water, 2015).

A significant portion of Kenya, over 80% of the land area, has an arid to semi-arid climate, with an average precipitation of 700 mm/year (FAO, 2013). The Indian Ocean coastal lands have a tropical climate with high monsoon rainfall in April and October, and the highland areas to the north of Lake Victoria have an equatorial climate with a predictable rainfall of nearly 1800 mm/year (FAO, 2013). Like many of the East African nations, the people of the rural areas of Kenya rely on subsistence smallholder agriculture, which is, primarily, rain-fed cultivation.

### 3.3 INDICATORS

As the literature review progressed, it became evident that there was a very mixed usage of ‘indicator’ and ‘index’ terminology. It is apparent that ‘index’ was the favored terminology before 2000, used to describe a derived measure of a parameter that serves to specify a value or quantity that is weighted or scaled against a base value; ‘indicator’ being used interchangeably with ‘index’ post-2000. Underlying all water resource indicators/indices is the understanding of two basic categories of water availability: water quantity and water quality.

Of the 115 studies from the literature review that met the search criteria for access to available potable water less than 10% addressed water access, and these were principally case studies. The majority of the studies focused on water quantity and quality without addressing access. The literature review identified a set of long-standing commonly used scientific indices developed since 1989 to define the availability of a water resource. Table 2 lists the key water availability indicators that are referred to most often in the literature.

**Table 2:** List of key water availability indicators described in the literature.

Indicator	Year presented	Notes
Falkenmark Index\Water Stress Index	1989	discussed below
Basic Water Requirements Index	1996	discussed below
Water Resources Vulnerability Index	1997	discussed below
Relative Water Scarcity Index	1999	discussed below; Moore et al. (2015) further adapted this index
Millennium Development Goal 7.8	2000	discussed below
Water Poverty Index	2002	discussed below
Water Availability Index	2015	developed for use in the US
Water Scarcity Index.	2015	developed for use in the US
Drinking Water Quality Index	post 1999	variation on Water Scarcity Index
Acceptability Water Quality Index	post 1999	variation on Water Scarcity Index
Climate Moisture Index	post 1999	variation on Water Scarcity Index
Health Water Quality Index	post 1999	variation on Water Scarcity Index

Of these twelve indices, only five were discernable as having been specifically utilized in practice to describe water availability in developing, semi-arid regions of the world; places where water withdrawal and water availability metrics are the most often presented data sets. Table 3 summarizes the five indices that fit the region of focus criteria; and include, in chronologic order by research year: the water stress index; the basic human needs index; the water resources vulnerability index; the indicator of relative water scarcity; and the water poverty index.

**Table 3:** Summary of indices that have been specifically used to address water scarcity issues in semi-arid regions.

Indicator/Index	Spatial Scale	Reference	Required Data	
Falkenmark Index/ Water Stress Index	country	Falkenmark, 1989	total annual renewable water resources ( m <sup>3</sup> /year) population (%)	
Basic Water Requirements	country	Gleick, 1996	domestic water use per capita (m <sup>3</sup> /cap/year)	
Water Resources Vulnerability Index	country	Raskin, 1997	annual water withdrawals (m <sup>3</sup> /year) total renewable water resources (km <sup>3</sup> /year) GDP per capita (\$)	national reservoir storage volume (km <sup>3</sup> ) precipitation time-series (mm) % external water resources (%)
Relative Water Scarcity Index	country	Seckler et al., 1999; Moore et al., 2015	water withdrawals in 1990 (km <sup>3</sup> /year) water withdrawals in 2025 (m <sup>3</sup> /year)	
Water Poverty Index	country, region	Sullivan, 2002	<ul style="list-style-type: none"> <li>internal and external access to safe water, and sanitation (m<sup>3</sup>/cap/year)</li> <li>irrigated land, total arable land, total area, (m<sup>2</sup>)</li> <li>GDP per capita (\$)</li> <li>GDP per sector (\$)</li> <li>under 5-mortality rate (%)</li> </ul>	<ul style="list-style-type: none"> <li>UNDP education index</li> <li>Gini coefficient</li> <li>domestic water use per capita (m<sup>3</sup>/year)</li> <li>water quality variables</li> <li>use of pesticides</li> <li>environmental data</li> </ul>

Worth noting is the observation that these indices make use of the measure of total renewable water resource: that water that is replenished yearly by surface water in rivers and streams within a specific region or from external sources. Renewable water includes groundwater inflow into rivers, streams, and lakes, as well as aquifer groundwater not drained by surface water channels. It is this estimate of a nation's river runoff that defines that country's water resource availability and water deficit (Shiklomanov, 1998). When considering water availability, these indices do not specifically address measures of access to quality water (Rijsberman, 2006; Brown et al., 2011, UNESCO Global Water Forum, 2012).

### 3.3.1 Water Stress Index

Of the several water scarcity indicators in the literature, the most commonly used is the 'Falkenmark indicator' or 'water stress index' (Falkenmark et al., 1989). The World Resource Institute provides an analysis of world water stress index values in an interactive map called AQUADUCT (WRI, 2017). This index originated as part of a study of water scarcity in semi-arid regions of the world and is still very applicable today. The index defines water scarcity in terms of a metric that is easily understood: the amount of renewable freshwater that is available for each person each year. Estimates of water requirements in the household, agricultural, industrial and energy sectors, as well as the needs of the environment, are the basis of this threshold value of 1700 m<sup>3</sup> per capita per year (Falkenmark, 2009a and 2009b; Kummu et al., 2010). Countries whose renewable water supplies cannot sustain this figure are said to experience water stress; when supply falls below 1000 m<sup>3</sup> per capita per year a country experiences water scarcity; and below 500 m<sup>3</sup> per capita per year, absolute scarcity (Falkenmark et al., 1989; Gleick, 2003). The data to calculate this index, the water use per capita per day, is

readily available from country census data. However, it does not help to explain the true nature of water scarcity, as the simple thresholds for each category of scarcity do not display the main differences in demand among countries due to climate, land use, lifestyle, and similar parameters (Falkenmark, 2007; Falkenmark et al., 2009). Additionally, the water stress index does not consider the human-made increases in water supply, such as desalination as well as recycled and reused water withdrawals.

### 3.3.2 Basic Water Requirements

A second widely used index is the basic water requirements (BWR) which was created by Gleick in 1992. The BWR refers to the water consumption per capita per day. According to Gleick, a personal entitlement should be 50 liters of water per person per day: 5 liters of drinking water; 20 liters of sanitation water; 15 liters of bathing water; and 10 liters for food preparation. This entitlement means each person needs access to 15 -30 liters of potable water each day. Only 20% of the world's population uses 5 liters, or more, per person per day (Gleick, 2016). Some nations use considerably more than this: North America and Japan use 350 liters per capita per day and Europe 200 liters per capita per day. On average, sub-Saharan Africa countries use 10-20 liters per capita per day (WHO, 2014; Institute Water for Africa, 2016;). De Villiers notes that the human 'need' for water varies widely around the world. The 'needs' of North American rural populations is very different to those of sub-Saharan rural villages. De Villiers and many others note that lack of water may not be solely a problem of supply, but is to a degree an issue of correctly managing the allocation and distribution of the resource (de Villiers, 2001). The quantity of available water must also take into consideration the water needs for agricultural and industrial use associated with a human population's everyday

existence. Consideration should also be given to the water consumption for the environment; for example, the water of a floodplain wetland which is not part of the stream flow, so often ignored (Rijsberman, 2006; UNESCO Global Water Forum, 2012).

The Basic Water Requirement index is used as a basic guide to water needs; the 5 liters of fresh water use is the amount that an average person, living in a moderate climate, needs to drink daily to survive. In many parts of the semi-arid and arid regions of the world, people can exist on far less, using the 5 liters per day as their total use (Gleick, 2016). The United Nations Educational, Scientific and Cultural Organization (UNESCO) adopted the BWR after modifying the definition to be 20 liters of water per person per day from an improved source, within 1 kilometer of the user's dwelling (JMP, 2008).

