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Sustainable Water Use in Agriculture: The Potential of Wastewater

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, 01. June 2017

Affidavit

I, **LISA DELLA PIETRA**, hereby declare

1. that I am the sole author of the present Master's Thesis, "SUSTAINABLE WATER USE IN AGRICULTURE: THE POTENTIAL OF WASTEWATER", 67 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

The natural water cycle is finding it harder to keep up with rising water demand due to population growth, climate change, increased urbanization and life-style changes. With rising water scarcity levels across the globe, new water sources like treated wastewater will be key for ensuring future sustainability. Since agriculture is the biggest global consumer of freshwater, its potential for alleviating water stress should be harnessed. For this reason, a quantitative analysis of secondary data was elaborated in this thesis. Firstly, the supply side was analysed to look at quantifying global treated wastewater production potential via municipal water withdrawal and access to improved sanitation. Secondly, this data was paired with the irrigation water demand of the three most popular dry cereal crops to estimate wastewater irrigation potential for 127 countries. While the biggest treated wastewater production potential was found in highly populated countries with high access to sanitation, the highest irrigation potential was found in countries with medium irrigation water demands and elevated amounts of treated wastewater production. Combining total irrigation demand and total treated wastewater production potential, this paper finds that wastewater irrigation could on average make up for almost 66 percent of total irrigation need of global dry cereal cultivation. Therefore, the paper concludes that if actual wastewater treatment infrastructure would be expanded to match the potential calculated in this study, the treated effluent could significantly alleviate water stress by decreasing agricultural freshwater withdrawals. This would not only increase global sanitation levels and water-use efficiency under 'Goal six' of 2015 Sustainable Development Goals but also increase food production in water stressed regions to combat hunger and food insecurity under 'Goal two'.

Keywords: wastewater reuse, agriculture, irrigation water demand, water scarcity, sustainability.

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List of Abbreviations

AU	African Union
GAEZ	Global Agroecological Zoning
GLAAS	Global Analysis and Assessment of Sanitation and Drinking Water
FAO	Food and Agriculture Organization
ISO	International Organization for Standardization
JMP	Joint Monitoring Program
IIASA	International Institute for Applied Systems Analysis
UN	United Nations
US	United States of America
SDG	Sustainable Development Goals
WHO	World Health Organization

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1 Introduction

Even Leonardo Da Vinci once said that *"water is the driving force of all nature"*(American Water College 2017). However, the natural water cycle is finding it gradually harder to keep up with the steadily increasing anthropogenic use of water resources. While the usage is rising progressively at almost double the rate of population growth, the reservoirs are not growing accordingly. In fact, even though the earth's planetary surface is covered in 75 percent water, the amount of freshwater resources reaches only 2.5 percent. Out of which two thirds are frozen in the polar icecaps, and one third or 0.7 percent of global water resources are accessible for human use (WWAP 2017a). Although these natural freshwater reserves are continually replenished, the process usually takes weeks and sometimes even years or centuries. On the one hand, these amplified water needs can partly be attributed to the massive population growth almost quadrupling world population during over the course of the 20^{th} century (WWAP 2012). On the other hand, increased urbanization as well as significant land-use and life-style changes go hand in hand with intensified water needs. In the end, climate change, pollution, urbanization, population growth and dietary changes are counted among the most important reasons for rising water stress and growing water scarcity levels. (Scheierling et al. 2010; Hussain 2002; WWAP 2012; Asano et al. 2007).

In general, rising water stress levels are connected to growing water demand from the three principal water withdrawal sectors (agriculture, industry and municipality). However, to make these levels comparable on a global level a standardized scale indicating quantitative observations on annual renewable water resources was developed. This scale identifies a value below 1.700 m^3/per capita/year as water stress and a value below 1000 m^3/per capita/year as water scarcity (B. E. Jiménez and Asano 2008; Mateo-Sagasta et al. 2013). However, these phenomena are also multifaceted, which is why it is important to make a distinction between physical and economic water scarcity. While physical water scarcity explores the issue of diminishing water resources and the actual physical lack of water in certain regions, economic water scarcity deals with lacking water infrastructure and the resulting absence of access to water. According to previous studies done by the United Nations (UN), around 20 percent or one fifth of the global population are threatened by physical water scarcity and almost 25 percent or one fourth are living in conditions of economic water scarcity. (WWAP 2012; B. E. Jiménez and Asano 2008; Mateo-Sagasta et al. 2013)

Hence, the world is currently on the brink of a water crisis and immediate actions might be decisive for securing a safe future. Now, more than ever, growing consciousness around scientists but also among policy makers marks the importance of finding sustainable solutions to solve the water issue. However, as the initial quote already stated, water is not an isolated problem or issue. It is an interdisciplinary matter due to its high degree of interconnectedness with some of the most basic features of human life. (Mateo-Sagasta et al. 2013)

The “food-water-energy” nexus highlights these connections very clearly, but also the United Nations (UN) Sustainable Development Goals (SDG), which were established in 2015, make reference to the importance of supply security of clean water. There is a target called ‘Goal six’ which aims at ensuring clean water and sanitation not only by finding innovative solutions to increase clean water supply and combat water scarcity but also by improving sanitation and reducing water pollution. The aim of ‘Goal six’ also serves as precondition or enabling factor for almost all of the other 16 goals, which range from poverty reduction, good-health and well-being to food security, sustainable cities, responsible consumption as well as life on land and below water (UN Water 2015). Therefore, a lot has been done to raise awareness, build capacities and transfer technologies, especially to developing countries. Particularly, increasing access to sanitation by building modern wastewater management facilities could prove to be a chance to increase population health as well as water quality and quantity. For this reason, there should be an increased focus on changing public perception on wastewater and converting it from waste which is polluting our freshwater resources to a reservoir of opportunities. 2017 has proven to be pivotal for the role of wastewater in water management. Not only by providing us with increased action under the SDGs but also with UN Water making wastewater recycling the topic of this year’s “World Water Day”. (UN Water 2015; WWAP 2017b)

However, it is important to underline that primary domestic use by humans is not the only and by far not the most important factor influencing water stress. The increasing scarcity levels are actually mainly caused by agricultural and industrial use of water resources. Agriculture in all its forms is responsible for almost 70 percent of global freshwater use (WWAP 2012). With physical and economic water scarcity levels rising and irrigation agriculture being largely done in semi-arid zones, this poses a big problem for ensuring safe and sustainable water resources for the future. Therefore, the tremendous potential of agriculture for improving sustainability and alleviating water stress needs be harnessed. For this reason, many new technologies have been brought forward to solve the issue of unsustainable water use in agriculture. Recently, there has been renewed interest in the potential of wastewater as a sustainable water source. While traditionally it is mainly used to replenish surface water resources, an increasing number of countries, are now using the treated effluent for agriculture and/or industrial uses. The past years have seen increasingly rapid advances in the field of wastewater treatment technologies as well as a rising number of treatment plants of various sizes around the world. Not only, because using treated wastewater has a positive environmental impact, but also because it could have huge additional benefits on agricultural yield, nutrient use and ensuring food security. Nonetheless, there is an urgent need to address the safety problems currently associated with using untreated wastewater in agriculture. This holds especially true in developing countries and transition economies such as China, India, Pakistan or Mexico, who are counted among the nations with the highest rate of untreated wastewater recycling for irrigation. (Hussain 2002; B. Jiménez et al. 2010; Mateo-Sagasta et al. 2013; WWAP 2017b)

With almost 40 percent of the world population suffering from or approaching physical and/or economic water scarcity, finding additional and sustainable water sources is crucial for the future (WWAP 2012). Currently, almost 80 percent of the annually produced municipal wastewater is directly discharged into natural waterbodies without treatment (WHO 2015). On the one hand, this causes pollution and additional stress for local water sources. On the other hand, it entails an enormous waste of an already vulnerable resource. Therefore, harnessing this new source via an expansion of wastewater treatment infrastructure could provide us with a new and steady water source to meet increasing global water demand. Since agriculture is the biggest global water user, its potential for alleviating water stress and increasing sustainability is immense. Consequently, this thesis wants to proof that an increase of wastewater treatment infrastructure and a subsequent establishment of standardized and efficient wastewater reuse schemes could potentially decrease agricultural freshwater abstraction for irrigational purposes and significantly increase water sustainability.

2 Goals and Objectives

The purpose of this paper is to assess the current global potential of recycling treated wastewater for irrigation to argue that it is a valid alternative for ensuring sustainable water resources for agricultural purposes. Therefore, the analysis will be organized along the following research questions:

1. What is the global potential of municipal wastewater?
2. What is the global potential of wastewater for agricultural irrigation of cereal crops?
3. What is the regional potential of wastewater irrigation of cereal crops on the African Continent and how would changes under ‘Goal six’ of the SDGs change it?

It estimates potential wastewater production in more than 167 countries on six continents via municipal water withdrawal and access to improved sanitation. In a second step, this data will be combined with the specific irrigation water demand of popular selected cereal crops for individual countries to calculate the potential for wastewater irrigation in 127 grain cultivating countries. In a third step, the specific treated wastewater irrigation potential of the African Continent will be analysed. Finally, the study aims at recombining the findings of the quantitative analysis to formulate concrete policy recommendations with regards to reaching the targets of the SDGs and particularly ‘Goal six’. Consequently, it will not only analyse the global wastewater potential but also go into more detail concerning its agricultural irrigation reuse potential, especially in the case study on the African Continent. Africa was chosen because it is not only rich in climatic and demographic variations but also because the water stress and water scarcity levels are very different on this diverse continent. Furthermore, agriculture is one of the core development areas of Africa. Especially, with the newly launched “Feed Africa” programme focussing on agricultural transformation for economic growth, combating poverty and food insecurity as well as achieving better living standards particularly in rural areas (AfDB 2016). The theoretical and practical basis for this quantitative analysis is a review of current international standards and guidelines for wastewater use in agriculture.

Due to practical constraints, this study is unable to encompass the entire topic of wastewater recycling. Therefore, the quantitative analysis, which was elaborated over the course of this paper, only focuses on direct reuse of treated wastewater in irrigation agriculture. Assessing the indirect use of the treated effluent as well as the direct and indirect use of untreated wastewater lies beyond the scope of this study. Especially, because the use of the untreated effluent, albeit very popular in developing countries, is still sparsely documented on a statistical level. Additionally, the use of untreated wastewater comes with big environmental and human health issues and can, therefore, not be considered as a sustainable solution. Consequently, including it in this study would defeat the purpose of promoting wastewater as a safe and reliable water source. However, this thesis acknowledges the importance of weighing both the positive and negative impacts of wastewater recycling. A comprehensive review of environmental impacts and potential negative health effects is, nonetheless, not possible within the limitations of this thesis. Therefore, this study excludes all health concerns related to wastewater recycling and solely focus on the quantitative possibility treated wastewater and the expected effect on increasing food security.

2.1 Structure

This study follows the approach of a mixed methodology split in two phases. The first is based on qualitative literature review and analysis of related books, scientific journal articles, conference papers as well as official documents and datasets by relevant international organizations. Furthermore, this phase analyses the already established guidelines concerning wastewater use for agricultural purposes and contrasts their quality parameters and safety standards. The second and central phase of this thesis focuses on a quantitative analysis of secondary data on actual and potential wastewater production and the possibility of its agricultural reuse for irrigation. This is done, in two ways. On the one hand, by looking at current treated wastewater production on a global scale and comparing it to potential wastewater production calculated via municipal wastewater withdrawal and access to improved sanitation. On the other hand, by matching the irrigation demand of five chosen cereal crops with the calculated wastewater production potential. While the general geographical and demographic data is extracted from various international sources, the ‘Food and Agriculture organisation’ (FAO) provides an array of data in FAOSTAT which is used in the quantitative part of this thesis. More specifically, the database AQUASTAT offers comprehensive data on water and wastewater. The software CROPWAT was used to calculate specific crop water demand, irrigation needs as well as growing periods detailed for the five chosen grain crops.

2.2 Definitions

The following section provides a brief explanation of the terms used over the course of this thesis. The definitions provided pertain to the sense in which they are used in the scope of this study and not necessarily their initial or general meaning.

Agriculture

It includes all conventional farming practices that serve to produce food and other products. It ranges from soil cultivation with crops to animal-rearing, but in the context of this thesis it specifically refers to irrigation agriculture that is growing different types of crops. (Pescod 1992a)

Direct reuse

In this thesis, direct reuse specifically refers to the anthropogenic use of treated wastewater for irrigation without additional natural barriers. This means that direct reuse refers to the use of treated wastewater straight from the treatment plant without by being diluted by discharging it into natural ground and surface water bodies. (Mateo-Sagasta and Salian 2012)

Fodder crops

These crops are primarily intended to feed animals and include crops such as grasslands, pastures, legumes and roots. (FAO 1994)

Food crops

These crops are produced for anthropogenic food use and are separated into different categories pertaining to their primary form of consumption (e.g. raw, cooked, and processed). (FAO 1994)

Indirect reuse

In this thesis, indirect reuse again refers to anthropogenic use of treated wastewater for agricultural irrigation. However, the treated effluent for indirect reuse has passed additional barriers of the natural water cycle by being discharged to local freshwater bodies. (Mateo-Sagasta and Salian 2012)

Municipal wastewater

Municipal wastewater is a mixture of different urban water flows from both, public (public institutions, hospitals, schools, etc.) and private (domestic households, small and medium sized businesses and industry) users. In this context, municipal wastewater refers to collected municipal wastewater which has been gathered via independent or collective urban sewer systems. (Mateo-Sagasta and Salian 2012)

Primary treatment

The first and most basic treatment of wastewater intended to rid the influent of coarse particles (e.g. sand, stones, plastics, personal hygiene products, etc.). Usual processes and technologies include sedimentation and septic tanks. Additionally, chemical treatment is used to increase . (Mateo-Sagasta and Salian 2012)

Restricted Irrigation

The use of the treated effluent for agricultural irrigation in zones with restricted public access due to formal or physical barriers. (WHO 2006a)

Secondary treatment

The second stage of treatment usually deals with biological processes like activated sludge or bio-filters. These processes are removing almost two thirds of the biochemical oxygen demand (BOD) and the chemical oxygen demand (COD). Apart from these technology-driven methods, the FAO database also counts natural biochemical processes which might happen in different types of ponds (e.g. waste stabilization, algal, etc.) or due to natural filters (e.g. soil in aquifers) under this category. (Mateo-Sagasta and Salian 2012)

Tertiary treatment

The most advanced treatment stage which uses further biological, chemical and technical methods like biological nutrient removal, membrane filtration, disinfection or activated carbon to rid the effluent of almost all its BOD and around 85percent of COD. Furthermore, this treatment step also significantly reduces the amount of nutrients (e.g. phosphorus or nitrogen), which can be used as natural fertilizers in agriculture. (Mateo-Sagasta and Salian 2012)

Treated effluent

The part of municipal wastewater that has been collected in a sewer system and run through at least one of the three treatment stages (primary, secondary, tertiary) of an urban wastewater treatment plant. (Mateo-Sagasta and Salian 2012)

Unrestricted Irrigation

Agricultural irrigation with treated effluent in zones with no public health or access restrictions. (WHO 2006a)

Untreated effluent

The part of municipal wastewater which has not gone through a treatment process and which has directly been discharged into a local existing water body. (WHO 2006a)

The following chapter three of this master thesis presents a general introduction to municipal wastewater as well as the history and practice of its reuse in the context of agriculture. Subsequently, the legal background in terms of international standards for wastewater recycling on the grounds of the various guidelines is elucidated in the fourth chapter. Next, the quantitative analysis and its core constituents are defined and combined in chapter five. Following this, chapter six outlines the results of the quantitative study on a global scale and explains them with regards to their implications for potential wastewater reuse. Chapter seven takes a closer look at the regional results of the African continent. A resume concludes the discussion with final remarks and a critical reflection regarding the role of wastewater in agriculture and its implications for attaining some of the targets of the SDGs.

3 Literature Review

This chapter aims at providing an overview of past literature and studies that have dealt with wastewater reuse for agricultural purposes. After a short introduction to the topic of municipal wastewater, the concept will be further examined by looking at past and current practices in the field of agriculture. Additionally, the legal framework provided by the international guidelines on safety and quality standards will be elucidated.