The index represents a need for a water resource and does not apply an access factor. Nations experiencing water scarcity will have a high rate of gray water reuse; for example, domestic water used for food preparation will be used to water a vegetable garden or fruit trees (greywateraction, n.d.) There are no measurements of gray water utilized in this index. Applying the same BWI across climatic, geographic and socioeconomic boundaries does not seem very realistic.

### 3.3.3 Water Resources Vulnerability Index

The water resources vulnerability index (WRVI), is the third index of interest. In 1997 Raskin et al. replaced water demand with water withdrawal (use) values in Igor Shiklomanov's comparison of a nation's annual water availability with the assessments of its national water demand by the agricultural, industrial and domestic users. Water withdrawals are defined as the amount of water taken out of rivers, streams or groundwater aquifers to satisfy human

needs for water. The WRVI is presented as a percent of available water resources and is referred to a region's water resource scarcity. A country termed 'water scarce' is one which has annual withdrawals are between 20% and 40% of the annual supply, and 'severely water scarce' if annual withdrawals are greater than 40% (Rijsberman, 2006). When a person does not have access to safe and affordable water for domestic use that person is termed 'water insecure' (Seckler, 1999; Rijsberman, 2006). When a group of households lives in an area that is water insecure for the majority of the time, that area is 'water scarce'. The measure of water withdrawal indicates that there is access to a water resource. However, the WRVI is calculated on the country or perhaps regional scale, for comparisons at that same scale, and will not indicate specific access values per household.

#### 3.3.4 Relative Water Scarcity Index

The fourth index of interest is the Relative Water Scarcity Index (Seckler et al. 1998; 1999). The index uses the same data and a similar approach to the WVRI but projects the change in demand over time. Seckler et al. looked at both the existing and projected water supply and demand values from 118 countries for the years 1990-2025. They then presented global data in the format of a map showing the projected percentage change in demand (only), by population, across the domestic, agricultural and industrial sectors for those countries across this period. They estimated that one-quarter of the world's population would be affected by water scarcity, again withdrawing 20% and 40% of the annual supply, by 2025; and that one-third of this population would occur in developing countries. This index provides only the best estimate value of the percentage change in demand, with no reference to access to water. The accuracy of this index becomes limited by the poor quality of the international data set (see

Chapter 3.5.2 for a full discussion on data quality). Moore et al. (2015) defined the Water Scarcity Index as the ratio of water consumption to available runoff, working on water statistics in California. As runoff is not a metric readily available in the focus region of this study further discussion of Moore's interpretation of water scarcity has not been included.

The literature review identified several other methods for quantifying and measuring water scarcity that takes into account various economic and physical parameters relating to water resource availability. These methods include measurements of lack of availability, the absence of variable volume to meet demand, and high levels of water use relative to available water supplies, but no measure of access to water. Gaupp et al. (2015) used a global water balance model to derived water scarcity values by considering large global river basins across country borders. They define water scarcity as occurring when the aggregated storage is less than 20% of the capacity, and define water storage dependency as the difference between months with no storage and months in which demand exceeds supply. Climate variation and human socioeconomic development have altered the world's hydrological cycle over the last century and a half (Vörösmarty et al., 2010; Wada et al., 2013; Rockström et al. 2014). Several studies have shown that river water depletion around the world is considerable. About half the river water withdrawn for general use has evaporated, and approximately 25% of the water has been changed due to overuse (Kummu at al., 2010; Jägerskog and Clausen, 2012; Kumar, 2013; Wada et al., 2013; Rockström et al., 2014). Hydrologic variability in a region is as important to that region's water scarcity as the average water availability (Gaupp et al., 2015). Such variability occurs in many river basins of the world, regions where water withdrawals have

resulted in over abstraction of river water to the detriment of the river's ecosystem as well as at the expense of the country; the Nile in Egypt is a case in point.

### 3.3.5 Water Poverty Index

The fifth index of interest is the water poverty index (WPI). This index developed out of the need for a universal tool to measure the water stress that disadvantaged populations tolerate; those who suffer most from inadequate access to water (Sullivan et al., 2003; Vörösmarty et al., 2005). The index is a weighted average of five standardized components: resources, access, capacity, use, and the environment. The resources component includes the physical availability of surface and ground water and takes into account the variability and quality of the resource as well as the total amount of water. The access component considers the extent of access to water for human use, for irrigation, industrial as well as domestic consumption, and accounts for the distance to a safe source, as well as the time needed for domestic water collection, and other significant factors. The capacity component accounts for the achievement of the population to be financially able to purchase the water. This element will include the aspects of population health and educational circumstance, both affecting income level. The use component is an indicator as to the purposes of the water purchase. The final element of the WPI, an environmental component, gives an estimate of the environmental reliability related to water, and of ecosystem goods and services that the aquatic habitats provide in the area of interest (CEH, n.d.; Sullivan, 2002). Collectively, the weighted average, the community's capacity for water management and other environmental aspects form a single number. This value is used to help to determine the priority needs for water management and distribution. Water consumption, resource reliability, and socioeconomic

coping capacity data for a community can be further grouped and may be used to indicate a region's overall water vulnerability (Gleick, 2015; Rodrigues et al., 2015).

### 3.3.6 Millennium Development Goal 7.10.30

Even though these five indices remain in use after more than thirty years, and have been further adapted and refined to particular fields of use, (Döll et al., 2003 and 2009), they have not helped us to successfully meet the United Nations' Millennium Declaration's 2000 commitment. The commitment "to halve by 2015 the proportion of people who are unable to reach, or to afford, safe drinking water" and "to stop the unsustainable exploitation of water resources, by developing water management strategies at the regional, national and local levels, which promote both equitable access and adequate supplies".

In the context of development goals, the UN defines drinking water as water used for consumption (drinking and food preparation) and basic hygiene purposes, and an improved drinking water source; one protected from outside contamination by an engineered structure.

Table 4 shows examples of unimproved and improved water supplies.

**Table 4:** Examples of unimproved and improved water supplies (summarized from UN, 2000; Opare, 2012; Dobrowsky et al., 2014)

<b>unimproved water supplies</b>	<b>improved water supplies</b>
unprotected well	household connection; piped water
unprotected spring	public standpipe
tank/truck provided water	boreholes/ tube wells
bottled water (considered unimproved because of quantity; may be considered improved if there is no secondary source of water )	protected springs
rainwater collection from roofs	rainwater harvesting in an enclosed cistern system

Improved water does not include surface water taken directly from rivers, ponds, streams, lakes, dams, or irrigation channels, all of which are common sources of water in developing rural communities of the world (Quin et al., 2011).

In 2015, more than 10% of the world's population still did not have access to improved drinking water. This percentage may seem small, but it is the location of these populations that is striking. The majority lived in the rural, water scarce, developing nations of the world, where rural households were still in desperate need of water resource planning (UNESCO, 2012).

The UN has monitored progress toward this commitment with the United Nations Millennium Development Goal 7, Target 10, Indicator 30 (MDG7.10.30). This indicator was developed to directly address the question of access to available water by measuring the proportion of population within 1-kilometer sustainable access to an improved water resource, calculated separately for urban and rural areas (WHO, 2006). In 2015 the Sustainable Development Goals (SDG) were defined to pick up where the MDGs left off, and achieve the target goals by 2030. SDG 6 addresses clean water and sanitation, with Target 6.1 stating "By 2030, achieve universal and equitable access to safe and affordable drinking water for all", and Indicator 6.1.1 being "the proportion of the population using safe managed drinking water services".

The UN states that fully understanding a nation's renewable water resources can only be reached if serious steps are taken to improve the existing controls, policies, planning, and administration of all water supplies within that nation. These steps require the development of global tools for monitoring and protocols for managing and coordinating water availability and

usage. The UN further states that beneficial water resource conversation between nations only occur once when these tools and protocols are made accessible to all nations (UN, 2014).