3.1 Municipal wastewater

Municipal wastewater is typically described to be a blend of different urban water flows from both, public and private users. The biggest part is coming from domestic wastewater, which consists of not only blackwater (e.g. toilet water containing faeces and urine) but also greywater (e.g. kitchen or bathing water containing soap and other personal hygiene products). Other sources of municipal wastewater are bigger public and private institutions (such as schools, hospitals or businesses), local industry and so-called storm water (e.g. excess surface water due to heavy rainfall) and urban run-off from impermeable surfaces (e.g. streets and houses) (Hussain 2002; van der Hoek 2004). Scientists have found that around 80 percent of all water supplied to commercial and domestic users in urban areas is actually not consumed by them (e.g. drinking, cooking evaporation or plant watering) but rather discharged back into the water management system as municipal wastewater. Granting that municipal wastewater composition strongly depends on the specific community, scientists agree that it almost always compromises organic and inorganic matter, nutrients, pathogens as well as possibly harmful chemicals. Therefore, untreated wastewater poses a direct threat to human health and the environment. In recent years, wastewater treatment has experienced a wave of renewed interest particularly in the developed world. Albeit an impressive leap in technology, since then, many developing countries are still struggling to provide a suitable sanitation system to their communities. This means that many urban areas in developing and especially in least developed countries are not able to successfully equip their cities with a sewer system connected to municipal treatment plants. For this reason, 'Goal six' of the SDGs is of utmost importance. First and foremost, to protect the urban population from health hazards but also to increase water management efficiencies and create new clean water sources. (van der Hoek 2004; Hussain 2002; Asano et al. 2007; Scheierling et al. 2010)

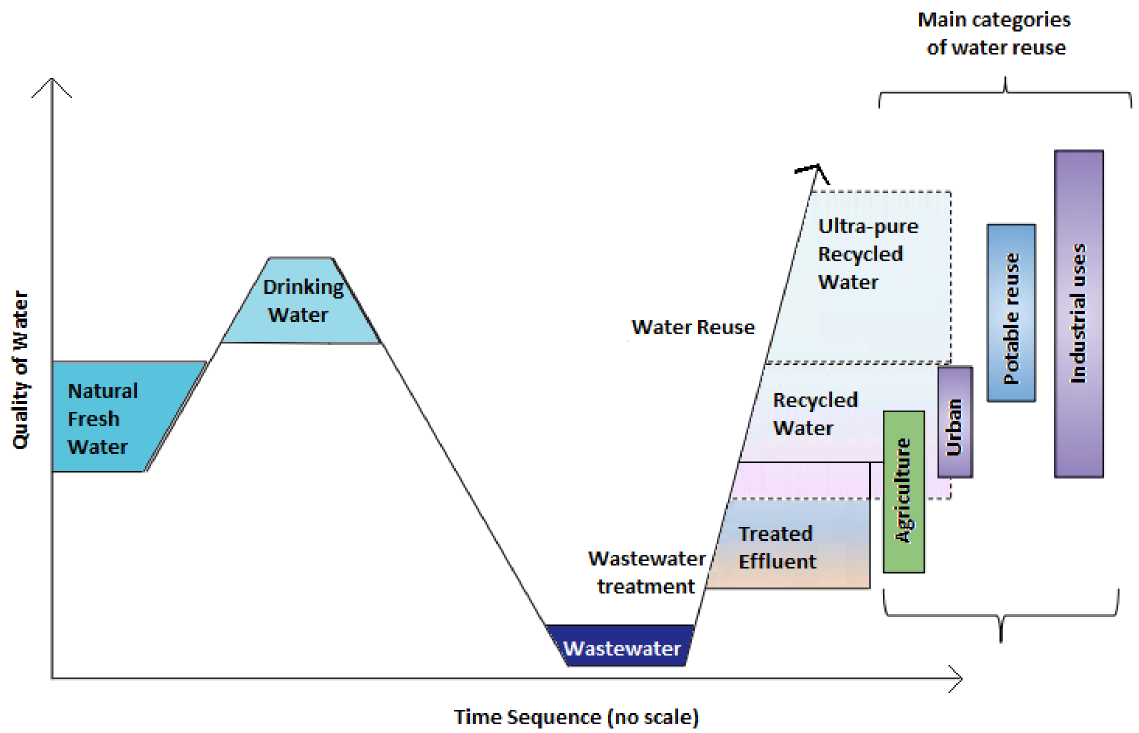

Figure 1: Urban Life-cycle of Water
(Source: own depiction after: Lazarova, Valentina, and Takashi Asano. 2013. "Milestones in Water Reuse: Main Challenges, Keys to Success and Trends of Development. An Overview." In Milestones in Water Reuse, 8, fig 5. IWA Publishing.)

The graph above shows the life cycle of urban water and particularly highlights the possible direct and indirect reuse options after successful treatment depending on the treatment grade. It clearly demonstrates that various treatment steps are necessary to turn municipal wastewater into a treated and useable effluent. The difference in treatment options but also quality parameters is essential in determining the reuse possibility. Wastewater that has run through at least primary and secondary treatment possesses the necessary basic quality parameters to be used for some agricultural purposes, such as irrigation of non-sensitive crops (such as fodder, fibre or seed) and other arable land. Logically, the higher the treatment level the bigger the reuse potential. Therefore, the highest level of treatment allows not only for industrial or agricultural reuse but even enables potable-water uses. The process of recycling wastewater for agricultural purposes will now be further elucidated in chapter 2.2.

3.2 Agricultural wastewater reuse

As already mentioned in the introduction, water stress and water scarcity levels are rising all over the world due to population growth, climate change, and lifestyle as well as dietary changes over the last century. A study done by Molden (2007) for the International Waste Management Institute shows a world map clearly indicating areas of both economic and physical water scarcity. This means that people living in these regions dispose of less than 1.000 m³ annually recharged water resources/per capita. Additionally, the map points out regions with significant potential of falling under physical water scarcity. Combining these three factors, it becomes clear that water scarcity mainly affects developing countries in Africa and Asia. Although, this map only gives a global overview which does not go into regional differences in countries (e.g. north and south of Spain), the trend of geographical distribution to developing countries is still indisputable. (B. E. Jiménez and Asano 2008; Lautze et al. 2014; Molden 2007)

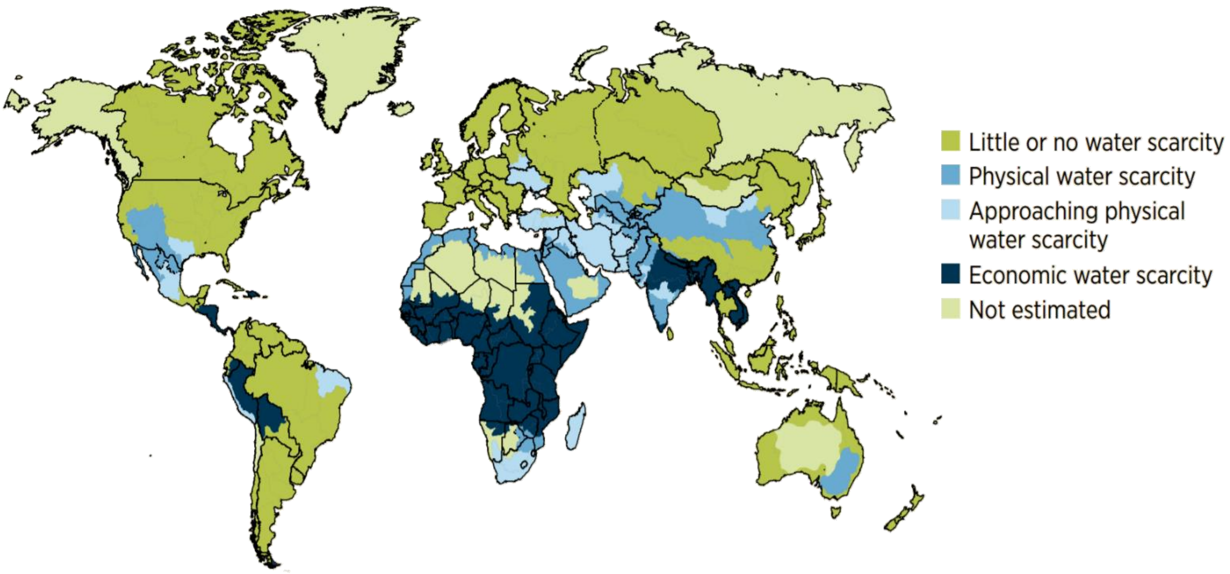

Figure 2: Global Overview of Water Scarcity Levels
(Source: Molden, D. Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. Edited by International Water Management Institute and Comprehensive Assessment of Water Management in Agriculture (Program). London ; Sterling, VA: Earthscan, 2007.)

In developing countries, water scarcity also goes hand in hand with food insecurity and other socio-economic challenges. Therefore, establishing new sustainable water sources for agriculture and irrigation is a key factor for the ensuring future development of water stressed regions. Especially since, global agricultural freshwater withdrawals are currently amounting to around 70 percent or more than 3 billion cubic meters (m^3) and are expected to rise to about 4,500 billion m^3 in 2030, mainly due to growth in Southern Asia and Sub-Saharan Africa (Hamdar, Hejase, and Sayed 2014). Water demand is especially high in developing regions that are still largely run by smaller and consequently poorer subsistence farmers who do not dispose of new water-saving irrigation technology and advanced agricultural capacities. Especially, spray irrigation who loses a lot of irrigation efficiency due to losses to the atmosphere via evaporation. Consequently, efforts of increasing sustainability in water use need to be focussed in this sector. Treated Wastewater will have a key role in this because it still is one of the great ‘untapped resources’ of our planet. (Scott et al. 2004; Hussain 2002; Asano and Levine 1996)

Nonetheless, there are already around 60 pioneer countries actively reusing wastewater for different purposes (e.g. irrigation, aquifer recharge, toilet water, industrial cooling water). Still, it remains difficult to quantitatively compare reuse data since there is no international standardization and reported data is based on national guidelines. Jiménez Cisernos (2014) tried to compare respective data and found that in terms of annual quantity of wastewater production the United Stated of America (US), China and Mexico are on the forefront. However, if considering reuse intensity, the leading countries are mainly found on the Arabian Peninsula (e.g. Qatar, Kuwait). A UN-report assessing future wastewater reuse potential, especially highlighted Australia, China, Japan, Spain and the US as areas with the biggest expected reuse growth over the next decade. Currently, the highest treated wastewater reuse can be found in Israel, with almost 80 percent of total wastewater production. Singapore is also increasing efforts but currently only supplies 30 percent of total water demand with treated wastewater. In absolute numbers, California and Spain are counted among the top countries with an annual amount of 860 m^3 and 500 m^3 respectively. (Angelakis and Snyder 2015; Angelakis and Gikas 2014)

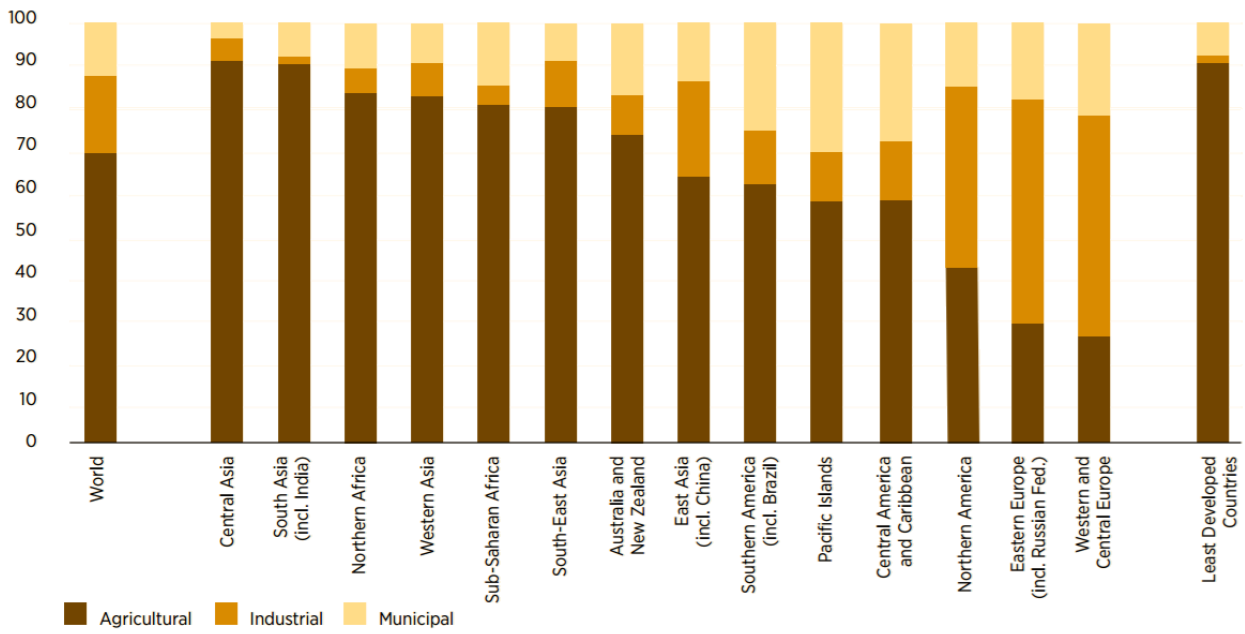

Figure 3: Global Water withdrawals by Sector
(Source: WWAP, (World Water Assessment Programme). 2012. Managing Water under Uncertainty and Risk. Edited by Unesco. The United Nations World Water Development Report 4. Paris: UNESCO)

The practice of recycling and reusing municipal wastewater for agriculture and mainly irrigation is not a new concept. Studies have shown that it goes back some 4000 years to the ancient Greeks (Scheierling et al. 2010, 3). Even if the usage back then was still very rudimentary, it was a first step in realizing the immense potential of wastewater. Not only as a source for replenishing freshwater reservoirs and/or as a back-up to alleviate water stress but also as a source for by-products such as nutrients for fertilizers to maintain soil productiveness and ensure food security. This was also practiced by the Chinese and quickly adopted by both the Koreans and the Japanese. Europe and the Western world only discovered the power of wastewater in the sixteenth and seventeenth century, when they started constructing the first sewage farms for agricultural use in Scotland and Germany. The real breakthrough of wastewater came with increased technology and rising demand from ever-growing urban centres. Especially, in the 1980s and onwards, cities in Europe but also South Africa have invested in this technology to cope with rising water stress levels and increasing demand. (Angelakis and Snyder 2015; Lazarova and Asano 2013, 15f.)

Nowadays, the concept of circular economy is gaining ground on all fronts and water professionals are stressing the importance of wastewater in that regard. Treating it as a resource rather than waste, just like paper or metal, harbours a chance to change agriculture and therefore food production forever. Especially, because most agricultural epicentres are located in semi-arid regions which are either suffering from or approaching physical water scarcity. As already mentioned above, there is still a massive divide between developed and developing countries in this regard. While most developed countries are now starting to increase their efforts to reuse wastewater as irrigation water, most developing countries have a long history of using untreated wastewater in agriculture. Therefore, improving wastewater treatment and its direct agricultural reuse for irrigation will be one of the key factors in ensuring food security and alleviating water stress. (Scheierling et al. 2010; Bixio et al. 2006; WWAP 2017a; Winpenny, Heinz, and Koo-Oshima 2010)

4 Wastewater Reuse Guidelines

After looking at the theory of agricultural wastewater reuse, this section will focus on giving an overview on international guidelines published this field. Although the main aim of this thesis is a quantitative analysis of wastewater potential, it is still important to establish a safe reuse environment for agricultural purposes. For this reason, this segment will shortly present relevant international guidelines with universal applicability. The most recent guidelines in this field ('US-EPA Guidelines', 'Title 22/California' and 'Australian Guidelines') will not be analysed, since they are specific to certain geographic areas. After a short individual introduction to the standards published by the three international organizations, their general quality parameters (if applicable) and safety classifications will be summed up in a contrasting table.

4.1 FAO Guidelines

The FAO is the world's leading organization in ensuring food security by combating global famine. Therefore, keeping their priorities within the 'food-water-energy' nexus, they are regulating wastewater reuse for agricultural purposes. On the one hand, to ensure supply security of water and eventually food supply but also to safeguard human health and promote access to sanitation. Since the 1990s, the FAO supports various types of alternative water sources but wastewater is especially enforced in semi-arid and arid areas suffering from physical water scarcity. The organization also cooperates with the WHO, which ensures uniformity in terms of water quality standards. However, their focus lies on the protection of human health with measures in four pre-defined categories to regulate irrigation agriculture. These include the treatment of wastewater, restriction of certain crops, control of wastewater usage, and safeguarding human health. The organization also clearly specifies rules and procedures concerning irrigation mainly to protect human exposure and promote general sanitation and good hygiene. These irrigation rules include recommendations on specific irrigation methods, water quality and quantity as well as timing of irrigation. They also separate irrigated land into two categories (restricted and unrestricted) based on public access and human exposure levels. (Pescod 1992b)

Based on their overall goal of ensuring food security and human health they have elaborated four categories of treatment standards, ranging from preliminary to tertiary or advanced treatment. Additionally, the FAO specifies disinfection mainly against pathogens as a supplementary treatment option. The water quality parameters largely depend on grade of water treatment and other restrictions depending on their primary use and the exposure of workers and consumers alike. To this end, the FAO has also separated crops into two bigger categories. First, they distinguish between food crops that are either to be eaten raw or after cooking. Depending on their end-use, they ask for more stringent water quality and treatment criteria. Second, they mention fodder crops which are either directly accessible to animals for their consumption or are harvested before they are fed to animals. Furthermore, inside the two categories crops are still calibrated on a sensitivity scale to a variety of factors (e.g. salinity). (Pescod 1992a)

4.2 ISO Guidelines

The ‘International Organization for Standardization’ (ISO) has published a comprehensive series of guidelines on wastewater reuse with one particularly focussing on its agricultural repurposing. Just like the WHO and the FAO, this organization also underlines the importance of safeguarding human health and ensuring sanitation and proper hygiene. However, they stress the ‘fit-to-purpose’ approach, meaning that the water quality of treated effluent should be based on the reuse objective. In this line of thinking they highlight the interconnectedness of water quality and food safety, because inadequately treated water could have negative impacts on crop health and yield and ultimately food security. Furthermore, they engage in environmental concerns of wastewater reuse and establish best practices for environmentally safe water reuse and suggest uniform regulation practices. Just like the WHO Guidelines, ISO puts a big focus on setting attainable standards, giving possible project development suggestions and implementing a successful monitoring system. (ISO 2015)

Although ISO recognizes the different reuse possibilities, they clearly stress the importance of irrigation as the biggest user of reclaimed wastewater and its enormous potential in increasing food security and combating water scarcity. Just like all other standards presented in this thesis, they pursue a ‘multi-barrier approach’. This means that the guidelines suggest not only possible water quality and treatment standards but also provides guidance in terms of recommended irrigation methods and other safety measures. To this end, ISO has established five categories of water quality ranging from very high to extensive quality. Spanning all different treatment options from advanced or tertiary to preliminary Furthermore, they differentiate irrigation areas and crop types based on the ‘end-user’ following the ‘fit-to-purpose’ principle. To ensure public health they therefore set not only microbiological standards but analyse also chemical compounds which could have adverse effects on the long run. Nonetheless, they do not stipulate specific water quality standards and parameter like the other two organizations (FAO, WHO). On the one hand, they distinguish irrigation areas into unrestricted and restricted irrigation as well as public and private irrigation. On the other hand, they separate crops into food crops, non-food crops and industrial and seeded crops. Additionally, due to direct human impact they further differentiate between raw and processed food crops (IWA 2016; ISO 2015). Last but not least, they are very much focussed on best agricultural practices. Not only to ensure agricultural productivity and efficiency by protecting crop health, soil fertility and water safety but also to limit harmful environmental side effects. To this end, they also focus on different technical challenges and possible political or economic pressures to deal with safety but also public perception issues. (ISO 2015)

4.3 WHO Guidelines

Since the 1970s, the ‘World Health Organization’ (WHO) has paid particular interest to wastewater and its agricultural reuse for irrigation purposes. The organization has always put a focus on finding rules and regulations to ensure a safe use of wastewater while keeping negative health and environmental impacts to a minimum. The WHO Guidelines represent the international consensus on both the scientific knowledge and best available technology, and encourage policy makers to tailor them to their specific geographic, demographic, climatic and socioeconomic conditions. In the past, there has been much debate about the limits set by the WHO. While developed countries would have liked to see more stringent parameters, developing countries were already struggling to achieve the current limits. Especially, since the WHO limits are only attainable by using state of the art sewage systems and treatment facilities. Furthermore, developing countries are not only struggling with the technological preconditions but also with insufficient funds, missing public support due to other more important policy priorities, as well as lacking enforcement possibilities for the regulations in place. Therefore, the third and newest edition of the WHO Guidelines, published in 2006, tries to take these different realities into account via providing alternative measures to facilitate the reduction of human health and environmental risks. (Ensink and Hoek 2007; Havelaar et al. 2001; WHO 2006a, 2006b)

To this end, they also introduced guidelines which deal not only with treated wastewater but also focus on the popular practice of untreated wastewater irrigation. Volume two and Volume four of these guidelines specifically deal with the issue of ‘Wastewater, Excreta and Greywater use in Agriculture’ by introducing risk management according to the ‘Stockholm Framework’. This framework is a recognized approach to assess and control risk of waterborne diseases, which underlines the guidelines focus on maintaining human health. Risk quantification is based on three separate assessments looking at the microbial and epidemiological status of wastewater. These assessments are used to set health-based targets for both developed and developing countries. To this end, the WHO has introduced a scheme of three crop categories that need to be treated differently according to their potential to influence human health and the environment. The first category “Group A” has the strictest regulations and refers to food crops which are usually eaten raw and other public green areas (sports fields, parks) with big public exposure. “Group B” has less stringent criteria due to the primary crops being fodder and industrial crops which are not intended for human use. However, there are still certain standards to abide by since they still harbour the possibility of damaging human health due to workers being exposed to wastewater. The last group “Group C” mainly refers to crops from “Group B” however, it has less strict parameters to abide by because there is no human exposure. Depending on the location or exposure of agricultural areas the WHO also differentiates between restricted, unrestricted and localized irrigation, which is mainly based on potential negative influences on human health or environment. (WHO 2006a, 2006b)

However, the targets and the following policy measures are not only influenced by the health risk assessment. Other important factors mentioned in the guidelines are environmental, socioeconomic and financial considerations. By including these aspects, the WHO finally responds to the differences that persist between industrialized and developing countries. Furthermore, the organization recognizes that not all goals set by the guidelines are attainable for all countries. Therefore, it introduces the system of ‘incremental implementation’. This means that countries are primarily urged to implement measures pertaining to the most pressing risks for human health. The other measures should be applied, however, only if the country’s particular situation allows for it. Ultimately, this new approach stresses the need to effectively manage risks associated with wastewater reuse in agriculture to protect public health and the environment, and to ensure safe food exports but it also presents different pathways to ensure this goal. (WHO 2006a, 2006b)

4.4 Summary of Guidelines

Table 1: Summary of international guidelines

Guidelines	Separation per		Parameters	
	Land	**Crop**	**Treatment**	**Quality**
FAO [1]	Unrestricted irrigation Restricted irrigation	Food crops: raw or to be eaten after cooking Fodder crops: directly accessible for animals or harvested and fed to animals Scale of tolerance and sensitivity to a variety of factors.	Preliminary Primary Secondary Tertiary/advanced Disinfection	pathogen content, total salt concentration, Ph-value, sodium adsorption rate, toxic ions, trace elements and heavy metals, nutrients
ISO [2]	Unrestricted irrigation Restricted irrigation Public irrigation Private irrigation	Raw food crops Processed food crops Non-food crops Industrial and seeded crops	A: very high quality B: high quality C: good quality D: medium quality E: extensive	
WHO [3]	Restricted irrigation Unrestricted irrigation Localized irrigation	Group A: Raw food crops and public green spaces Group B: Fodder crops, Cereal crops, Industrial crops, pasture & fruit trees Group C: Group B without exposure of workers to the treated wastewater	Pre-treatment On site and low cost Decentralised and high cost	pathogen content, salinity, sodicity, specific ion toxicity, other chemical elements, nutrients

(Source: own depiction of information provided by Pescod 1992a [1]; ISO 2015 [2]; WHO 2006b [3]).

5 Methodology

This chapter is outlining the quantitative wastewater analysis carried out over the course of this thesis. After a short introduction to the methodology and the limitations of this study, the basic parameters will be further examined by looking at how they play into the investigation on wastewater reuse for agricultural irrigation purposes.

5.1 General Methodology

This paper aims at underlining the significance of treated wastewater reuse by showing that it is a viable and sustainable water source for agricultural purposes. It strives to display the quantitative wastewater production capacity and emphasize its potential for increasing food security by reusing it for irrigation. For this reason, the analysis was split up in two parts. On the one hand, the supply side which aims at estimating the global treated wastewater production potential of 167 countries on six continents via municipal water withdrawal and access to improved sanitation. In a next step, this quantitative analysis looks at specific city wastewater production potential by looking at cities with more than 10.000 inhabitants. On the other hand, the demand side which quantifies irrigation water needs of five selected dry cereal crops (Barley, Millet, Maize, Sorghum, Wheat) to calculate the potential for wastewater irrigation in 127 grain cultivating countries. Furthermore, the specific treated wastewater irrigation potential of the African Continent will be analysed in a Case Study linked to Goal 'six' of the SDGs.

5.2 Supply

The supply side identifies the amount of potentially produced wastewater on a global scale by looking at municipal water withdrawal. With irrigated areas shifting closer and closer to city centres all over the world, the significance of agricultural use of treated municipal wastewater from urban areas becomes increasingly important. Therefore, this quantitative investigation is dived into two basic layers of geographical dimensions. On the one hand, the country level which analyses overall wastewater potential via municipal water withdrawal (m^3/year) and the total access to improved sanitation (% of population). On the other hand, the city level which focuses on potential wastewater flows of cities with more than 10.000 inhabitants, because a functioning wastewater reuse scheme needs a certain number of people to guarantee a steady amount of produced wastewater. To make this global study feasible, domestic municipal water withdrawal is set equivalent to domestic municipal wastewater discharge. This means that the calculated values for potentially produced wastewater do not include transportation water losses due to leaking pipes or household water consumption which usually varies between 5 – 15 percent in urban areas (Frenken and Gillet 2012). The data collected for municipal water withdrawal comes from the FAO database AQUASTAT which compiles national and international datasets and includes latest value data mainly from 2010 but none earlier than 2000. However, since this data was collected from a variety of sources, some countries[1] only provided for total water withdrawal. Therefore, these 21 datasets have been corrected to represent only the amount provided to households via the EUROSTAT proportioning formula (36 % of total water withdrawal for domestic users) suggested by AQUASTAT ("AQUASTAT Database" 2017). Although no level is older than 2000, the African continent has witnessed significant population growth over the last 10 years. Therefore, if one corrects the values to current population levels, the wastewater production potential might be slightly higher than the levels presented in this study. To provide an estimate of the annually produced wastewater per country, annual domestic water discharge is combined with the level of access to improved sanitation as provided by the 'Joint Monitoring Programme' (JMP) of the WHO (WHO and UNICEF 2015). Since this paper is trying to quantify the wastewater potential it does not take into account the actual number of wastewater treatment plants. It simply assumes that access to improved sanitation equals wastewater treatment. Although this is not always the case on a global scale, especially not outside of megacities and larger urban agglomerations, it at least holds true for developed countries. In developing countries, access to improved sanitation at least gives an indication of current wastewater collection infrastructure which could later be connected to wastewater treatment plants. Especially, with increased efforts made under 'Goal six' of the SDGs.

In the city level analysis, it has to be taken into account that access to improved sanitation still varies enormously between urban and rural areas. Consequently, this analysis was separated into two steps. First, cities with a population great than 100.000 inhabitants were classified as larger cities and therefore treated as urban centres (Simplemaps 2015). To this end, the calculated municipal water consumption per city (m^3/city/year) was multiplied with the urban access to improved sanitation (% of the urban population) of each country as extracted from JMP (WHO and UNICEF 2015). Second, the smaller agglomerations from 10.000 to up to 100.000 inhabitants were treated as rural centres (Simplemaps 2015). Here, the municipal water consumption per city (m^3/city/year) was multiplied with the rural access to improved

[1] Algeria, Argentina, Bangladesh, Brazil, China, Georgia, India, Indonesia, Iran, Iraq, Italy, Japan, Mexico, Nigeria, Pakistan, South Korea, Ukraine, United Kingdom, United States of America, Uruguay, Venezuela.

sanitation (% of the rural population) as extracted from JMP (WHO and UNICEF 2015). Although the differences between access to improved sanitation for urban and rural populations might be minor in developed countries, large differences can still be found in developing countries. Therefore, this step was taken to increase the relevance of the calculated treated wastewater potential. In general, this thesis assumes that the potentially treated wastewater is of uniform quality standards, since it does not take local differences in wastewater treatment infrastructure and quality parameters into account. The figure below summarizes and illustrates the general supply side methodology outlined above.

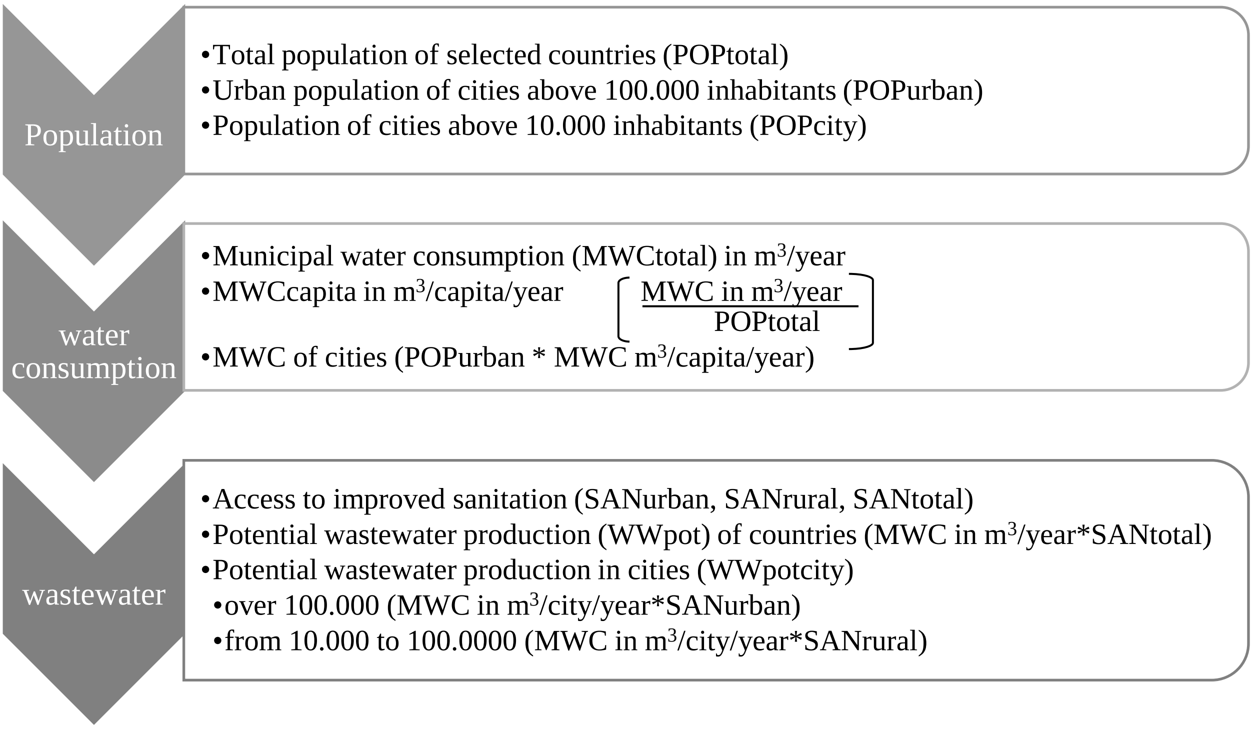

Figure 4: Methodological Overview of the Supply Side Calculations
(Source: own depiction for illustrational purposes of the applied methodology)

Table 2: Key indicators to quantify municipal wastewater potential

Total population (in 1000)	
POP_{total}	Indicates the total population of a country[1].
Total population of urban area	
POP_{urban}	Defined to be a major urban area with 100.000 or more inhabitants [1].
Total population of city	
POP_{city}	Defined to be an agglomeration of at least 10.000 but not more than 100.000 inhabitants [1].
Volume of municipal water consumption (10^9 m3/year)	
MWC_{total}	Indicates the annual quantity of municipal water demand in the country (domestic) [2].
Volume of municipal water consumption per capita (m3/capita/year)	
MWC_{capita}	Indicates the annual quantity of municipal water demand per capita in the country (domestic) [2].
Access to sanitation (percent of urban population)	
$SAN_{popurban}$	Indicates the percentage of the urban population using improved sanitation facilities and wastewater treatment [3].
Access to sanitation (percent of rural population)	
$SAN_{poprural}$	Indicates the percentage of the rural population using improved sanitation facilities and wastewater treatment [3].
Potential volume of total produced wastewater (m^3/year)	
WW_{pot}	Indicates the potential annual quantity of domestically produced wastewater
Potential volume of produced wastewater in cities (m^3/year)	
$WW_{potcity}$	Indicates the potential annual quantity of domestically produced wastewater per capita.

(Source: own depiction of data provided by Simplemaps 2015 [1]; FAO 2017a [2]; WHO and UNICEF 2015 [3])

5.3 Demand

The demand side analyses the specific crop irrigation needs of the five most popular dry cereal crops (Barley, Millet, Maize, Sorghum, Wheat). This analysis is focussing solely on dry grains because they are the among the most produced crops worldwide but also because they are vital to ensure global food security under ‘Goal two’ of the SDGs. In a first step, crop production and yield data on the five chosen dry cereal crops was extracted from FAOSTAT for each of the 127 grain producing countries (FAO 2017b). According to this data, the three most produced grains in tonnes per year were determined for each country. In a next step, each country was grouped into a larger regional area (e.g. Central Africa[2]) which was assigned to one of the 12 agroecological zones[3] (see Chapter 5.4.1.) as developed by the FAO and the ‘International Institute for Applied Systems Analysis’ (IIASA). In a third step, climatic data of average monthly temperature and average precipitation were extracted from the CRU database for all 127 countries (Goonetilleke, Liu and Gardner 2016). This data was summarized and averaged for the aforementioned geographical groupings and their specific agroecological zone. To be able to calculate crop irrigation demand, the FAO developed program CLIMWAT was used to extract average humidity levels, monthly wind speed and sun hours for at least three countries of each region. This data was then again integrated to portray a representative picture for the specific region. In a fourth step, this climatic data was inserted into the FAO developed programme CROPWAT to determine the specific irrigation water demand of the aforementioned three most popular crops per region. In order to get a comparable result, the soil data was set to medium for all agroecological zones and the irrigation water demand was set to yield safety[4]. Finally, the specific crop data on growing periods was provided by the CROPWAT database. As outlined in Chapter 5.4.3, all of this information was used by CROPWAT to calculate effective precipitation and crop evapotranspiration to determine the irrigation need of each crop under the given climatic preconditions. In a last step, the specific irrigation demand[5] of each of the three most popular crops per agroecological zone was scaled to m^3/ha/year and then matched up with the cereal production of the 127 countries via their harvested area (ha). The area harvested was chosen because it typically equals the potentially irrigated area of the chosen country. These values were summed up and ultimately compared to the potential municipal wastewater production calculated under the supply part of this analysis. In the end, the comparison of potential

[2] Angola, Central African Republic, Congo, Democratic Republic of the Congo, Equatorial Guinea and Gabon.
[3] Variations of tropical, subtropical, temperate, boreal and artic climates.
[4] The minimum amount of irrigation needed for the crop to be able to survive.
[5] In millimetre (mm) /depth per growing period

wastewater production with country specific irrigation water demand shows the wastewater irrigation potential of each country in percent. Since this thesis is excluding all wastewater treatment quality concerns, it is assumed that all the potentially produced wastewater is suitable and available for agricultural irrigation of cereal crops. Furthermore, this thesis assumes that potential treated wastewater production is constant over the whole year and 100 percent of the produced amount is stored and therefore available for direct reuse. The figure below sums up the general methodological steps taken in this section and illustrates the three main influencing parameters of this section.