To be noted is the fact that many year-round engineered water sources are often unavailable due to maintenance issues or inadequate quantity, which in turn affects the quality of the water. Not incorporated into the AQUASTATS data, used as a basis for this indicator, is the detail that 1 in 3 hand pumps in sub-Saharan Africa does not function year round due to lack of maintenance (Ntouda et al., 2012; Shiferaw, 2014). Improved water does not include surface water taken directly from rivers, ponds, streams, lakes, dams, or irrigation channels, all of which are widespread sources of water in developing rural communities of the world.

The UN's World Water Development Reports (WWDR) gathers statistic in the form of an annual thematic report that focuses on different strategic water issues and aims to provide decision-makers with the tools for sustainable use of water resources. At present, these statistics require no fewer than 150 variables to be measured. The governance issues combined with the subject of data gathering for these indicators puts heavy constraints on trying to achieving the SDGs. The refined of this vast number of parameters into a smaller set of significant variables is of great importance if the reporting of water resources is to be a success. A set of targets comprises each of the 8 MDG's and 17 SDG's, with a series of indicators assigned to each target to gauge how each target is being achieved. There are four target indicators categories: those that focus on the context of the water resource, those on function, those on governance, and those that emphasize the performance of the resource within each region of interest. Table 5 shows the relationship between the MDG and SDG that is related to

clean water and sanitation and summarizes the specific indicators that address access to drinking water.

**Table 5:** Summary of Millennium Development Goal 7.10 and Sustainable Development Goal 6.1.

Goal	Objective/Target Description/Required Data		
MDG 7 (Pre-2015)	<b>ensure environmental sustainability</b>		
	Target 10	halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation	
	Indicator 30	<i>% of population using an <b>improved</b> drinking water source, urban and rural (WHO, 2015)</i>	
SDG 6 (Post-2015)	<b>ensure access to water and sanitation for all</b>		
	Target 1	by 2030, achieve universal and equitable access to safe and affordable drinking water for all. AQUASTATS	
	Indicator 1	<i>% of population using safely managed drinking water services (WHO, 2015)</i>	

The AQUASTATS-TARWR parameter is the source data for both of these development goal indicators, and as previously discussed (3.1.2) TARWR is a quantitative value created from stakeholder participation via qualitative census questionnaires; there is no actual measure of quantity used per person per day, or cost/affordability data. Hence, neither the MDG target 7.10 nor the current SDG target 6.1 is a measure of the quantity of accessible a household. Neither does either target represent a cost per liter per day for each household in financial terms, nor the cost in terms of the time taken to collect the water and transfer it to the home.

The annual WWAP and JMP monitoring and reporting continue, and the indicators are regularly reviewed by the UN to ensure that the outcome of the analysis of the measurements is still focused on water resource usage and management.

### 3.4 CHALLENGES TO QUALITY WATER

The literature shows that there is a direct correlation between quantity of water and the quality of the water. In most scenarios as the quantity decrease so does the quality. Poor water quality provides the habitat paths as well as a delivery medium for water-borne diseases, further re-enforcing the importance of clean potable water for healthy populations.

In many rural, developing regions of the world, the sole source of drinking water is from sanitized surface and near-surface water. Water for drinking is water taken from the rivers, lakes and standing ponds, irrigation ditches, rainwater harvesting, or shallow wells rather than more sanitary infrastructure delivery, such as wellhead pumps and taps (Leiter et al., 2012). Very often the hardest acquired water is contaminated, and in some instance may be deadly to the very young and poor. The standard set by the UN for a water resource to be considered potable is often too high for a nation to achieve. There are several point-of-use disinfection methods already in use around the world; all have been shown to be very effective in improving water quality (Lule et al., 2005). However, the initial condition of the water will govern the amount and type of effort that has to go into disinfecting the water. A flocculant, such as ferric sulfate, must be used to treat water that has the slightest amount of turbidity. Once the flocculant is stirred into the water the container must be left to sit for a half hour, or so. The sediment will coagulate and fall to the bottom of the container and the treated water can then be filtered out and disinfected. Low-cost disinfecting methods, ideal for use in undeveloped, semi-arid, rural areas of the world, and already widely in use include solar treatment and boiling. The reuse of undamaged plastic water bottles is a very effective way to solar heat a liter of water at a time. Leaving water filled bottles in the full sun for at least 12 hours has been

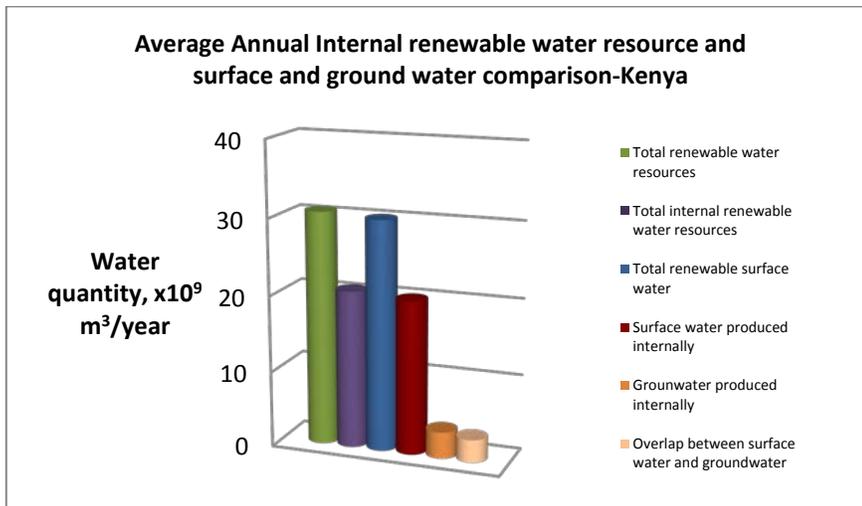
found to be a very cheap and productive way to sanitize the water (Lule et al., 2005). Boiling is another commonly used sanitization method. However, this approach requires a supply of fuel and is therefore often an expense that many householders are not able to expend. Boiling water containers are also a source of danger to householders with young children. The use of a solution of a sodium hypochlorite is a very cheap (cents per day) and easily available disinfectant for both drinking water and water for other domestic purposes (UNESCO, 2013). The solution is added to a water container and stirred, and the water is ready for use almost immediately. Water filtration is an alternative method of treatment, and like the sodium hypochlorite has created markets in many developing nations. Filters are most often locally manufactured clay filters placed at the top of a container, with the untreated water flowing under gravity through the filter, collecting at the bottom of the container where a spigot enable the homeowner to pour out the clean water. Large set-ups using sand and gravel filters often act as an alternative to the clay filters, and result in larger quantities of clean water. The cleanliness of the containers and utensils used and the quality of the filters will determine the quality of the final product. Novel innovations abound; the straw- filter is a recent innovation. Sucking the water through a fiber filter removes any suspended particles (causing turbidity) from the water, as well as waterborne bacteria and protozoan cysts; LifeStraw® is an example. These niche solutions for water cleansing offer individuals access to small, affordable quantities of useable water.

#### 3.4.1 Potable Water in Kenya

Figure 1 shows the Kenyan AQUASTATS data for the annual average surface, ground and renewable water resources for the period 2012-2014 (estimated, best available data). The data

shows that 98% of the total internal renewable water comes from surface water, with 67% being of internal water resources. Less than 10% of this water is groundwater. The total renewable water resources in Kenya are  $30.7 \times 10^9 \text{ m}^3/\text{year}$  (FOA, 2013), and external water resources are estimated at  $10 \times 10^9 \text{ m}^3/\text{year}$ , giving Kenya a dependency ratio of 33% (WHO, 2015).

Annual freshwater withdrawals in Kenya are  $3.2 \times 10^9 \text{ m}^3/\text{year}$ , 16% of the total of internal freshwater resources (FOA, 2013), putting Kenya close to the water vulnerability index of ‘water-scarce’. This value is an average across the country; in the semi-arid and arid regions of the country, which are located away from the lakes and rivers the water vulnerability index is certainly at ‘severely water scarce’. It is quite evident that Kenya is a country that is almost entirely dependent upon surface water for its available water resources.