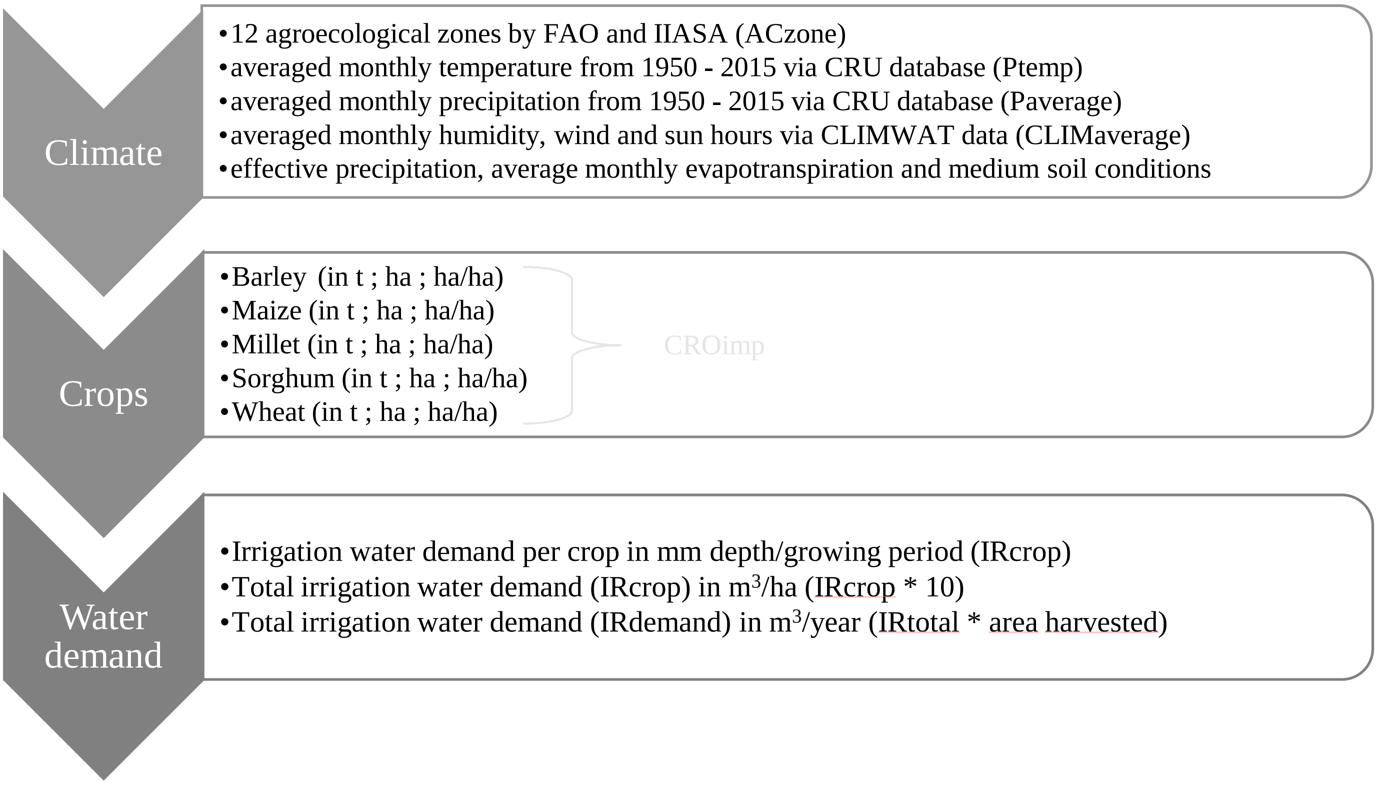

Figure 5: Methodological Overview of the Demand Side Calculations
(Source: own depiction for illustrational purposes of the applied methodology)

Table 3: Key indicators to quantify irrigation water demand

Agroecological Zone	
AC_{zone}	Indicates the specific agroecological zone after the GAEZ methodology of the FAO and the IIASA [4].
Average monthly precipitation (mm/month)	
$P_{average}$	Indicates the average amount (time and space) of water falling on a certain area in the form of precipitation (both snow and rain) [1].
Average monthly temperature (Celsius)	
IR_{area}	Indicates the average temperature in a certain area [1].
Average crop evapotranspiration (mm/month)	
ET_{crop}	Indicates the sum of average evaporation and crop transpiration, which mean water losses to the atmosphere [2].
Effective precipitation (mm/month)	
$P_{effective}$	Indicates the amount of average precipitation that is stored in the soil and used by crops to meet their crop water demand [2].
Average climatic conditions (humidity, wind speed and sun hours)	
$CLIM_{average}$	Indicates the average climatic conditions per chosen agroecological zone as extracted by CLIMWAT.
Cereal crops (t; ha; hg/ha)	
CRO_{imp}	Indicates the 3 most produced cereal crops in tonnes produced, hectares harvested and yield in hectograms per hectare [3].
Crop irrigation demand (mm depth/growing period)	
IR_{crop}	Indicates the specific crop water demand of the chosen cereal crop in agroecological zone in mm depth per growing period.
Total crop irrigation demand (mm depth/growing period)	
IR_{demand}	Indicates the specific irrigation demand of the chosen cereal crop in agroecological zone in mm per 10 days (decade).

(Source: own depiction of information provided by Goonetilleke, Liu and Gardner 2016 [1]; Brouwer and Heibloem 1986 [2]; FAO 2017b[3] IIASA/FAO 2012[4])

5.4 Visualization of results

The results of this quantitative study are summarized and illustrated in maps designed with the analysis tool CARTO. The maps show values calculated for cities in little dots representing the location of the city and values calculated for the whole country inside the borders of said country. Figure 8 below, shows the treated wastewater production potential in *10^9 m^3/year*. The different shades of blue indicate potentials ranging from high in the US (62,09) to low in (). The same is done for cities in the little red dots, ranging from 4,85 to 0,00 *10^9 m^3/year*. and the same for cities in various shades of red in the little dots. On the other hand, the tables elaborated in Chapter 6.1 show the 'TOP 10' highest and lowest potential areas. While Table 4 shows the potential treated wastewater production in *10^9 m^3/year* for the ten highest and ten lowest potential areas, Table 5 shows the wastewater irrigation potential in percent. This was calculated by matching the total treated wastewater potential and total cereal irrigation demand of each of the 127 grain producing countries.

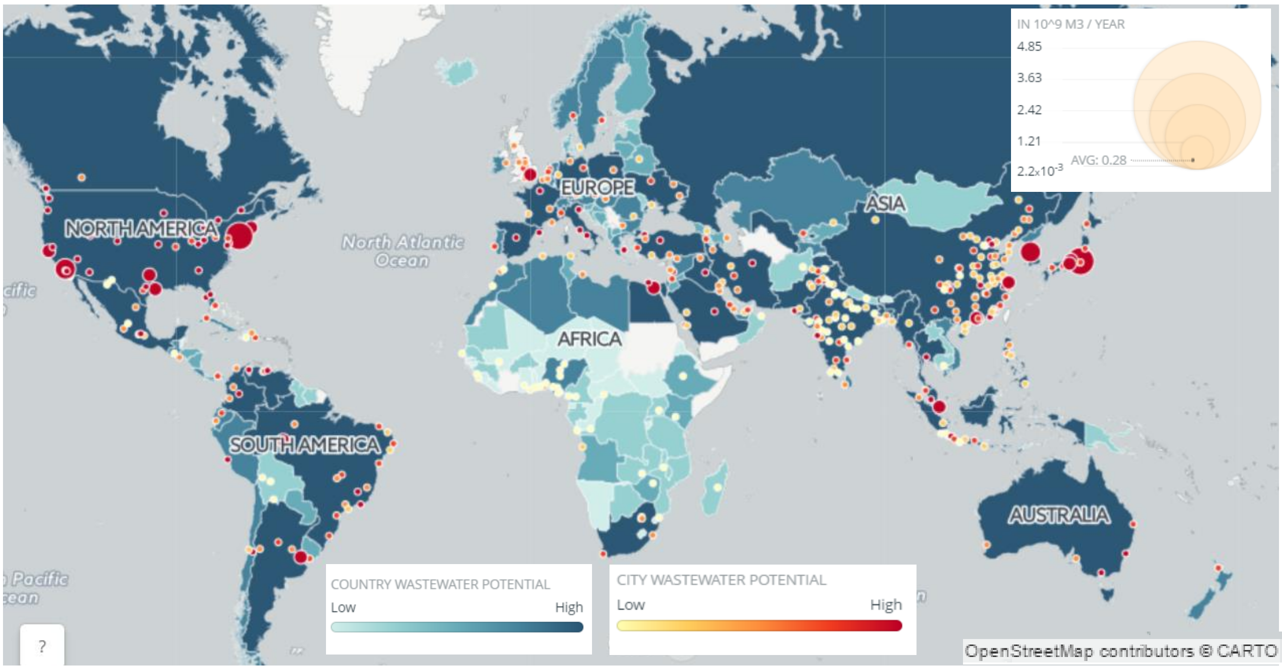

Figure 6: Global Wastewater Potential with cities larger than 1.000.000 inhabitants
(Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)

5.5 General Parameters

Consequently, this thesis will not only show the potential for global wastewater reuse but also how this new source could make up for lacking irrigation water due to water scarcity or dry climatic conditions. This study is only interested in the potential for wastewater irrigation and therefore excludes irrigation limitations due to water quality standards as well as health and safety guidelines. To successfully analyse the potential for irrigation with treated municipal wastewater on a global scale, this investigation needs to look at a broad variety of parameters which have been grouped to the following categories.

5.5.1 *Climatic Conditions*

Climatic conditions play an important role in determining not only water availability and demand but also crop health, overall yield efficiency and most importantly crop water demand. Therefore, cultivation agriculture is largely influenced by climatic factors such as temperature, vegetation or spatial and temporal precipitation distribution. First, because the specific climatic zone determines not only physical water scarcity levels but temperature and precipitation variations influence soil moisture, evapotranspiration and ultimately the individual crop irrigation demand. Consequently, climatic zones also mark the difference between rain-fed and irrigated agriculture. Usually, irrigation agriculture usually achieves higher yields due to less crop failure. Especially since, this agricultural practice is less vulnerable to draughts or other natural phenomena. However, it is largely dependent on sufficient freshwater sources and functioning irrigation infrastructure. This is a big concern, especially in regions suffering from physical and/or economic water scarcity because agriculture makes up 70 – 90 percent of freshwater withdrawal. Many of the previous steps taken to ensure irrigation water supply also negatively influenced existing natural water systems. The construction of dams and artificial lakes for water storage has not only influenced river flow and discharge but also increased evapotranspiration and water losses to the atmosphere. This increase in evapotranspiration from irrigated plants but also from water storage implies temperature and soil moisture changes which could eventually lead to crop dehydration and yield shortfalls (Kang, Khan, and Ma 2009; Fischer et al. 2002). Therefore, the FAO and the IIASA developed specific climatic zones for agriculture under the Agroecological Zones (AEZ) methodology. They divided the world into 12 zones (Figure 7) ranging from tropical to arctic climates. Since these zones also represent agricultural suitability, they already include considerations on temperature, soil, wind and precipitation (IIASA/FAO 2012).

Since this study is only looking at grain cultivation agriculture, arctic and boreal climates are not included in the quantitative analysis. The focus areas for wastewater irrigation potential will, therefore, be variations of tropical, subtropical and temperate climates.

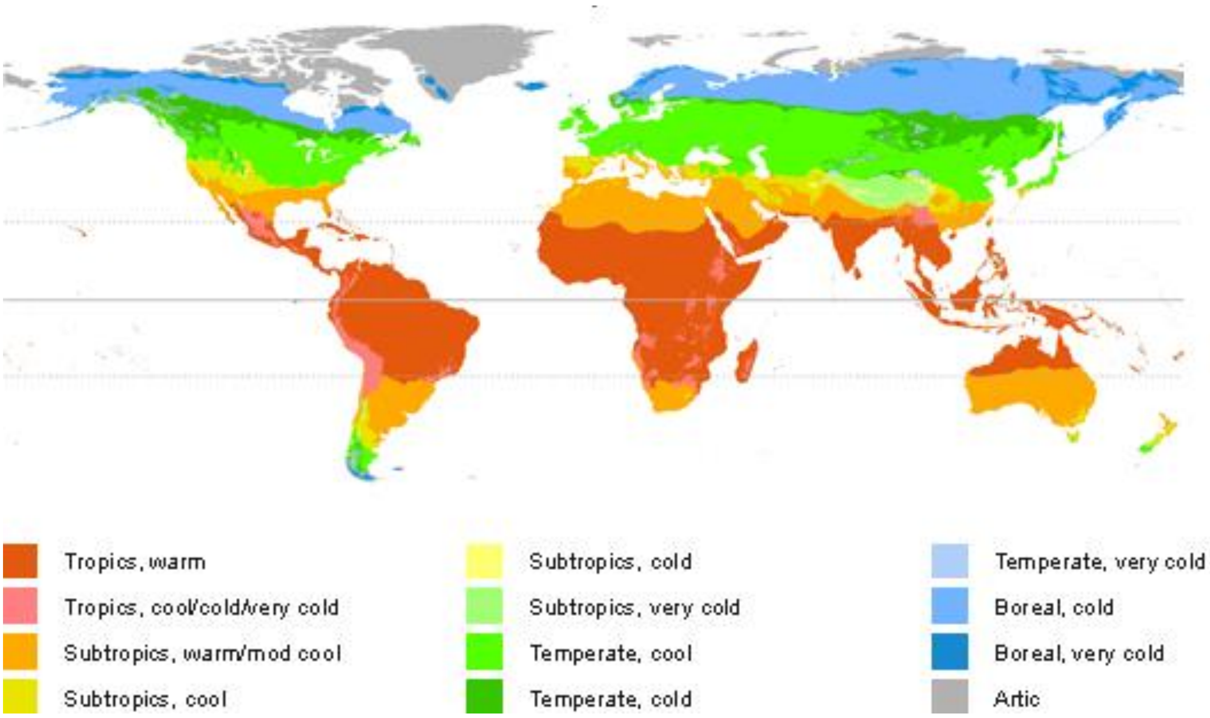

Figure 7: Global agroecological zones
(Source: IIASA/FAO. "Global Agroecological Zones (GAEZ v3. 0)." IIASA, Laxenburg, Austria and FAO, Rome, Italy, 2012. Accessed May 21, 2017. http://pure.iiasa.ac.at/13290/1/GAEZ_Model_Documentation.pdf)

5.5.2 *Water and municipal wastewater production*

As already mentioned before, global domestic demand for water is exponentially growing with population growth, increased living standards and climate change. This water withdrawal also leads to corresponding amounts of wastewater being produced by households. Therefore, municipal wastewater is becoming an increasingly important topic in the global context of water scarcity, environmental pollution and sustainable agriculture. However, much of the produced wastewater is still directly discharged with only 60 percent of the world population being connected to sewer systems. Out of these 60 percent, only a marginal amount is already connected to wastewater treatment plants. (Mateo-Sagasta and Salian 2012) To this end, the FAO database AQUASTAT has elaborated data collections on four levels of scale entailing wastewater source, collection, treatment plants and the amount of the treated effluent by country. However, actual data on produced, collected and treated wastewater is still scarce, especially in developing countries. (Mateo-Sagasta and Salian 2012)

Consequently, this thesis will mainly be looking at potential municipal wastewater production to underline its future potential as a clean and viable water source. This is done by quantifying domestic municipal water withdrawal on a country, city and capita level and relating it to the total, urban and rural access to sanitation levels. This is a very general way of estimating potential municipal wastewater, however, the data limitations on actually produced wastewater and the global scope do not allow for a different methodology. Nonetheless, this method is still relevant. Although the infrastructure might be still lacking in certain areas, municipal water withdrawal will only grow and governments will have to introduce wastewater reuse schemes to keep up with this trend. However, it is important to underline that a successful wastewater reuse scheme can only function if certain preconditions are fulfilled. The most important one being steady municipal wastewater production which is also linked to an efficient sewer collection system connected to a maximum of local households. If these preconditions are fulfilled the construction and maintenance of a treatment plant are only linked to small financial and obligations. Therefore, for the purpose of this study, the indicator of access to improved sanitation which usually refers to collection in a sewer system was set to equal both access to wastewater collection and treatment.

5.5.3 *Agriculture*

Agriculture, in the sense of this thesis, especially refers to cultivation agriculture, meaning the growing of food and fodder crops for both human and animal use. Nonetheless, since the scope of this study is limited it mainly focuses on food and especially five chosen cereal crops (Barley, Maize, Millet, Sorghum and Wheat). This was done, to highlight the potential for increasing food security by additional wastewater irrigation but also because these crops tend to be less sensitive to water quality standards. The five chosen grains are planted and harvested almost all over the world and require a similar soil and water standard, which makes them ideal for this investigation. Their specific crop irrigation demand depends on a variety of climatic factors like humidity, temperature or wind speed. With the highest demands registered in tropical and subtropical and lowest in arctic and boreal agroecological zones (IIASA/FAO 2012; Brouwer and Heibloem 1986, chap. 2).

This relationship between crop and climate is usually quantified in the ‘reference crop evapotranspiration’ (ETo). This is later combined with the so-called crop factor (Kc) which quantifies the influence of the crop type on its water needs. This is done by comparing it to the standard crop water need of grass. In the end, these two factors are used to determine the crop evapotranspiration (ETcrop), a factor unique to each crop. (Brouwer and Heibloem 1986, chap. 3)

$$\boldsymbol{ET}_{crop} = \boldsymbol{ET}_{O}\ x\ \boldsymbol{K}_{C}$$

This factor plays into the irrigation water demand, because the higher the specific crop evapotranspiration, the bigger the loss of water to the atmosphere and the higher the need for irrigation. To simulate actual conditions, the concept of effective precipitation (Peffective) was introduced. It refers to the actual amount of average precipitation that can be used by crops to fulfil their specific waster demand via storage in the soil. (Frenken and Gillet 2012)

$$\boldsymbol{P}_{effective} = \boldsymbol{P}_{average} - \boldsymbol{K}_{C}$$

While in rain fed agriculture the water demand is met by effective precipitation, drier and hotter climates such as the tropics and subtropics have a high irrigation water need to compensate the lack of effective precipitation. This situation is intensified with the driest time coinciding with the mid-season grain development stage which usually has the highest crop water demand. (Brouwer and Heibloem 1986, chap. 3)

$$\boldsymbol{IR}_{demand} = \boldsymbol{CW}_{demand} - \boldsymbol{P}_{effective}$$

The typical growing period usually depends on the specific crop; however, the FAO has proposed a model to track the stages of crop development. For Barley and Wheat, the growing period lies between 120 to 150 days, while Maize ranges from 125 to up to 180 days. Sorghum and Millet account for shorter periods of 105 to up to 120 days. The highest crop water need for cereal crops is usually measured during the mid-season when the grain is setting (see Figure 8). Since, these grains are dry crops they do not to be fresh during the harvest which significantly reduces the water demand in the late season. (Brouwer and Heibloem 1986, chap. 3)

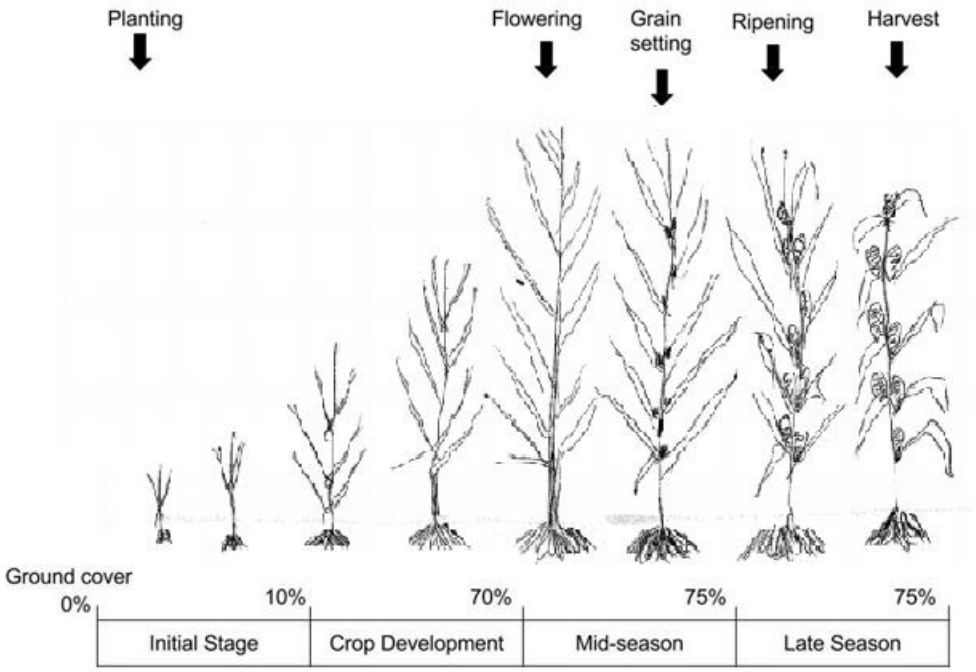

Figure 8: Stages of crop development

(Source: own depiction after: Brouwer, C., and M. Heibloem. "Irrigation Water Management: Irrigation Water Needs." Training manual 3 (1986). p 17 http://www.academia.edu/download/7341272/manual3.pdf)

6 Results of the Quantitative Wastewater analysis

After looking at the methodology behind the analysis, this section focuses on examining the results for both, global treated wastewater production potential and its prospective use for irrigation. After a short overview, each continent will be further examined by looking at the results for highest and lowest potential countries and cities on each of the six continents.