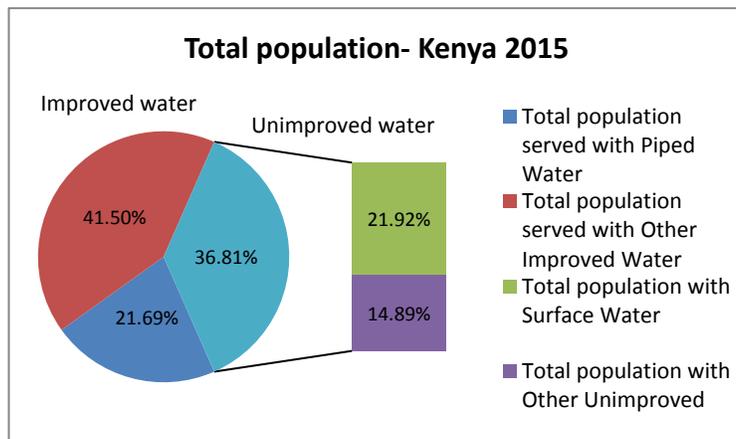
**Figure 1:** AQUASTATS average annual data for the Republic of Kenya 2012-2014.

The annual renewable water resources per capita in Kenya for 2015 were  $667 \text{ m}^3/\text{capita}/\text{year}$  (WHO, 2015), which falls within the water stress index category of ‘scarce’. Future projections show that by 2025, water availability will drop to  $235 \text{ m}^3/\text{capital}/\text{year}$

(water.org, 2017), which places Kenya’s population into the ‘absolute scarcity’ range of the water scarcity index. The most recent data for the basic water requirements for Kenya were at 46%; this places the country below the 50 liters per person per day threshold (WHO, 2015; WHO, 2017). Data collected by the World Resource Institute (WRI) for Kenya demonstrates the many water quantity resource issues : a low to medium drought risk; a medium to high risk for interannual variability in water resources; a high risk for flood occurrence; and a low to medium risk for drought severity (floodlist, 2016; WRI, 2017).

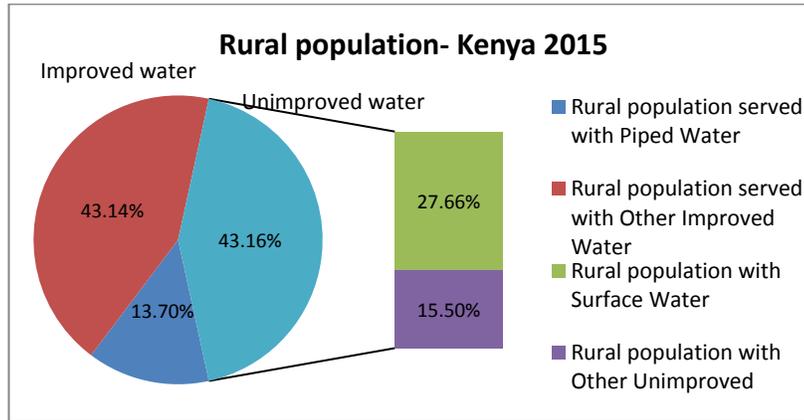
The research shows that the primary water source in developing, semi-arid, rural regions of the world is most often surface water in the form of lakes, rivers, stream, irrigations ditches, ponds and water holes, and occasionally engineered infrastructures. Figure 2a shows the 2015 WHO-UNICEF water supply statistic for Kenya’s total population. It must be noted that in 2015 79% of Kenya’s population were rural dwellers (UN, 2006; FOA, 2013), and recalled that an improved water resource is one that is engineered (see Chapter 3.3.6).

The data shows that in 2015 21.4% of the total population of Kenya was served with piped water and 41.5 % with other improved water supplies.



**Figure 2a:** Proportional distribution of total population water statistics for Kenya in 2015 (WHO-UNICEF knoema data, 2015).

Figure 2b shows that in 2015 43.16 % of Kenya’s rural population of over 34 million people lived with unimproved water supplies; 27.66% of those people get their water supply from surface water.



**Figure 2b:** Proportional distribution of rural population water statistics for Kenya in 2015 (WHO-UNICEF knoema data, 2015).

Leiter et al.(2013) and Kiulia et al. (2014) state that 56% of the rural Kenyan population uses unsafe drinking water from streams, ponds, lakes, and rivers. Kenya has three major rivers, each with several large tributaries, and is at the headwaters of the Nile River Basin. Over the length of each river and stream, the water is the single water resource for many thousands of people. A second major source of fresh water in this part of East Africa is from the lakes; East Africa has three of the four largest African lakes in the rift valley region, holding greater quantities of water than all the rivers and streams combined (Solomon, 2010). Kenya shares the waters of Lake Victoria with Uganda and Tanzania; Lake Tanganyika with Burundi, the Congo and Zambia; and Lake Nyasa with Mozambique and Malawi.

With all this seemingly abundance of surface waters the East African nations of Kenya, Tanzania, Burundi, Rwanda, and Ethiopia, are countries that are critically short of water (de Villiers, 2000; Bordalo et al., 2007). At least 40% of the population of this region of the world

will experience drought stress at least once in each generation (Falkenmark et al., 1989; Gleick, 2003; Falkenmark, 2009a and 2009b; Kummu et al., 2010; Vörösmarty, 2010). The existence of chronic water stress is very often an indicator to flash point locations for future water scarcity in a region (Vörösmarty et al., 2010). This lack of investment in water infrastructure by the Kenyan government has resulted in Kenya ranking as having one of the lowest water supply coverages in the world (WRI, 2017), creating the observable economic water scarcity.

The Millennium Development Goal 7C set for 2015: “to achieve universal access to basic drinking water, sanitation and hygiene for households, schools and health facilities” was partially reached in this part of the world. Over the period 1990-2015 Kenya had a 73% increase in the rural population using improved water resources; however, by 2016 this percentage had fallen to 57% (UN, 2016; justoneafrica, 2016).

Rapidly growing populations, increasing agricultural development, urbanization, and industrialization over the last quarter of a century has led to poor land management contributing to a change in the water resources (Carter and Parker, 2009; UN, 2015). The literature alludes to the skew of the assessment of common resources by governments in these nations to manipulate supplies to the urban areas (Reddy, 1993; Raditloaeng, 2012; UN, 2014).

Across much of semi-arid East Africa, there has been a recent move from nomadic pastoralism as a livelihood to cattle farming on a larger scale to supply meat to a growing market in the Arabian Peninsula. This overstocking is depleting traditional water resources, and has resulted in deforestation, the degrading of the soils, and the silting and polluting of the watersheds, lands that are already vulnerable and drought-prone (GWP, 2015). The lack of domestic and industrial waste treatment has led to further deterioration in water quality of the

rivers and the groundwater, water needed by so many for domestic purposes (GWP, 2015; UNESCO, 2015).

#### 3.4.1a Associated Sanitation Issues

Tied to the scarcity of potable water is the lack of availability of water for sanitation purposes. One-third of the global population defecates in the open air, with 86% of those people living in rural areas (WHO, 2014b). In Kenya, nearly 10% of the rural population defecates in the open. When there were western type toilets installed during the British colonial era, poor maintenance and age have resulted in the collapse of the sewage pipes. Some of these sanitary systems have been replaced by pits, with the use of the pit contents as fertilizer in the fields. Historically, water development programs have focused on education as the key to reducing open-air sanitation practices (O'Reilly et al. 2017; WHO, 2014b). However, these are not educational issues. There are complexed gender cultural issues that prevent females from accessing proper sanitation facilities and cause the female population to suffer severe health and safety issues as a result of these cultural taboos.