6.1 Global Overview

The first part of this analysis aimed to quantify global wastewater production potential by looking at municipal water withdrawal and access to improved sanitation of 166 countries on six continents. The results indicate that the highest wastewater potential can be found on the Asian Continent followed by North America. On the other hand, the lowest potential is found on the African Continent and especially in the Sub-Saharan Africa[6] with values as low as 0,01 (10^9 m^3/year). This result is logical, not only with regards to development levels and subsequent access to sanitation but also because these high potential regions are counted among the most populous regions of the world and the higher the population the bigger the municipal water demand and the corresponding wastewater discharge.

The table below shows a similar picture, by summarizing and ranking the 'TOP 10' countries and cities with respectively the highest and lowest wastewater potential. On a country level, the US has the biggest treated wastewater potential with 62,09 (10^9 m^3/year). This result is not surprising, considering that the US has one of the highest municipal water demands and largely disposes of 100 percent access to improved sanitation across the country. Also on a city level, the US is well represented with three cities (New York, Los Angeles and Chicago) in the highest potential category, However, China follows closely behind with an overall wastewater potential of 57,38 (10^9 m^3/year). Although, China makes up for 37 percent of world population with 85 cities of more than one million inhabitants, it only has one city (Guangzhou) in the 'TOP 10' ranking. This is mainly due to lower total access to improved sanitation levels (76 %) compared to the US (100 %). The rest of the 'TOP 10' countries lie far behind the two frontrunners with values between 22.18 (10^9 $m^{3/}$year) for India and 6.92 (10^9 m^3/year) for South Korea. On the other hand, Central and Eastern Africa countries and cities account for the lowest potential mainly due to poor very poor access to sanitation, ranging from 2.9 percent to up to 18 percent.

[6] Eastern, Southern and Western Africa.

If we compare the calculated wastewater potential values to actual treated wastewater production levels, there is certainly still a lot of room for improvement in global wastewater treatment. Especially, in India where out of a potential of 22 billion m^3/year only 4 billion m^3/year are actually produced. However, there are also countries whose current treated wastewater production almost matches the values calculated in this study (e.g. South Korea with a potential of 6,9 billion m^3/year and an actual treated wastewater production of 6,5 billion m^3/year). ("AQUASTAT Database" 2017)

Table 4: Global ranking of wastewater potential (in10^9 m^3/year)

Countries				Cities			
HIGH		LOW		HIGH		LOW	
1	US	1	Cabo Verde	1	Tokyo	1	Cotonou
2	China	2	Comoros	2	New York	2	Pointe-Noire
3	India	3	Eritrea	3	Los Angeles	3	Lilongwe
4	Japan	4	Monaco	4	Seoul	4	Antananarivo
5	Brazil	5	Maldives	5	Guangzhou	5	Kumasi
6	Russia	6	Lesotho	6	Osaka	6	Lomé
7	Italy	7	Niger	7	Buenos Aires	7	Mbuji-Mayi
8	Egypt	8	Guinea-Bissau	8	Chicago	8	Lubumbashi
9	Indonesia	9	Djibouti	9	Cairo	9	Brazzaville
10	South Korea	10	Benin	10	Sao Paulo	10	Bangui

(Source: own depiction of data assembled in the quantitative analysis)

To make comparability of city potential more relevant, even the lowest potential (2 – 5 million m^3/year) cities all count at least one million inhabitants. Still, the lowest potential cities are all found on the African continent and especially in Congo, with four out of 10 cities in the lowest potential category. The cities with the highest treated wastewater production potential can be found on the Asian Continent with Tokyo, Seoul, Guangzhou and Osaka ranging from 4,85 to 2,17 (10^9 m^3/year). In the special case of Japan that means that two cities make up for almost 50 percent of the total treated wastewater potential of the country. A similar trend can be observed for South Korea, where Seoul makes up more than 50 percent of the total wastewater potential. This is especially relevant with regards to increasing peri-urban agriculture all over the world. If cultivation activities move closer to city centres treated wastewater irrigation schemes could become reality. For this reason, the next step of this quantitative analysis is taking a closer look at global wastewater irrigation potential for five chosen cereal crops[7]. To this end, the above illustrated wastewater potential of countries was combined with the irrigation water demand of the aforementioned grains. In order to correctly analyse these results, the existing irrigation infrastructure and the importance of agriculture in these countries has to be taken into account. Therefore, the irrigation water demand was scaled to the country's actual grain production via the area harvested which usually corresponds to the cultivated area. Consequently, the largest grain producers are China (Maize), US (Maize) and India (Wheat) with more than 30 million hectares of harvested area. During the analysis 18 countries[8] had a very high irrigation potential of more than 1.000 percent due to modest grain cultivation or more favourable climatic conditions for rain fed agriculture. In order to avoid distortion and produce a representative result, these countries have been excluded. Furthermore, the 'TOP 10' ranking only includes countries that produce at least two out of the five chosen grains. Unsurprisingly, eight out of 10 high potential countries (ranging from 710% - 72%) are located in warm tropical and subtropical climates. Therefore, there is a clear trend of higher irrigation potential in drier climates due to overall higher water withdrawal in these regions. The only 'TOP 10' country classified as temperate (cool) is China. However, China's main cultivation product - rice - is not included in this analysis. The low potential countries are solely found on the African Continent and especially in the Sub-Saharan region with percentages ranging from 1 to 5 percent. This is mainly due to still very poor access to improved sanitation (11% - 18%) but also less municipal water withdrawals due to lacking infrastructure and physical water scarcity concerns.

[7] Barley, Millet, Maize, Sorghum, Wheat.

[8] Qatar, Malaysia, Mauritius, South Korea, Japan, Djibouti, Fiji, Maldives, United Arab Emirates, Papa New Guinea, Costa Rica, Kuwait, Ghana, New Zealand, Sri Lanka, Thailand, Indonesia, Guinea-Bissau.

Table 5: Global ranking of wastewater irrigation potential (in %)

Countries			
HIGH		**LOW**	
1	**China**	**1**	**Tanzania**
2	**Brazil**	**2**	**South Sudan**
3	**Poland**	**3**	**Benin**
4	**Italy**	**4**	**Eritrea**
5	**Iran**	**5**	**Chad**
6	**Egypt**	**6**	**Malawi**
7	**Pakistan**	**7**	**Uganda**
8	**Uruguay**	**8**	**Lesotho**
9	**India**	**9**	**Mozambique**
10	**Germany**	**10**	**Togo**

(Source: own depiction of data assembled in the quantitative analysis)

The significance of these results is underlined when looking at total irrigation demand for the three most popular dry cereal crops in each country. Two out of the 10 countries[9] with the overall highest irrigation demand also have the highest wastewater irrigation potential (Egypt and India). Both, India and Egypt lie in hotter and drier climates of the topics and subtropics, where they largely cultivated Maize and Wheat. With an annual irrigation demand of around 27 million m^3/year most of the required wastewater in India is produced in the bigger cities of Dehli, Mumbai, Bangalore, Chennai, Kolkata, Hyderbad. The same can be observed for Egypt where almost 30 percent of the nine billion m^3/year irrigation demand is produced in Cairo, Alexandria and El Giza. On the contrary, Tanzania has the 8th highest irrigation demand but the least wastewater irrigation potential due to very low access to improved sanitation levels (around 15%) and lacking water infrastructure. Figure 9 illustrate this by showing total irrigation water demand of the 127 countries in shades of red (from 19.000 m3/year in Djibouti to almost 153 billion m3/year in the US). The little dots represent the cities from the 'TOP 10' wastewater potential ranking. While the dark blue dots illustrate high potential (4.85 – 1.60 billion m3/year), the light blue dots illustrate low potential (2.2 –5.7 million m3/year). Figure 10 elaborates on this and shows the general wastewater irrigation potential of each country in shades of green. Ranging from values of around 900 percent for the highest potential (China) and one percent (Tanzania) for the lowest potential.

[9] US, Turkey, India, Mexico, France, Argentina, Australia, Tanzania, Morocco, Egypt.

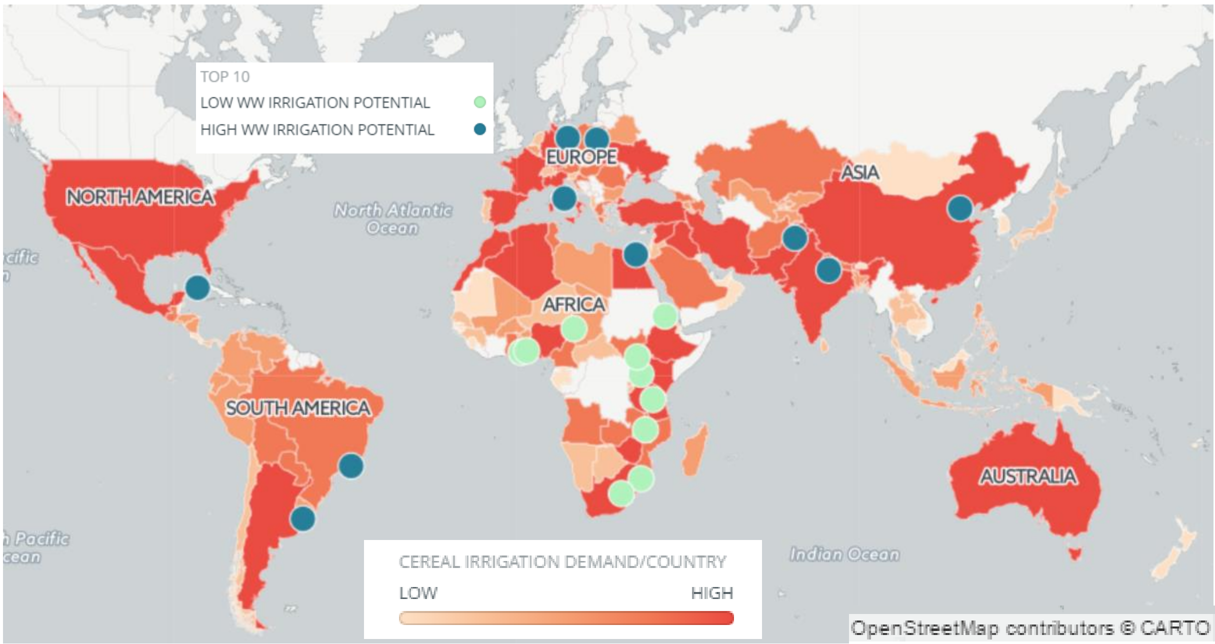

Figure 9: Total irrigation Water demand for the 3 most popular dry cereal crops
(Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)

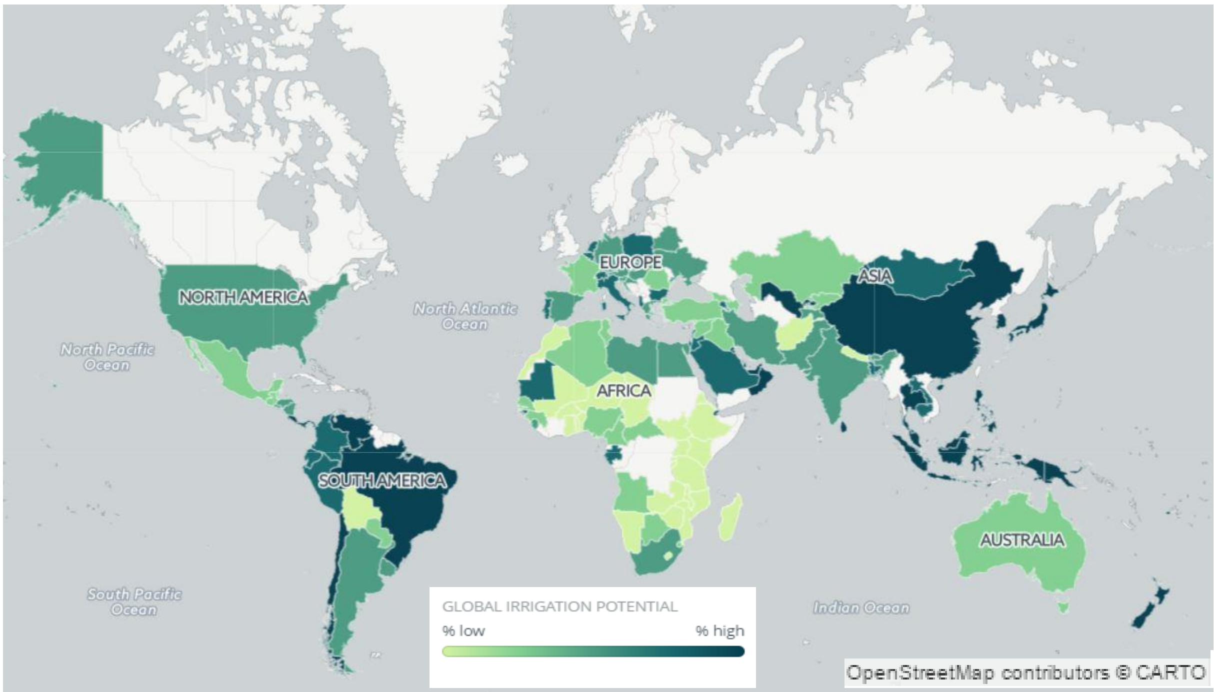

Figure 10: Global treated wastewater irrigation potential
(Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)

6.2 Africa

The African Continent is mainly made up of two agroecological zones. The subtropics (warm/moderate) in Northern and Southern Africa as well as the tropics (warm) spread all over Central, Eastern and Western Africa. In terms of water scarcity levels, a similar separation can be observed (see Figure 2). While the Northern and Southern regions are highly influenced by physical water scarcity, the Sudano-Sahelian area (Central, Eastern and Western region) is largely suffering from economic water scarcity (Molden 2007). This difference is also directly proportional to the level of access to improved sanitation levels in these regions. While Northern Africa disposes of high to medium level access for urban and rural areas with percentages ranging from 60 to 90 percent, the Southern counterpart is a bit more divided. There, levels span from 10 percent in rural Mozambique to almost 70 percent in urban South Africa, with similar situations in the Western, Central and Eastern part of the continent. Consequently, the potential wastewater production is also highest in the Northern part as well as in South Africa. The highest wastewater potential of the continent can be found in Egypt, with an annual production of more than eight billion m^3. Especially, in cities like Cairo, Alexandria and El Giza. In South Africa, the wastewater potential is considerably lower with less than 3 billion m^3 per year. Still, almost 30 percent of this total amount is made up by the Greater Gauteng province and especially the city of Johannesburg. The lowest wastewater potential is mainly focused in the Western region. Especially, in countries like Cabo Verde, Comoros, Eritrea, Niger and Guinea-Bissau which show annual levels between one and seven million m^3. The irrigation potential portrays the exact same picture. While irrigation water demand is highest in drier countries (e.g. Egypt, Tanzania, South Africa) spread all over the continent, the irrigation water potential is mainly concentrated in the North. There, countries like Egypt and Libya lead the ranking with 90 and 75 percent respectively. However, South Africa is also elevated (compared to other African countries) with 39 percent. Out of 52 African countries 16[10] show an irrigation potential lower than five percent. These countries are principally found in the Sudano-Sahelian area but also in Northern (Morocco) and Southern Africa (Lesotho, Madagascar). The map below shows that the highest wastewater irrigation potential can be found in cities like Cairo, Alexandria, Johannesburg, Tripoli, Casablanca, Lagos, Durban and Cape Town. A further analysis of the African Continent can be found in the case study under Chapter seven of this thesis.

[10] Tanzania, South Sudan, Benin, Eritrea, Chad, Malawi, Uganda, Lesotho, Mozambique, Togo, Ethiopia, Zimbabwe, Mali, Ghana, Niger, Zambia, Rwanda.