#### 3.4.1b Associated Health Issues

Water-related diseases are prevalent in this region of the world (Devi and Bostoen, 2009). Water-borne diseases in Kenya are attributed to cause 70-80% of local health issues (Kenyan Aid Programme, 2009). Where precipitation and infiltrating runoff are the primary water resources, the flow of water accommodates and transports the bacteria and viruses (naturally occurring and pathogens) into the surface and groundwater system (Gerba and Bitton, 1984). Communal latrines and bathing areas are usual in developing, and undeveloped countries and the location of human wastewater and domestic animal waste is often close to

the primary water sources, leading to cross-contamination of sanitation systems with drinking water. If shallow, hand-dug wells offer a potable resource for water, they often have no wall isolation and unprotected wellheads (Lema et al., 2014; Okello et al., 2015). These wells draw water from the surface layers of soil rather than bedrock, and it is the permeating, polluted runoff that feeds these wells. These types of water resources fail the quality requirements set for potable water and cannot be considered to be a source of safe drinking water in the analysis of access to available water. Where these shallow ground water and surface water sources are the only accessible, available water resources improving the health and well-being of these communities with education in the disinfecting of the water is of prime importance.

Water-borne diseases most adversely affect low-income groups and children, especially since malnutrition is already prevalent in this sector of the population (WHO, 2011). By increasing access to clean water, and improving sanitation and hygiene, 94% of intestinal illnesses that kill so many people in this region of the world are preventable (WHO, 2008).

Water storage has been shown to have a significant effect on the spread of water-borne diseases. Jerry can storage is the most economical method of storage, but has been found to correlate with high numbers of hospitalized water users (Rodrigues et. al, 2015). Some of the more common diseases caused by drinking dirty water and poor sanitation in Kenya include malaria, cholera, typhoid fever, hepatitis, and schistosomiasis (bilharzia) (Young et al., 2015).

Over 23,000 Kenyans die each year from diarrheal disease. Many water-related illnesses have been shown to increase during the wet season (Rodrigues et. al, 2015; Pearson et. at, 2016). Spatial survey data were collected using household surveys in rural communities in Uganda and Tanzania by Pearson et al. (2016), and in the Lake Victoria area of Kenya by

Rodrigues et al. (2015) to study what the effect the seasonality of the water availability has on the socioeconomic health of a community. The questionnaires asked householders if their source of their water changed between the wet and dry seasons. Questions enquire if the householders recognized a difference in the quality of the water between the seasons, with or without a change in the source due to the seasonality of the water source. Another question asked if there was a corresponding shift in the health of the community as a result of the water source change. The results from both research projects showed that it is the ease of access to water that defines which water source a user chooses. Households with access to sources with lower risks of contamination sometimes decide to use more contaminated sources if they are easier to access (Pullan et al., 2014; Rodrigues et al., 2015; Pearson et al., 2016). Where tap water is available, this is the first choice of source, with borehole water taking second place, again when available. When neither of these two sources is an option, lake/pond/stream water is the primary source of water (Rodrigues et al., 2015; Pearson et al., 2016). The awareness of waterborne diseases being the cause of intestinal related illnesses was very high, over 95%, (Rodrigues et al. 2015) in all the communities surveyed, and people were very aware that water treatment and hand washing prevents water borne diseases (Mohamed et al., 2016). Both studies found that the quality and quantity of water sources might vary due to any number and combinations of reasons, including seasonal differences in precipitation, variations in the maintenance of the resource, and governance associated with the resource. These same reasons will affect access to a water resource (Pearson et al., 2016).

### 3.4.1c Infrastructure

In many places in East Africa the existing water infrastructure cannot keep up with demand from the spiraling increase in the population numbers; and like many developing nations, this region lacks access to the financial resources needed to develop their water supply infrastructure (Young et al., 2015). It is not until persistent and extensive droughts, such as occurred in the 1970s and 1980s in East Africa that the water troubles come to the attention of the rest of the world. Such world agencies as the United Nations are then able to then step in to help find the core issues for this lack of water, usually the result of underlining environmental and social pressures that have arisen as a consequence of the inadequate water delivery infrastructure of quality renewable freshwater resources. Another pressure that helps to bring international agencies into an area is the lack of access to available drinking water and the associated public health issues that arise from the pollution of available water. All of these issues are endemic to this focus region of interest and thwart the socio-economic development (Fogden, 2009; Omole and Ndambuki, 2014; WHO, 2014b; UNESCO, 2012 and 2105; GWP, 2015; Rodrigues et al., 2015; UNDESA, 2016).

### 3.4.1d Governance

Poor governance can lead to catastrophic water scarcities in semi-arid parts of the world. An example being in the Yemen, where, in 2015, after ousting President Hadi, poor water management led to the over extractions of groundwater; well drilling becoming the norm over other collection and storage methods. The poor rural areas have been left water scarce while what water is available is piped to the wealthy city dwellers (Whitehead, 2015; Ayana, 2016).

Kenya is well ahead of other countries in the region in setting a legal and policy framework for its integrated water resources management (GWP, 2015). Kenya first enacted a Water Act in 1952 as Chapter 372 of the Laws of Kenya. This Act has been revised several times and defines ownership, control, and management of all freshwater sources around the country (World Bank, 2012). The Water Act emphasizes the importance of local stakeholder participation in planning, implementing, and decision-making in addressing key issues of governance and social equity. Achieving such involvement in Kenya can be attributed to applying three water resources management levels: national, basin and sub-basin/catchment levels. The stakeholder's participation at the sub-basin/ catchment level, and possibly the local level, enables equitable benefit sharing regarding water sharing, so minimizing the possible risk of conflict during dry periods (Wolf, 2007; Marson and Savin, 2015). This involvement also allows for a feeling of shared resource ownership and cooperative management amongst the stakeholders, which in turn helps to ensure the security and quality of that the water resource at the basin and national levels (GWP, 2015).

In Kenya, a government agency, the Rural Development Department, has been charged with developing strategies, policies, and plans that ensure water is available for sustainable food production and rural development around Kenya. By forming water users associations at the local level the water user fees are reviewed on a regular basis, ensuring that the charge is manageable by the householders. Of note is that the focus that these government agencies is not on fresh water for domestic use, but on agriculturally based uses. However, by exploring some of the agricultural programs, it becomes apparent that water for human consumption is made more readily available to the rural communities because of these policies.

Also, recall that the primary water sources in these rural areas are in the form of rivers, streams, ponds and irrigation ditches (Leiter et al., 2013).

Kenya also has a National Soil and Water Conservation Programme, which encourages farmers to help improve water availability through soil moisture conservation by using conservation tillage, mulching, and soil conservation. The program also encourages farmers to become more aware of the harmful effects that agriculture can have on water quality (Chen and Hu, 2004; Lema et al., 2014). As with all countries in this region of the world putting policies into practice, and enforcing and monitoring the rules all present a challenge. In Kenya budgetary constraints, as well as the fact that water resources management is not given the same political priority as water supply and sanitation, also challenge the development of a fully-functioning water supply system (Gleick, 2014; GWP, 2015). In the developing, semi-arid rural setting the responsibility for the public service management of the water supplies has very often been offloaded at the federal level to the community level, the women in particular (Chowns, 2015). The result has not been the improvement of the technical performance or the financial sustainability of the water supplies, in fact, this offloading of responsibility has placed greater burdens on those communities already in need assistance (Hope, 2015). The question of access to available water at the local level is still not specifically addressed.

#### 3.4.1e Data Inaccuracies

Data inaccuracies also arise in country data deriving from shared water boundaries. The transboundary flows are not proportioned to neighboring countries but are often incorporated into more than one nation's data set Gaupp et al. (2015).

An example is the Mara River, which forms 250 miles of the border between Kenya and Tanzania, and Lake Rudolph, which forms a section of the frontier between Kenya, Tanzania, and Uganda. As Gaupp et al. (2015) point out, transboundary flows depend very much on border delineation, and trying to rescale national AQUASTAT data would not make sense. STRATA is an example of a statistical modeling program (see Chapter 3.7. for more details of the model) that has been run using best available data sets for East Africa. The model results show a significant decrease in the water supply across East Africa over the 2005-2015 period (Devi and Bostoen, 2009). Ninety million people proved to be water deprived, and thirteen million people may have had access to quality water but were less likely to have sufficient quantities of water for maintaining personal and domestic hygiene. This data result coincided with a decade that had been declared by the UN to be the Fresh Water Decade and emphasized the need to more realistic water availability data to be made available.

#### 3.4.1f Role of Women

The role of women as water providers and managers is well established in water literature. Where there are no standpipes and the water resources are scarce, it is the women and children who are most often affected by this water scarcity, as they do most of the domestic water collection, storage, and household distribution. This essential, daily, household chore requires that household members walk considerable distances, and spend many hours searching for water (Laurie, 2011; <http://water.org>). Forty billion hours are spent walking for water across the African continent every year (Adams et al. 2016). It is normal for people in rural East Africa to walk anywhere between 2-6 kilometers to collect their water supply (UN Habitat, 2010; Leiter et al., 2013); 74% of East African women must spend an average of 8 hours

per day obtaining water for their families (Snyder, 2012). The cost can be excessive regarding time; young girls are often taken out of school to take up this household chore, so adding to the socio-economic issue of undereducated women.

The storage and distribution role the women undertake in this life-giving resource is to the benefit to their societal respect (Falkenmark, 2013; Masanyiwa et. al, 2015; UNESCO, 2012). However, this role can also place a huge burden on the women when water becomes scarce. In the dry season, competition for the water will arise between the female's focus of the household's health and welfare, and the male's concentrate on the need for water for livestock. In some areas there is a culture of preventing recent widows from sourcing water from the community access; these issues display the intense gender politics that are associated with water scarcity in this region of the world (Rodrigues et al., 2015). In many instances, rural schools lack toilet facilities, which creates hardship for the females teachers and causes many girls to leave school once puberty is reached (WHO, 2015; WHO, 2017). This lack of an education is a guaranteed entrance into the cycle of poverty for these girls.

The UN, through the World Health Organization (WHO) and United Nations International Children's Emergency Fund (UNICEF) for women and children, has become involved in finding a solution to the devastating cycle of poverty that exists in so many undeveloped and developing regions of the world as a result of water scarcity. The aim of the UN is to improve the lives of those in need, and to "secure sustainable water for all". In a report of the same title released in 2014, the UN described how human well-being and economic prosperity, as well as the preservation of sustainable water, might be achieved.

### 3.4.1g Finding New Sources of Water

Finding new sources of water is critical to meeting the UN's Sustainable Development Goals in Africa; more than 90% of Africans still dig for their water (de Villiers, 2000).

Groundwater is a significant source of drinking water in the region. In some areas, the wells are so deep that a chain of people has to pass the water up to ground level (de Villiers, 2000). Very often, the quality of the water in the aquifers is threatened by a combination of over-abstraction (quantity) and microbiological and chemical contamination (quality). A study carried out by Wahome et al. (2014) on limited potable water sources in unplanned residential settlements of Kenya showed that the water from the sampled boreholes drilled into the aquifer was not suitable for human consumption due to microbiological and chemical contamination. They also found that there was an alarming increased incidence of antibiotic resistance among the pathogens present in that water. The study surmises that the lack of proper waste and wastewater management in these over populated settlements was responsible for the contamination of the aquifers. Once again, the fact that there is access to an available water resource in the environment of interest is not a guarantee that the water is suitable for drinking.

### 3.4.2 Water Quality - Case Study

Leiter et al. (2013) studied the quality of drinking water in seven rural villages in southeastern Kenya. The water is piped from unprotected dammed streams and springs and flows to collection points along the pipelines. The water then flows into community taps, kiosks, and tanks in the villages, where it goes into storage containers in the homes.

Communities, within the study area, experience both water quality and quantity problems. Five

of the communities regularly experience water shortages. During shortages, some of the villagers also drew their drinking water from shallow, hand-dug holes, which contained visible suspended sediment, and when tested was high in dissolved solids and had low in dissolved oxygen (Leiter et al., 2013). This water could have originated as rainwater, surface runoff, shallow seepage water or ground water flow. Rock catchment rain pools were also a source of drinking water; again this water had visible suspended solids and when tested was high in nitrates and phosphates, indicating that the water most likely originated as runoff from nearby fields. There was also a deep borehole in the area. The water tested from the borehole was high in concentrations of dissolved solids. Water samples were taken from all the village supplies and tested for nutrients, trace metals, and pathogens. All of the water samples tested, including that from the taps, were contaminated with total coliforms, and nearly all with *Escherichia coli*, from fecal contamination (WHO, 2008 and 2011; Bain, 2014). The piped sample results indicated that the water was entering the system already contaminated, a result of open and unprotected reservoirs. The study showed that bacterial contamination of water stored in the home would increase when stored for long periods in the house (Le Chevallier, 2003). Potential sources of this increased pollution include the buckets and jugs used to transport the water to the homes. The barrels used to store the water in the homes, the utensils used to serve the water, and unclean hands will all increase the potential for the pollution of the water (Pickering et al., 2011; Mattioli et al., 2014 and 2015).

The study also showed that the quality of drinking water in homes where treatment was applied was no better than in homes with no water treatment. It is possible that insufficient chlorine was being used to disinfect the water or that the water became contaminated long

after cleansing. Not all of the people who felt their water was unclean treated their water, possibly due to the high cost associated with the fuel required for boiling water or additives such as chlorine, a flocculent, and disinfectant. For those communities without access to a neighborhood water resource, a large part of the day is spent in the collection of this life-giving element (Leiter et al., 2013).

### 3.5 CHALLENGES TO AN ACCESS METRIC

By defining the actual value of the measurement of available water to the developing, semi-arid, rural communities as being the ability of the users to access the water resources, sometimes an access constraint is found at the household level. This limitation can be due to several issues, not least the socioeconomic circumstances that this demographic of the world population face; semi-arid, rural communities are some of the poorest communities in the world. Data further enhance the challenges; the consistency and reliability of data from different nations are often not appropriate to use in global analyses.

#### 3.5.1 Access: Socioeconomic and Demographic Considerations

A World Bank study carried out over a period of three years, from 1987-1990, in selected developing regions of Brazil, Nigeria, Zimbabwe, Pakistan, and India found that there are three explanations as to why or why not a householder is willing to use, or to pay for, an improved and type of water supply.

The first reason is the socioeconomic and demographic characteristics of the household. For these characteristics to be defined the education level of the family members, their occupation(s), the size and composition of the household as well as the amount of income, expenditures, and belongings of that family unit must all be understood. Better-educated,

employed, large sized family households were more willing to use, or to pay for, an improved water supply. The second explanation for why or why not a householder will be prepared to use, or to pay for, an improved water supply is the whether the improvement is an upgrade when compared to the existing or traditional sources of water. Included in this explanation must be the aspect of the financial cost and the cost regarding the time that is required to collect water, and the quality and the reliability of the supply. The study results showed that a household would be more willing to pay for an improved source when the quality and reliability of the existing water source is limited. In almost all cases, people were prepared to pay far more for the independence of a private connection than for access to a public tap. The third explanation is the households' overall attitudes toward government policy in the water supply sector. In many parts of the world, people feel that it is the government's responsibility to provide free or subsidized water; there is a sense of entitlement to government services. At the end of the study, four broad categories of village types were discernible in which the associated water plans ranged from the delivery of house connections at full cost to no improvement in traditional supplies. Table 6 summarizes these village environments and the associated utilized plans that might result in village participation from the World Bank study.

In summary, every community requires a different set of policies; policies that reflect the needs of the community as a whole, as well those of the individual householder's, and consideration as to their ability to pay for the water resource.

**Table 6:** Policy consequences- possible village participation (summarized from World Bank, 1993).

<b>Village Type</b>	<b>Householder's willingness to pay for access to water</b>	<b>Plans that would work best</b>
Type I	high willingness to pay for private connections; low willingness to pay for public taps	water service should be delivered through private metered connections or yard taps
Type II	a few will pay the full costs of private connections; the majority will pay the full costs of public taps	use of public taps, with the option of private metered connection, if householders are willing to pay for the full cost of the service; Kiosk are also an option, giving the households more flexibility and control over their expenditures
Type III	households are willing to pay for improved service, but cost is above their means	the service level for most households would be public taps, again with the option of a metered connection if a household can pay for it.
Type IV	low willingness to pay for improved water service; should be a government responsibility	the rural water supply policy response is simply to do nothing.