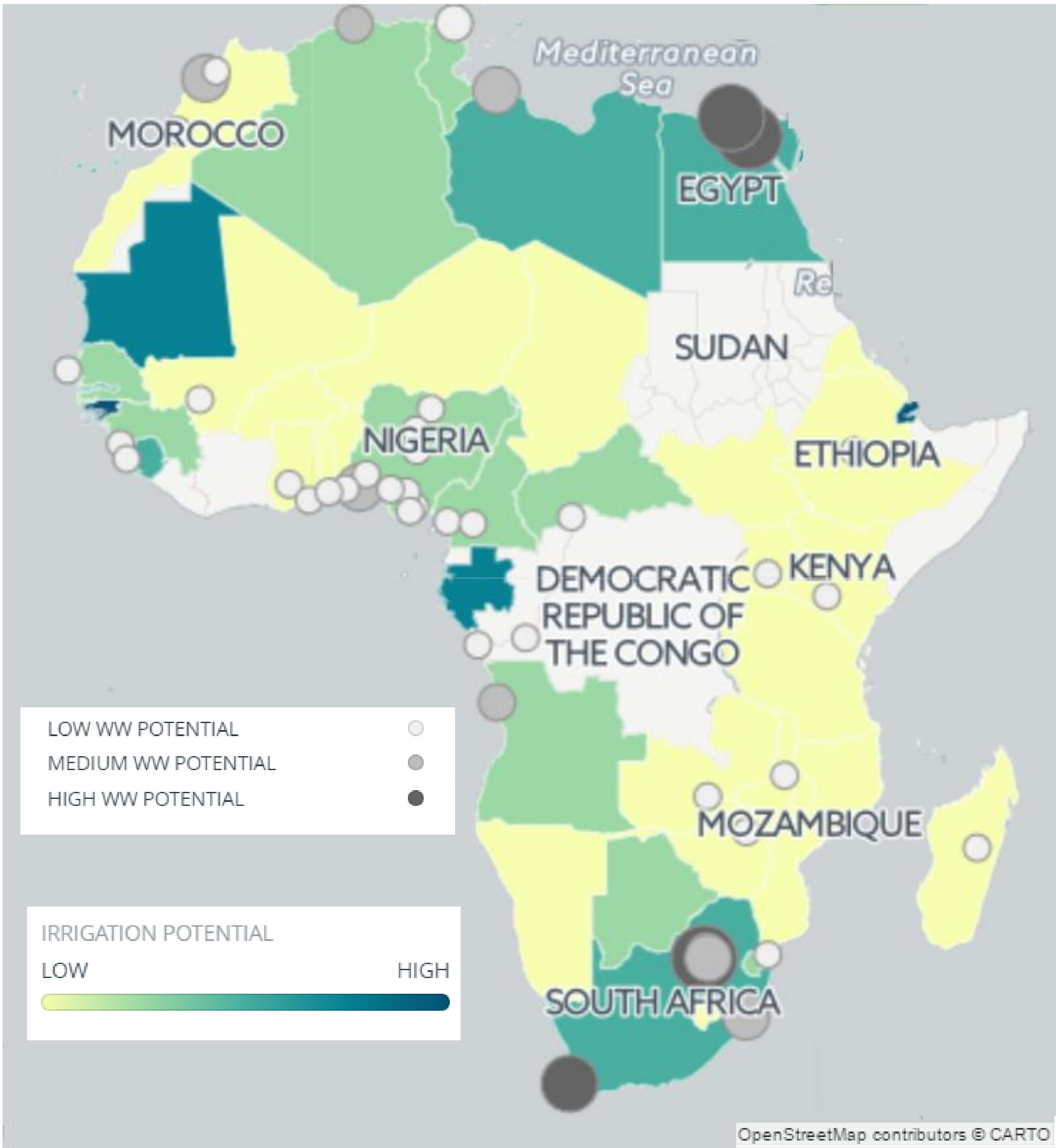

Figure 11: African Wastewater potential
(Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)

6.3 Asia

The Asian Continent spans more than 44 million km^2. Therefore, climatic conditions vary significantly depending on the specific region. The GAEZ methodology has split it into six[11] different agroecological zones, ranging from temperate (cool) in Central Asia to tropical (warm) in the Southern and South-Eastern part. The water scarcity index offers a similarly divers picture. While the Eastern part is mainly without risk for or exposure to water scarcity, the Southern part (especially India and Pakistan) is suffering from both physical and economic water deficiencies (Molden 2007). The South is also the region with the lowest levels of access to improved sanitation with an average of 55 percent in rural and 70 percent in urban areas. The rest of the continent largely disposes of levels ranging from 90 to 95 percent respectively. As a result, the wastewater potential analysis shows the lowest values for the Southern and South-eastern part. Representing more than 4 billion of the world population, it comes as no surprise that five countries and four Asian cities can be found in the 'TOP 10' for wastewater production potential (see Table 4). Consequently, the biggest potential is found in these countries ranging from 57 billion m^3 per year in China to almost 7 billion m^3 in South Korea. The lowest potential is largely found in Southern and South-eastern Asia. Especially, in on the Maldives, Bhutan and Timor-Leste (0,01 – 0,04 10^9 m^3/year). On a city level, the highest potential can be found in Eastern Asia ranging from 4,85 billion m^3/year in Tokyo, Japan to 1,44 billion m^3/year in Shanghai. However, since grain cultivation agriculture is mainly done in the Southern region wastewater irrigation potential is elevated in countries like India and Pakistan. Nonetheless, the highest potential according to this study can be found in China, with more than 900 percent. Although, as already mentioned before, rice is the most popular grain in China and therefore, the wastewater irrigation potential might be much lower if rice were included in this analysis. Other high potential areas are located on the Arabian Peninsula[12], especially United Arab Emirates (over 8000 %) and Oman (710%). The lowest wastewater irrigation potential can be found in Central Asia, especially in Afghanistan (4%), Nepal (6%) and Azerbaijan (15%). These trends can also be observed on the map below (see Figure 12).

[11] Central Asia (Temperate, cool); Eastern Asia (Subtropics, very cold); Southern Asia (Tropics, warm); Southeast Asia (Tropics, warm); Western Asia (Subtropics, cool); Arabian Peninsula (Subtropics, warm/moderate)

[12] Grain cultivation is very modest in this region; therefore, the significance of this result should not be overestimated.

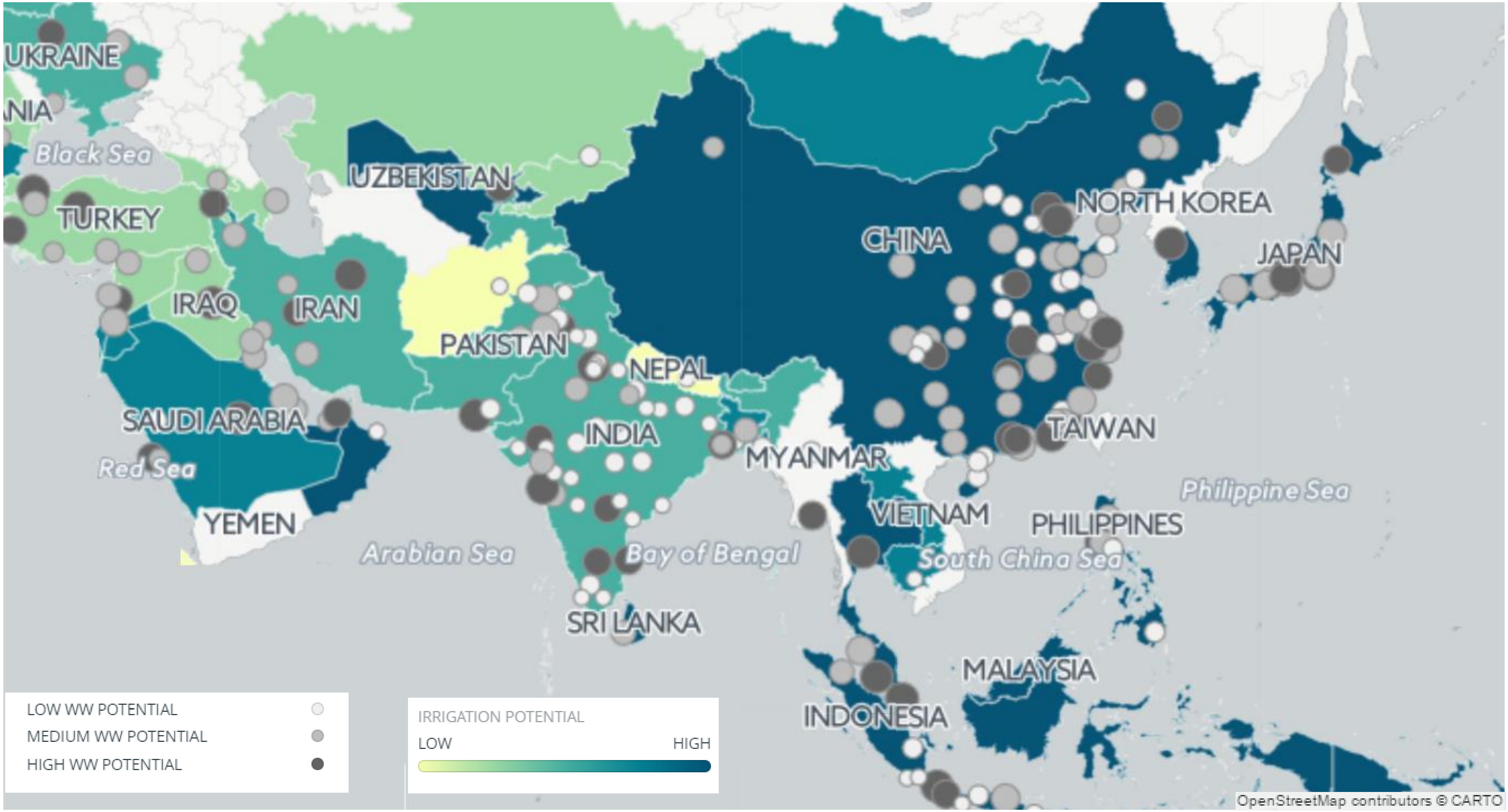

Figure 12: Asian wastewater potential

Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)

6.4 Europe

The European Continent is mainly divided in three very different agroecological zones. While Southern Europe lies in the subtropical (cool) zone, Northern Europe is counted among the boreal (cold) climates. Therefore, this northern part of Europe is also not part of this analysis. Apart from these two polar opposites, the Eastern and Western region mainly lie in the temperate (cool) zone. In general, water scarcity is not an issue on this continent. However, some semi-arid zones like the South of Spain are facing physical water shortages especially during the hot and dry summer months (Molden 2007). With on average 95 percent access to improved sanitation is high across the European continent, although there are some regional differences. These can be particularly found between Western (99%) and Eastern Europe (79%). Especially on the European continent, the relationship between country size (in terms of area as well as population) and wastewater production potential is easily noticeable. While the highest levels are found in Russia, Italy, France, Germany and Spain, the lowest potential is observed in Monaco, Malta, Luxembourg, Estonia and Iceland. In absolute values the highest potential ranges between 9,6 billion m^3 per year in Russia and 5,3 billion m3 in Spain. The lowest values are spread over annual values of 5 million m3 in Monaco to 80 million m3 in Iceland. The cities with the highest wastewater potential in Europe mainly lie in the Southern region with levels from over 800 million m3/year in Paris, France to around 7000 million m3/year in Madrid, Spain. In terms of irrigation, the biggest potential is found in temperate climates (Switzerland, Netherlands, and Poland). However, there are also some Southern countries with an elevated wastewater irrigation potential like Portugal (200%), Albania (160%) and Italy (139%). On the contrary, the lowest levels are also found in the temperate climate in countries like Romania (27%), France (37%) or Hungary (40%). The map below (Figure 13) clearly illustrates these trends with little data points for the city's possible wastewater production and colour coding to indicate the country's wastewater irrigation potential.

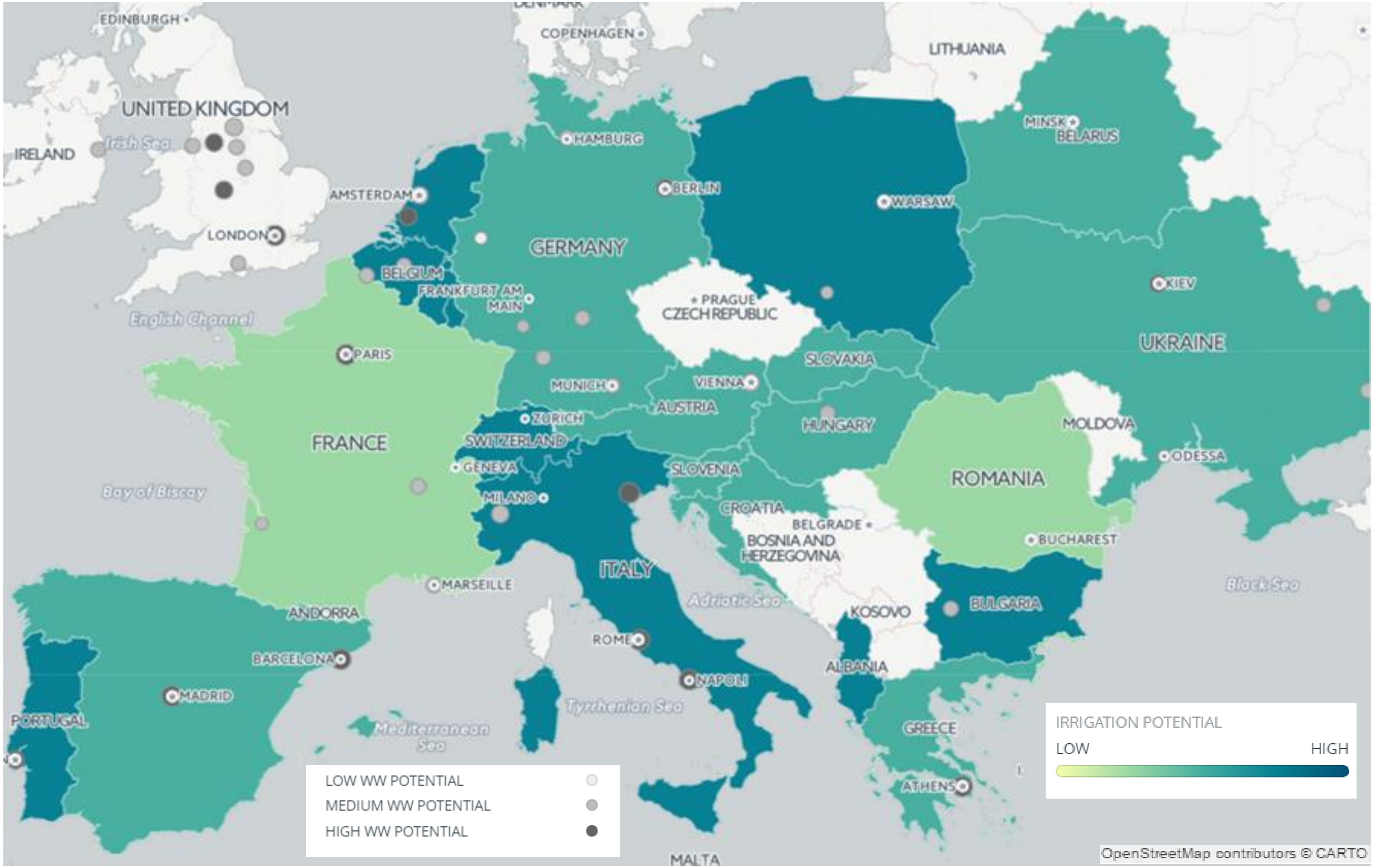

Figure 13: European wastewater potential
(Source: own depiction of analysed data with CARTO. "CARTO. ". Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)Tool. Last modified 2017.

6.5 North America

The North American continent constitutes of mainly three agroecological zones. Canada mainly lies in the boreal (cold) climate, while the US constitutes as a temperate (cool) zone. It needs to be noted that these countries span more than 9 million km^2 and that there are various regional differences between the East and West Coast which are not considered in this general classification. However, the main grain producing belt of the US lies in the temperate (cool) climate which is why this classification was chosen for the whole country. Central America and the Caribbean, largely dispose of the hotter and drier climate in the tropical (warm) zone. In terms of water scarcity levels, a similar separation between the East and West Coast can be observed (Molden 2007). Additionally, the North American continent also includes Central America and the Caribbean which both lie in the tropical (warm) zone. Due to significant differences in terms of development, the highest access to improved sanitation levels (100%) can clearly be observed in the US. Central America and the Caribbean are lacking behind with 85 percent in Mexico and 27 percent in Haiti. This combined with population figures demonstrates that the US has not only the biggest global treated wastewater production potential (62 billion m^3/year) but logically also the highest level on the North American continent. The lowest levels can be found in the Caribbean ranging from 10 million m^3/year in Belize to 28 million m^3/year on the Bahamas. The cities with the highest potential are again mainly found in the US. Out of the 20 cities with highest wastewater production possibility levels nine[13] are located in the US. (New York, Los Angeles, Chicago, San Francisco), while the lowest potential is around 39.0000 m^3/year in Fort-Liberte on Haiti. While the wastewater irrigation potential of the US lies at only 39 percent, the highest value can be found in Costa Rica (over 6000 %). This is mainly due to favourable climatic conditions as well as moderate grain cultivation. On the contrary, the lowest levels are found in countries like Mexico (23 %), Belize (28 %) or Guatemala (35 %). However, these ‘low’ levels are high compared to other regions on the African or Asian continent. The Figure below (Figure 14) summarizes this elaboration on wastewater irrigation potential by comparing it to potentially produced treated wastewater in cities over 1.000.000 inhabitants.

[13] New York, Los Angeles, Chicago, San Francisco, Boston, Philadelphia, Dallas, Houston and Miami.