### 3.5.2 Data: Major Challenges to Developing a Global Indicator

There are three major challenges to developing a global indicator. The chief challenge is the data limitations, the quantity, the quality, and the scalability of the data (Gleick, 2015). Of note is that to date the quality of the collected data sets across nations has been found to be so variable that the analysis of trends in the data is difficult to achieve (UNEP, 2016). There is a global lack of continuous data sets that include basic hydrologic data such as groundwater availability, runoff, evapotranspiration and metrological data such as precipitation at the fundamental level, and climate variation at the upper level; all so essential to the core assessment of any water availability parameters (Ndzabandzada, 2015). The data set scale is watersheds and countries. This scaling makes accurate local analysis impossible.

The second series of challenges to be considered are the changes in definitions and methods of data collection over time, and inconsistent collection and definition of water-use

data; these inconsistencies can be at the regional, watershed, or economic sectors level, not to mention at the global scale.

Governmental restrictions on accessing water statistics in some regions is a third challenge to the development of global indicators. Of similar challenge are the institutional variables such as governance, regulatory effectiveness, and management capability that may affect the regional data collection (Alexander, 2015; Gleick, 2015; Ndzabandzada, 2015; Padowski et al., 2015; Akamani, 2016). Some governments show an inability to quantify some kinds of water metrics, such as the ecological water needs and recreational usage, also need to be overcome (Gleick, 2015). Uncertainties about how, and whether, climatic change around the world is affecting the already altering water supply in terms of demand and quality, and what the future changes might include are also variable across nations.

Another issue that varies across nations is in the comparison of available data. Often no consideration is given to the aerial extent, climate, and development level of the country in question (Molden, 2007).

### 3.6 DATA CHALLENGES AND DATA SHARING

The indicators identified in this research as being most useful in assessing water availability and access to that available water rely on several metrics. The measures of the quantity of renewable water available per capita per year (Water Stress Index), the water use per capita per day (Basic Water Requirements), the quantity of water used (Water Resource Vulnerability Index), and the percentage change in demand (Relative Water Scarcity Index). None of these parameters have any measure of actual access to the available water resource. However, the Water Poverty Index requires a series of parameters for its derivation, and the

combination of so many aspects of a community or region's data make this index the most comprehensive of all those shortlisted. This index specifically address access as a series of parameters, which include the percentage of households having a piped water supply; reports of conflicts over water use; percentage of water carried by women; time spent in water collection, including waiting; as well as access to sanitation as a percentage of population and access to irrigation coverage adjusted by climate characteristics (CEH, n.d.; Perez et al., 2015). From these last two variables an indication of the quantities of available water, which, with additional treatment, might be usable for domestic use.

The data that measure the progress toward the UN's development goals in developing regions of the world are gathered by intergovernmental agencies as well as individual government organizations and then reported at the county or regional scale (Grenken, 2010; UNESCO, 2012; UN, 2015; FOA, 2014). The UN states that all indicators and goals are applicable at any scale, and in any location around the world (UN, 2015). To measure progress towards the MDG, the UN classified the world's countries into three regions: developed regions, developing regions and undeveloped regions (UN, 2015). Since 1990 the UN has collected global water resource statistics from more than 100 national governments around the globe. The UN used the 1990 dataset as the base data to calculate the MDG water and sanitation targets (UN, 2001). The Joint Monitoring Programme (JMP) monitors and reports on the progress made towards the water and sanitation develop goals on an annual basis (UN, 2000; UN-Water, 2008).

Vörösmarty et al.(2010) point out that a worldwide consistency in the description, measurement, and reporting of water supply metrics, and meaningful policies and

management procedures need to need investigating before making valid global comparisons of any resource. Ideally, an access indicator should be a gauge of the ease with which an available water resource, of sufficient quality and quantity for domestic use, is made attainable to the user. An indicator that can be easily measured and understood by various level of water professionals and any user, and at any scale, from the local level to the regional level.

### 3.7 PROPOSING THE FUNDAMENTS OF A MODIFIED ACCESS INDICATOR

It became evident from the literature that any progress that is to achieve within the water sector about access to available water in developing nations requires a multidisciplinary approach, especially when reviewing the quantitative and the qualitative assessments made to the monitoring of water resources. The views and values of all the stakeholders must be incorporated. For an access indicator to be truly representative at the local level, the series of parameters comprising that indicator should represent the socioeconomic issues of access that people at the local level encounter.

Before drawing up any new water indicators and policies, it is imperative for planners to be willing to spend the time to research and fully understand the local water demands and supplies of the region under study. The Kenyan example demonstrates that for an access indicator to be a metric of practical use the parameters should include: locational access, a measure of distance to the available water resource; the time that is taken to fetch water, including waiting time at the source and waiting times; and the financial access, the actual monetary cost per measure of the water.

Some communities do have quantities of quality water made available to them, but the distances to those resources are often great, and thus there is a cost associated with its

collection (Hutton and Haller, 2004). The health and sanitary literature, imply that while access is the most realistic indicator of water availability, it does not necessarily mean that an accessible water source is safe to use. Other parameters that must, therefore, be included in an updated access indicator would be microbiological and chemical quality, which includes whether a source is improved or unimproved. Availability and reliability are particularly significant when measuring access to surface water sources in the developing, rural, semi-arid regions of the world (Pearson et al., 2016), and are additional parameters to include in the updated access indicator.

Educating each householder into the identification of the underlying quality of the water at point-of-use is essential. Combining this identification of safe water with the knowledge of basic treatment and storage methods for that water, this will ensure that the water they access remains in a condition suitable for drinking (Mwabi et al., 2011; Arvai and Post, 2012; Leiter, 2013). A series of basic water descriptors, such as speed of flow, temperature, clarity, odor, and color, would go a long way to help define poor water quality. A low flow, warm, turbid, brown water source that is shared by various animal species is one that is unsafe for domestic use.

### 3.8 NEW TECHNOLOGY THAT WOULD IMPROVE SPATIAL AND TEMPORAL DATA COLLECTION

Understanding the data challenges and resulting data inaccuracies require the use of more advanced technology- the wave of future data acquisition is via the cell phone and satellite data.

### 3.8.1 Technical Data: Remote Sensing Data

Remote sensing is a relatively new technology that can provide spatially and temporally distributed information on surface and ground water components that are revolutionizing the understanding of many aspects of world disasters, including diseases, flooding, and drought. (Yang et al., 2005; Lettenmaier et al., 2015; Birtwistle, 2016; Hermance et al. 2016; McNally et al., 2016; Tekeli and Fouli, 2016). Satellite imagery data can provide information about many diverse physical features of the land mass contained in that imagery, for example, the geomorphology, the soil types, the drainage patterns, and the geologic structures. The images are used to evaluate such water resource indicators as vegetation, rainfall, evapotranspiration, and water recharge zones (Mutiti et al., 2010; Guo et al., 2012; Stanley, 2012; Ndzabandzaba, 2015; Ruvaga, 2015). A single remotely sensed image covers a large spatial area and provides a noninvasive and relatively economical way of carrying out the reconnaissance stage of ground water exploration (Mutiti et al., 2010). Regional scaled maps are produced of the landscape, and by combining remote sensing with on-ground data, the land surface features that help to define the hydrogeology and hydrology of the area can be shown (Mutiti et al., 2010).

There are several satellites from various nations that gather remote sensing data relating to soil moisture. Soil moisture is an essential variable in the hydrologic study of a watershed as it has a direct impact on the flood area mapping, the water resources management, the agricultural productivity, the ecosystem health monitoring, and drought prediction of the watershed. The measurement of soil moisture requires a high degree of both spatial and temporal accuracy and resolution. Each measurement technology, however, can only partially provide the necessary high spatial and temporal resolution, full spatial coverage,

optimal sensing depth, and desired accuracy required to retrieve soil moisture over moderate vegetation condition. For the region under discussion, the semi-arid regions of East Africa, the data accuracy would be very questionable (NASA, n.a.; Piles et al., 2016). The application of satellite imagery to soil moisture is a science that continues to advance, and within the next decade is likely to become a more readily available measurement. Table 7 describes a few of the more efficient technologies that are presently in use. Satellite data combined with global resources modeling is certainly the direction forward for defining many of the intricacies of world water availability (Zaitchik et al., 2008; Davies, 2011; Huho, 2012; Swenson, 2013; Molero et al., 2016; Roth and Lemann, 2016).