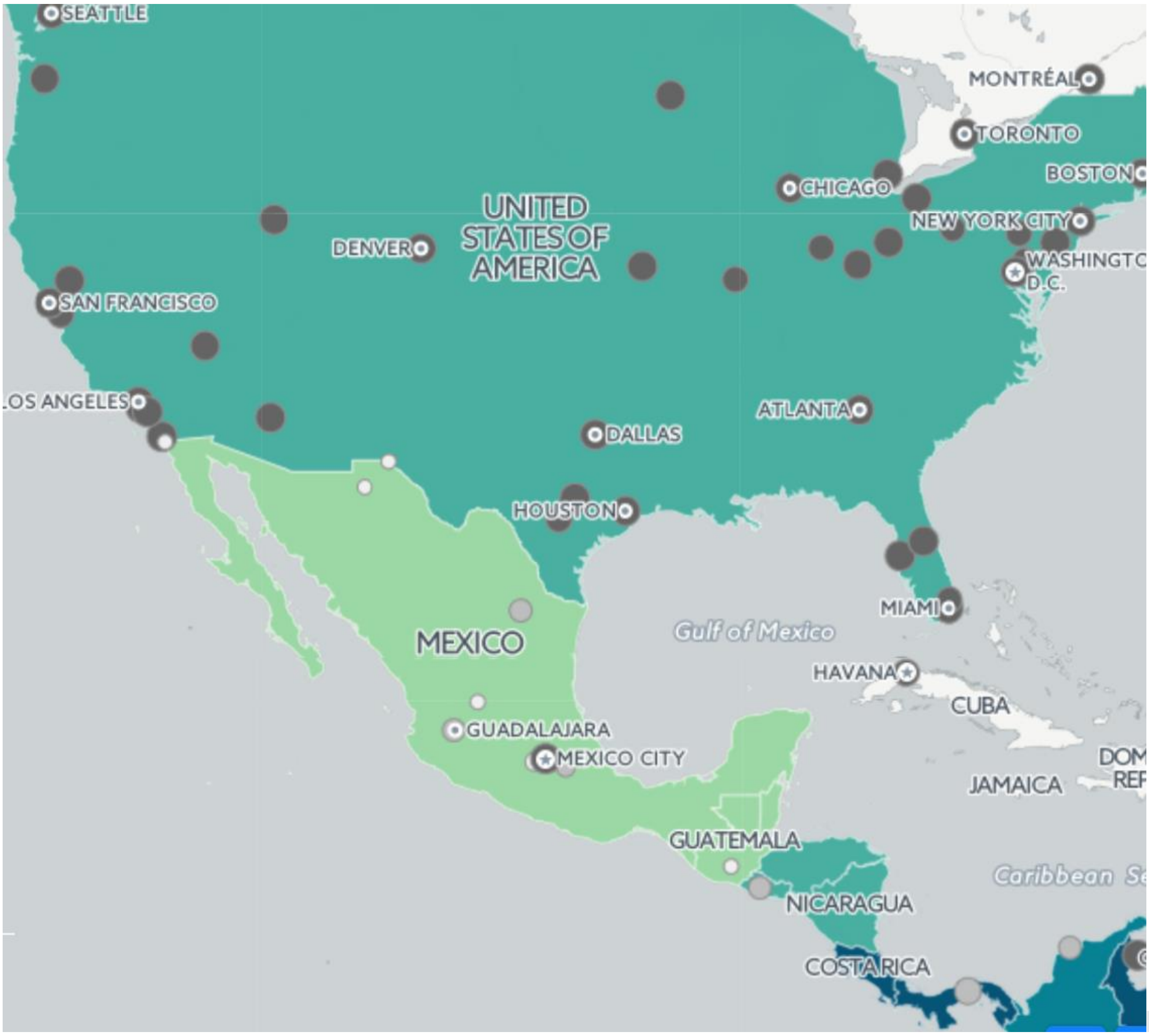

Figure 14: North American wastewater potential
(Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)

6.6 South America

South America constitutes of tropical and subtropical agroecological zones While the Andean region[14] lies in the tropics (cool/cold/very cold), the tropics (warm) can mainly be found in Brazil. The Southern Cone[15], on the other hand, is made up by subtropical (warm/moderate) climate. Thanks to a higher level of water infrastructure development and favourable natural conditions (rainforest, etc.), the continent in general not influenced by water scarcity. However, the Andean region, especially Peru and parts of Bolivia, are still suffering from economic water scarcity. Furthermore, the Peruvian and Bolivian coastal area as well as the area around Recife, Brazil are slowly approaching physical water scarcity. Across the South American continent, access to improved sanitation is on average at 88 percent with values ranging from 51 percent in rural Brazil to 96 percent in urban Argentina. Consequently, the wastewater potential analysis shows a similar picture with Argentina, Venezuela and Colombia showing higher wastewater production potential ranging from 5,59 billion m3 to 2,11 billion m3 per year. Nonetheless, the highest potential is achieved in Brazil. Their potential wastewater production levels are slightly over 14 billion m3/year due to occupying the biggest area, inhabiting 50 percent of the total South American population and having a significantly higher municipal water withdrawal than other countries of the region (17,21 *10^9 m^3/year* compared to 5,8 *10^9 m^3/year* in Argentina). The lowest levels can be found in Bolivia, Paraguay and Uruguay with annual values ranging from 68 million m^3 to slightly under 400 million m^3. The highest city wastewater potential can be found around Buenos Aires (2,06 *10^9 m^3/year)* which makes up almost half of the total wastewater potential of Argentina. In Brazil, the potential is more spread out with Sao Paulo (1,60 *10^9 m^3/year)* and Rio de Janeiro (0,93 *10^9 m^3/year)* making up for less than 5 percent of the potential wastewater of the country. The map below (Figure 15) illustrates wastewater irrigation potential by matching it with possible wastewater production of the biggest cities in the region. While the highest irrigation demand is found in Brazil, Paraguay and Bolivia, the highest wastewater irrigation potential is observed in Brazil, Colombia and Ecuador. The last two have a high potential because their grain cultivation is modest and their irrigation water demand is significantly lower than other countries in the region. Brazil's high irrigation potential can be explained due to the very high wastewater production potential but also lower irrigation water needs for Maize (1,70 mm/growing period) and Wheat (76,10 mm/growing period)

[14] Chile, Colombia, Ecuador, Peru and Venezuela.
[15] Argentina, Bolivia, Paraguay and Uruguay.

Figure 15: South American wastewater potential

(Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/*.)*

6.7 Oceania

Although Oceania is the smallest continent, climatic preconditions vary from the tropical (warm) agroecological zone on the Pacific Islands, to subtropical (cool) in New Zealand and subtropical (warm/moderate) in Australia. Across Oceania, access to improved sanitation is on average at 70 percent with values ranging from 100 percent in Australia to only 19 percent in Papua New Guinea. Consequently, the wastewater potential analysis displays a similar picture. Australia is showing the highest wastewater production potential with 1,85 billion m^3 per year, while the lowest levels can be found in Papua New Guinea and on the Pacific Islands with annual values of 42 million m^3 and 23 million m^3 respectively. The highest city wastewater potential can be found around Sydney (0,38 *10^9 m^3/year)*, Melbourne (0,35 *10^9 m^3/year)*, Auckland *(*0,27 *10^9 m^3/year)* as well as Brisbane (0,22 *10^9 m^3/year)* which make up almost half of the total wastewater potential of this continent. The map below (Figure 16) illustrates wastewater irrigation potential by matching irrigation demand of the three most popular dry cereal crops with possible wastewater production of the biggest cities in the region. While the highest wastewater irrigation potential (%) is observed in New Zealand and Papua New Guinea, the highest irrigation demand (m^3/year) is found in Australia.

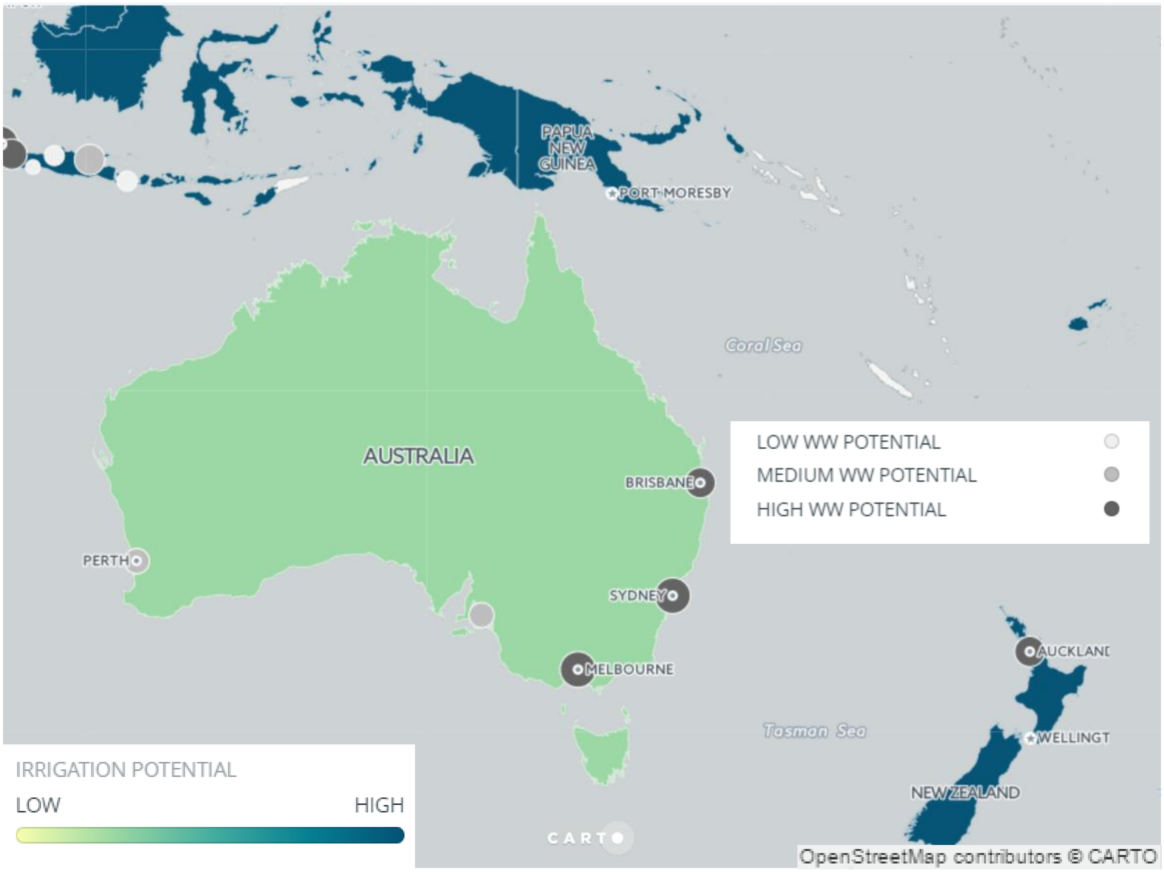

Figure 16: Oceanian wastewater potential

(Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)

7 Case Study: Regional Results on the African Continent

This chapter aims presenting the results the quantitative analysis with a case study on the African continent. After a short introduction to the special case of Africa, the seven regions will be further examined by looking at their wastewater irrigation potential and how this relates to the regions current situation.

7.1 The special case of Africa

As mentioned before, Africa was chosen because of its rich climatic and demographic variations but also because of the huge disparities concerning water stress and water scarcity levels on this very diverse continent (see Figure 2). With its almost 30 million square kilometres, Africa makes up around 20 percent of the world's landmass and inhabits 15 percent of the world's population. The climatic conditions depend on a variety of factors but are mainly influenced by the Kalahari and the Sahara deserts, the equator and the two tropics on the Northern (Tropic of Cancer) and Southern Hemisphere (Tropic of Capricorn). This already shows that the continent is shaped by the combination of very diverse climates, ranging from very dry deserts to wet equatorial conditions and everything in-between. (United Nations 2015; Frenken 2005; UN Water 2014; WWAP 2017a, chap. 9)

However, Africa also presents a special case since it is still counted among the countries with the lowest level of access to sanitation in both urban and rural areas. Furthermore, it is predicted to be one of the fastest growing economies of the next century due to exploding population growth. This new growth wave will mainly happen in already urban or peri-urban centres. Which is why, experts estimate the number of urban population on the African Continent to leap to almost 50 percent in 2030. This would result in Africa hosting not only seven of the world's megacities, meaning urban areas with more than five million inhabitants, but also more than 700 bigger cities with more than 100.000 inhabitants. This rapid increase in urban population puts increasing pressure on the continents natural resources, especially land and water due to lacking sanitation systems, water management and little to no official pollution control. This combined with the widely spreading trend of changing towards a more Western and developed lifestyle, presents a challenge in terms of access to water and but also increased pollution of water resources due to amplified wastewater discharge. (Frenken 2005; Bahri, Drechsel, and Brissaud 2008; UN Water 2012)

As Figure 3 shows, agriculture is still responsible for almost 90 percent of the freshwater withdrawal in most of the African continent, which also makes it one of the biggest water saving opportunities in these countries. Currently around 11 million ha of the total area ready for irrigation are in use, out of which close to 60 percent are semi-arid to arid areas in the North of Africa. They face little to no precipitation and therefore rely heavily on agricultural freshwater withdrawal (Siebert and Frenken 2014, 18f.). However, right now most of the wastewater is directly discharged into local water bodies, polluting not only valuable water resources but also endangering aquaculture. Furthermore, many African countries still heavily rely on directly reusing untreated wastewater for irrigational purposes, endangering not only food security and human health in the region but also putting the ecosystem in peril. This is not always out of choice but out of lack of better options due to lacking water and sanitation infrastructure. Therefore, a safe sanitation and water management system in urban areas is indispensable. (Bahri, Drechsel, and Brissaud 2008; Wang et al. 2014)

Currently, most of the African population is living in areas where sanitation coverage is poor, ranging from almost 80percent in urban to less than 50 percent in rural areas. This means that general access to sanitation in these cities is still very low which makes it hard to improve water security but also hygiene. Currently, only around 70 percent of the African population has access to a sufficient amount of water and sanitation. This means that there is a real infrastructure problem due to the absence of sewer systems or professional treatment plants even in many urban and peri-urban areas. Many households are still connected to on-site sanitation systems via septic tanks, whose sludge regularly pollutes storm sewers and local river systems. This effectively, turns water bodies into large wastewater streams leading from the city centre to the downstream rural areas. Especially in Western Africa, wastewater treatment is almost non-existent with a mere one percent of all cities being connected to a sewage system with a treatment plant. Nonetheless, there are also other examples where treated wastewater reuse has become good practice and a necessary means to ensure water security. Among these countries are Namibia, South Africa and Tunisia, who have planned reuse schemes for the treated effluent in place. (Bahri, Drechsel, and Brissaud 2008; Jacobsen, Webster, and Vairavamoorthy 2013; Wang et al. 2014; WWAP 2017a, chap. 9)

For this analysis, the 53 countries of the African continent were split into five bigger regions according to international conventions and similarities in both geography and climate. Especially, since these factors directly influence irrigation and crop water demand.

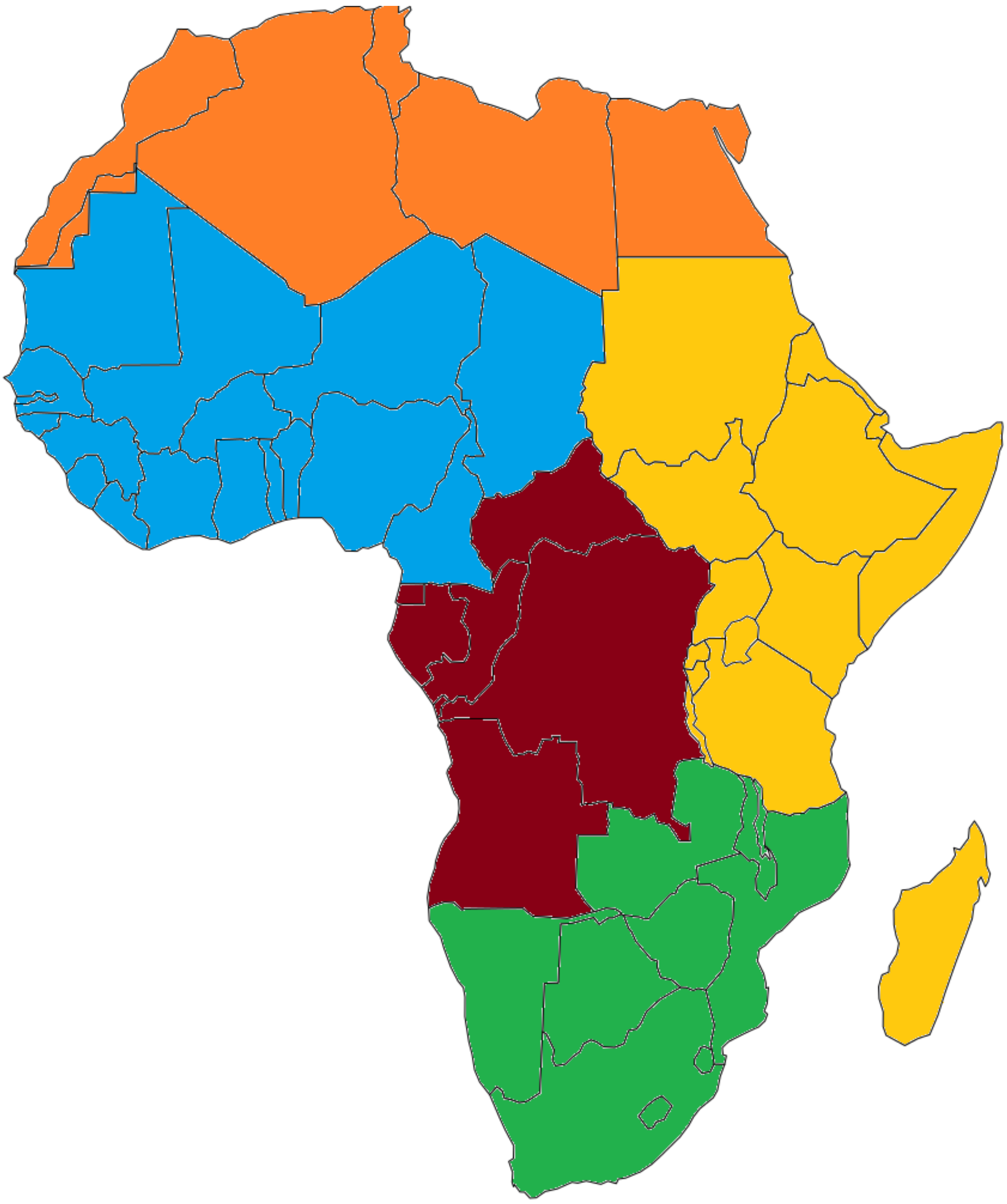

Figure 17: African regions
(Source: own depiction with the use of Simplemaps. 2017. "Free Blank Africa Map in SVG." Database. Simplemaps - Geographic Data Products. http://simplemaps.com/resources/svg-africa.