**Table 7:** Summary of satellite data\ Global water resources modeling.

<b>Technology</b>	<b>Abbreviation</b>	<b>Owner</b>	<b>Spatial resolution</b>	<b>Accuracy</b>	<b>Notes</b>
Soil Climate Analysis Network	SCAN	USDA	40 km (poor)	good	
Climate Reference Network	CRN	NOAA	40 km (poor)	good	
Earths Observing System 3	EOS	U.S. Navy	> 50km (coarse)	poor	Combines Advanced Multichannel Scanning Radiometer (AMSR-E) + WinSAT
Agency's Soil Moisture and Ocean Salinity	SMOS	The European Space Agency	40 km	5cm	
Airborne Microwave Observatory of Sub-canopy and Subsurface	Air MOSS	NASA NASA's Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR) is being flown on a Gulfstream-III aircraft.	100meters at sub-weekly, seasonal, and annual timescales	good	Capable of penetrating vegetation canopies and soil to depths down to approximately 1.2 meters

**Table 7** (cont.)

<b>Technology</b>	<b>Abbreviation</b>	<b>Owner</b>	<b>Spatial resolution</b>	<b>Accuracy</b>	<b>Notes</b>
Soil Moisture Active Passive 7	SMAP	NASA	9km	fair	incorporates an L-band radar (active for spatial resolution only) and L-band radiometer (passive for soil moisture resolution) observations
Gravity Recovery and Climate Experiment	GRACE	NASA	Very coarse	poor	detailed measurements of Earth's gravity field used with terrestrial observations in numerical models

In the last decade, remote sensing has also emerged as an economical tool that complements surface geophysical techniques in groundwater exploration (Mutiti et al., 2010). Discovering and developing new groundwater sources are often held up by the high costs of exploration and drilling. Geophysical techniques such as surface resistivity can reduce the cost of finding groundwater resources (Devi et al. 2001). There is a limited understanding of groundwater resources in Kenya, which at present provides less than 10% of the national supply (Grenken, 2010; FOA, 2016). This region of Africa could obviously benefit from the development of some of its yet untapped groundwater resources, especially in the rural areas (Mutiti et al., 2010). In 2013, the first large-scale survey of groundwater resources in Kenya was conducted by UNESCO with funding from Japan. This survey took place in central Turkana County, the impoverished, arid and semi-arid land (ASAL) in the north of Kenya. Here there are hundreds of thousands of pastoralist communities as well as three refugee camps for South Sudanese people. The satellite imagery defined two aquifers, the Lotikpi Basin and the Turkana Basin (UNESCO, 2013; Ruvaga, 2015), and the hope was that water from these two aquifers

would provide a much need supplement to the already very scarce and well guarded existing water supply. Test boreholes into the two aquifers found that there were significant quantities of water. However, the saline content was seven times higher than the WHO threshold of 20mg/liter for sodium carbonate (WHO, 1996), making it unsuitable for drinking. For the present, the cost of drilling the wells, installing and maintaining the pumping equipment to draw the water to the surface, as well as to desalinize and the distribution of the water is not considered to be economically feasible, and the Kenyan government has shelved plans for the water resource development of these aquifers.

### 3.8.2 Models

Modeling is a useful tool to analyses available data. Modeling will become a more precise representation of the water resources environment as data sets become more extensive and the data becomes more reliable. Statistical modeling programs, such as STRATA, have been run using best available data sets for East Africa by Devi and Bostoen (2009). The models show a significant decrease in the water supply across East Africa over the 2005-2015 period, a decade declared by the UN to be the Fresh Water Decade. For the modeling, 'access to water' was defined as an improved water source is less than 30 minutes collection time away from a household. The modeled results are dependent upon the accuracy of the country data sets, but the overall results are consistent with the actual JMP reports data for the period 2005-2008. The models show a very apparent change in access to an improved source of water in rural areas; where there was a 10% average reduction in the availability of quantity, the model showed that more than 62% of the rural population had no access to a public water source.

More than 10% of the same population spent more than 30 minutes collecting water from improved water sources, i.e. water source was not accessible (Devi and Bostoen, 2009).

## CHAPTER 4: SUMMARY

Clean drinking water is essential to human survival. By defining the ability of the users to access water, the value of an available water resource becomes apparent. To understand a nation's true water resource availability, the dynamics behind a community's access to that resource must be tied to realistic metrics; one that assesses water access at that same scale.

In the developing, semi-arid, rural regions of the world water is often a scarce commodity, and the socioeconomics of these communities often put further pressures on any available water, making access all the more important (Bouwer, 2000; Shiferaw et al., 2014). A prime driver in the quantity of a nation's water demand is the result of population growth and increased standards of living due to rapid economic development, bringing about challenges to significant agricultural water use. A close coordination of the agricultural demands with the overall water management needs to be of priority in undeveloped and developing countries.

Undeveloped and developing countries have especially modest per capita incomes, high economic vulnerability, and low levels of education. A large proportion of these nations are in sub-Saharan Africa (UN, 2011); nations that specifically suffer from perennial water and food shortages leading to health problems. Recall that when water is scarce the quality of the water becomes secondary to the quantity. Human's need for water to survive will always outweigh the most basic of water quality standards.

The literature shows that the relationship between water quality and water quantity is a function of many factors including: the hydrology of the area of interest; the environmental condition of the region; the infrastructure used for conveyance of water resources; the governance of such resources; and the overall socio-economic situation of the area being

studied (Davies, 2011; Rodrigues, 2015; Lui, et al., 2016). The general water literature shows that water shortages in the area of focus are due in large part to that the lack of capital to invest in the individual nation's infrastructure (i.e. water treatment and distribution systems) (UN, 2014a; Moss, 2017). The literature review showed that most of the more recent water and health research has focused on water quality. All the while, neglecting the importance of water adequacy with regard to access, particularly in the focus region: the developing, rural, semi-arid parts of the world (Barbier and Hochard, 2014; UN, 2011). With the pressing issues of climate variation scarcity of water around the world is no longer a rare phenomenon, and as meaningful discussions of the policies and management of available water resources need to continue to take place a genuinely representative indicator that addresses the issues of access is required.

A series of water availability indicators have been derived from global discussions in the water resource field and are being used to identify the needs of the general population. Key findings demonstrate that five of these current indicators focus on the physical availability of the water, but do not give metrics for quantity or quality, and more importantly, they do not account for access to it. The findings also show that these indicators are based on data collected at the country or regional macro-scales, but are often applied to the fundamental local level, giving erroneous availability statistics. To this end, the UN created the Millennium Development Goals (MDGs) and post-2015 the Sustainable Development Goals (SDGs), which address the cycle of poverty. The MDG/SDG indicator is the only indicator reviewed (out of the six commonly used indicators) that uses a representative metric for access at the scale of the user (Sorenson et al., 2015).

To achieve the 100% SDG for universal and equitable access, everyone needs to do their part: the government, the private sector, civil society and the individual. The parameters used to derive the indicators need to: be more representative of water access conditions experienced at the local level, use data beyond water quantity and quality, and to have metrics that specifically describe access to water regarding cost and accessibility by the targeted communities.

There may not be a suitable singular indicator. However, any indicator needs to be: easy to calculate, cost effective to implement, scalable to the micro-level, based on existing data, developed using a transparent process and, not least, must be easy to understand by all the stakeholders. The veracity of the collected data for all indicators will be enhanced as satellite derived data become the norm rather than the exception around the globe. The ideal system will put information and new technologies into the hands of the people who manage and use water at the local scale.

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