7.2 Northern Africa

Northern Africa spans an area of around 6 million km^2 and compromises six countries[16]. Situated on the top part of the African continent, all six countries are surrounded by the Mediterranean Sea in the North and the Sahara Desert in the South. Consequently, these two extremes have a great influence on the climatic preconditions of this region. While the northern part lies in a more moderate subtropical zone, the southern area is very hot and dry. Therefore, average precipitation also varies vastly from around 750 mm in north-western Morocco to nearly no detectable precipitation in southern Egypt. In general, population is mainly concentrated on the coastline as well as along the Nile (Delta and Valley) (Siebert and Frenken 2014; Frenken 2005). Nonetheless, Northern Africa enjoys the highest possible municipal wastewater production on the African Continent with around 65 percent of total potential or 12 billion m^3/year in absolute values. Especially, thanks to Egypt who makes up for almost 47 percent of the total potential by being able to produce up to 8,52 billion m^3/year. The highest potential in Egypt is clearly found in Cairo (1,63 *10^9 m^3/year)*, but higher treated wastewater production can also be observed in Alexandria (0,50 *10^9 m^3/year)* and El Giza (0,26 *10^9 m^3/year).* This is especially relevant, considering that the majority of the Egyptian population still lives in rural areas. Other high potential cities in the North African region are Tripoli and Casablanca with 0,13 and 0,11 10^9 m^3/year respectively. According to Frenken (2005), the total area equipped for cultivation in Northern Africa spans 65 million ha, out of which only 28 million ha or close to 40 percent are actually cultivated. Since the region mainly produces Wheat (18 million tons produced/year), its irrigation demand is also highest for this crop with almost 14 billion m3/year. However, there is also Maize production in both Egypt (8 million tons/year) and Morocco (97 thousand tons/year) which amounts to an additional irrigation water demand of 7 billion m3/year. Last but not least, around 3 million tons of Barely are produced per year in North Africa. This adds 6 billion m^3/year to total irrigation water need in this region. Overall, the highest potential for wastewater irrigation can be observed in both Egypt (90 %) and Libya (75 %). While the Egyptian potential is mainly due to high wastewater production possibilities, the Libyan potential is high because grain cultivation is very modest (only 4 % of total North African dry cereal production) in comparison to the other countries of the region.

[16] Algeria, Egypt, Libya, Morocco, Tunisia, and Western Sahara.

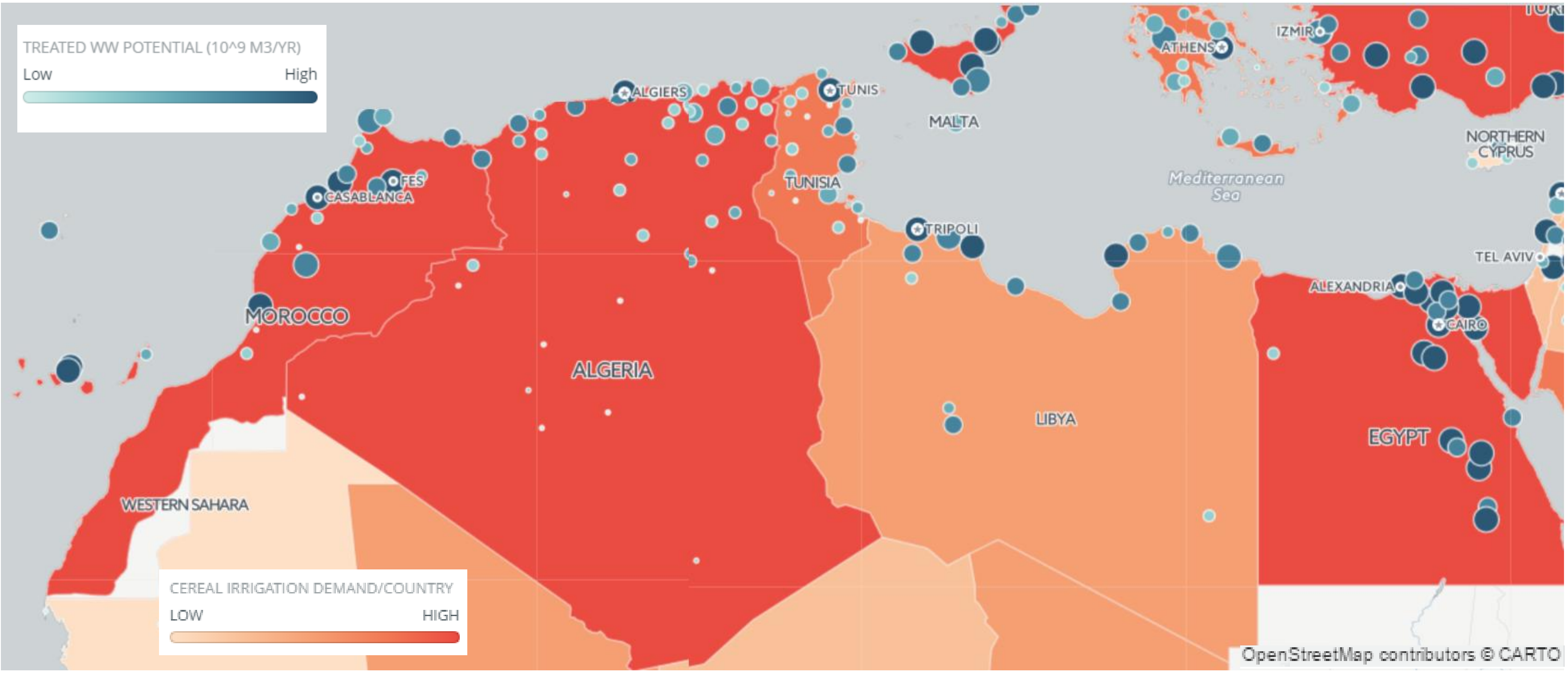

Figure 18: North African wastewater irrigation potential

(Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)

7.3 Eastern Africa

The east of Africa compromises 9 countries and 4 islands [17] who span a total area of three million km^2. Almost two thirds of this total landmass are made up by the larger countries of Ethiopia and the United Republic of Tanzania. Eastern Africa also counts among the most populous and fastest growing regions of the African continent, with a population of more than 400 million people. Taking into account the size and geographical variety of this region climate also differs from drier and hotter conditions in the east to equatorial in the centre and more humid and tropical in the west. Accordingly, annual average precipitation lies under 1000 mm/year and shows huge gaps between the two biggest countries. While the north-eastern area of Ethiopia receives barely 100 mm/year, certain parts in Tanzania register up to 3000 mm/year (Siebert and Frenken 2014; Frenken 2005). Consequently, this region possesses one of the lower municipal wastewater production potentials on the African Continent with around 7 percent of total potential or 1.07 billion m^3/year in absolute values. More than 70 percent of this potential are made up by Kenya (0,36 *10^9* m^3*/year*), Ethiopia (0,23 *10^9* m^3*/year*) and Mauritius (0,20 *10^9* m^3*/year*). The biggest city potential can be found in Port Louis (0,06 *10^9* m^3*/year*) and in Nairobi (0,04 *10^9* m^3*/year*). Out of the total three million km^2 around 80 million ha are equipped for cultivation and only a bit more than a third of this area (approximately 29 million ha) is actually cultivated (Frenken 2005). Since the region mainly produces Maize (21 million tons produced/year) and Sorghum (6 million tons produced/year), its irrigation demand is high with almost 30 billion m3/year. The highest irrigation water need is observed in Tanzania, who makes up for almost one third of the total dry cereal irrigation water demand of this region. The Wheat production in this part of the continent is marginal with around 300 thousand tons produced per year. Consequently, it only adds another 200 million m3/year to the total water need for irrigation in this region. Overall, the highest potential for wastewater irrigation can be observed in Mauritius and Djibouti with more than 1.000 percent respectively. However, these values should be disregarded since grain cultivation agriculture is marginal in these two countries. Therefore, the highest levels are found in smaller cultivation areas such as Comoros (22%), while the cereal producing centres like Kenya (6%), Ethiopia (3%) and especially Tanzania (1%) are showing the lowest potential.

[17] Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Somalia, Sudan, Tanzania, Uganda, plus the islands (The Comoros, Mauritius, the Seychelles and Madagascar).

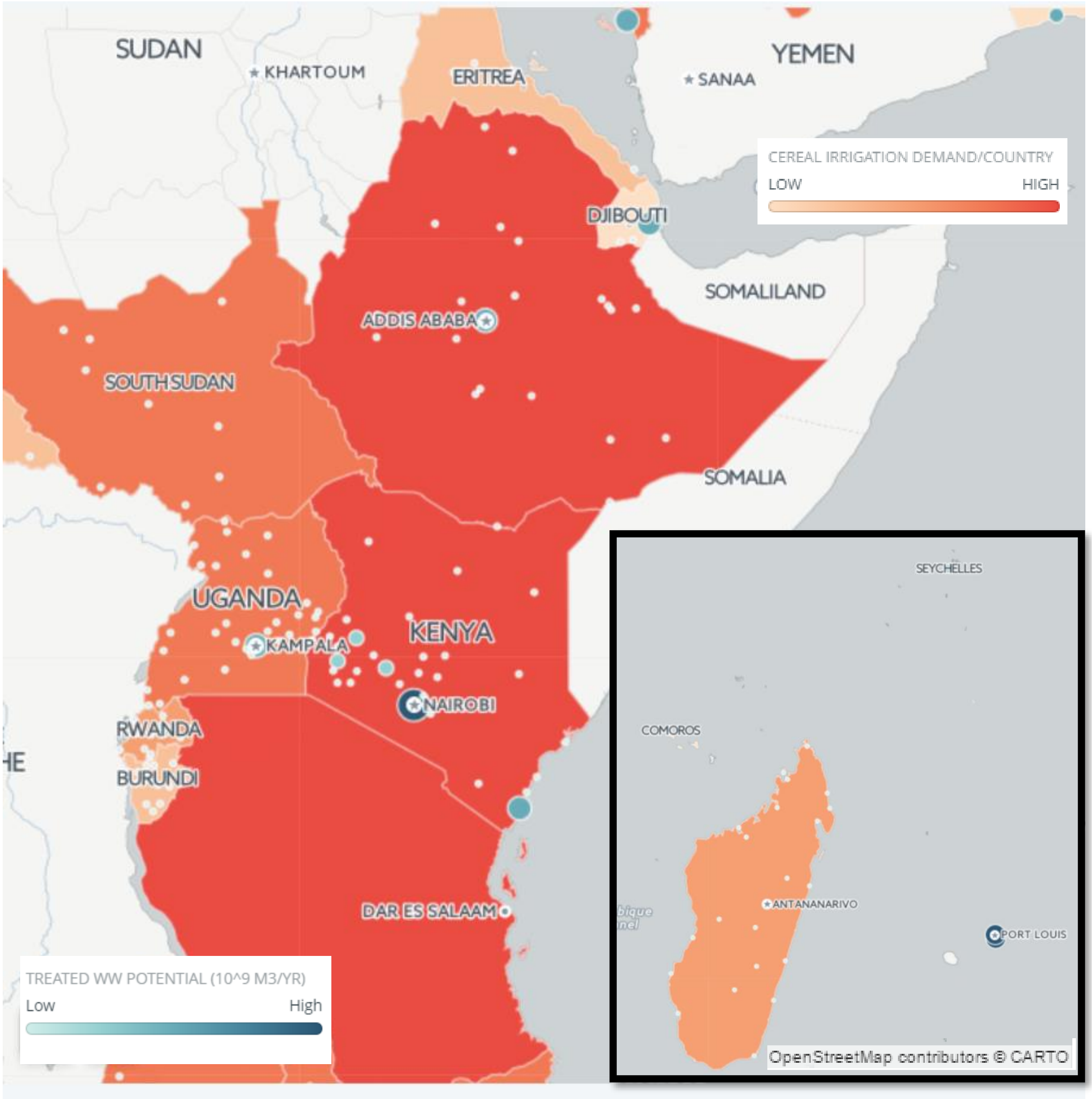

Figure 19: Eastern African wastewater irrigation potential

(Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)

7.4 Central Africa

Central Africa spans a total area of around 5 million km^2 (20% of the total African landmass) and compromises seven countries[18]. The population of 133 million is largely found in the three bigger countries[19]. The biggest country in the region, Democratic Republic of the Congo, does not only account for almost 60 percent of the population but it is also the biggest in terms of occupied land area. Climatic conditions in the region lie between tropical (dry and wet) to equatorial with an average annual precipitation of 1425 mm/year. However, this varies extremely across the region. While Sao Tome and Principe receives less than 1000 mm/year, certain parts in the South-western register up to 6000 mm/year (Siebert and Frenken 2014; Frenken 2005). Accordingly, this region possesses one of the lowest municipal wastewater production potential on the African Continent with around 2 percent of total potential or less than 0,40 billion m^3/year in absolute values. The highest potential is concentrated in the bigger countries with 0,16 billion m^3/year in Angola and 0,13 billion m^3/year in the Democratic Republic of the Congo. This trend continues also on the city level with Luanda (0,08 *10^9* m^3*/year*) and Kinshasa (0,03 *10^9* m^3*/year*) respectively showing the highest wastewater production potential. The lowest potential can be found in Congo, Equatorial Guinea and the Central African Republic who all show values of 0,01 billion m^3/year. Overall, the Central African region possesses around 173 million ha equipped for cultivation. Out of this total area only 12 percent or 1 million ha are actually cultivated (Frenken 2005). Since the region mainly produces Maize (3 million tons produced/year) and Sorghum (2 million tons produced/year), its irrigation demand lies around 3 billion m^3/year. The highest irrigation water need is observed in Angola with 1,7 billion m^3/year for Maize, Sorghum and Millet. The Millet production in general is marginal with around 700 thousand tons produced per year, who add another 500 million m3/year to the total water need for irrigation in this region. Overall, the highest potential for wastewater irrigation can be observed in Gabon (139 %). However, Gabon only produces Maize on a much smaller scale than the rest of the region. Therefore, the highest effective levels are found in the Central African Republic as well as Cameroon with 11 percent respectively. The lowest potential is primarily found in Chad with only 2 percent.

[18] Angola, Central African Republic, Congo, Democratic Republic of Congo, Equatorial Guinea, Gabon, and São Tomé and Príncipe.
[19] Democratic Republic of the Congo, Cameroon and Angola.

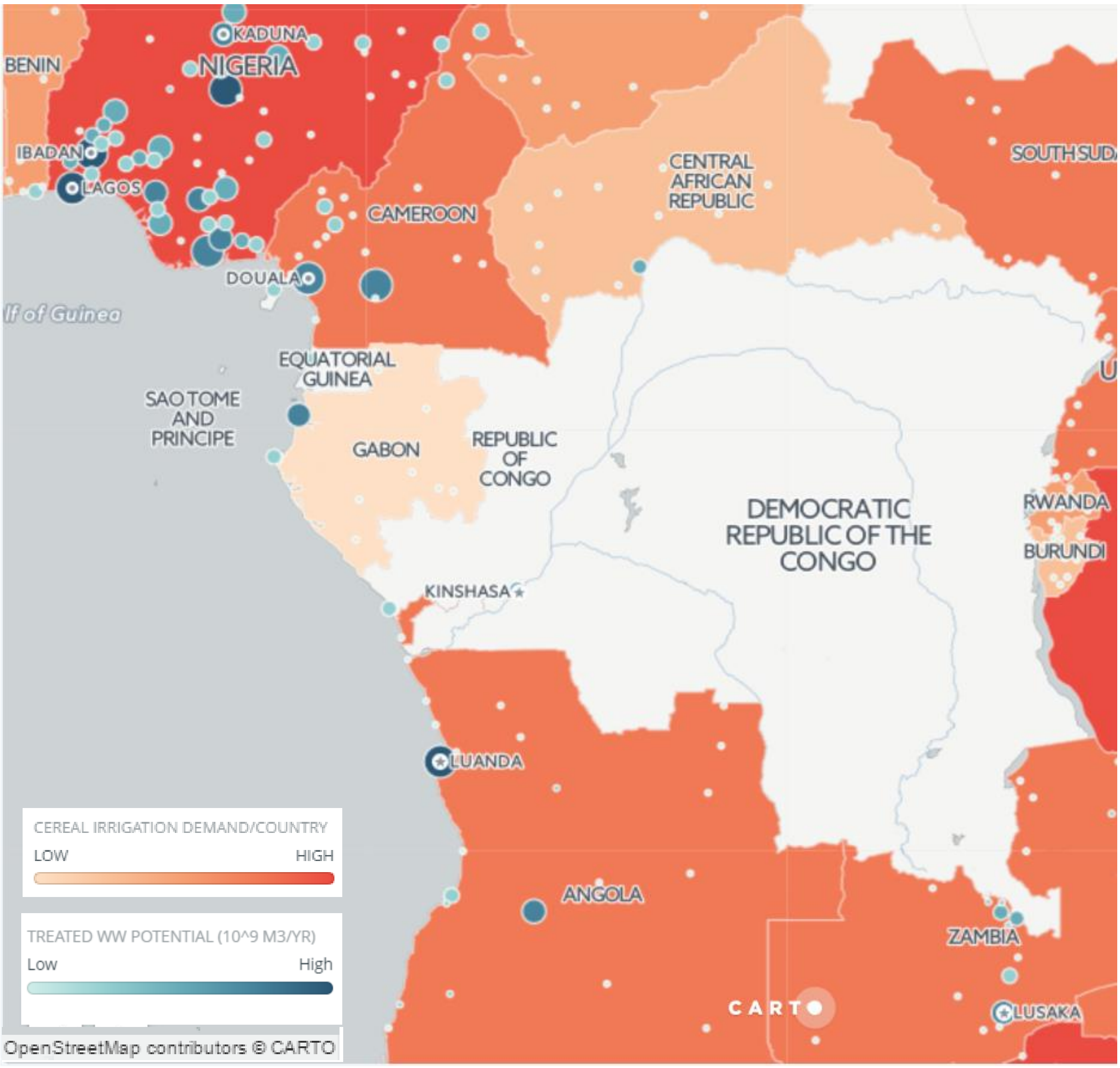

Figure 20: Central African Wastewater irrigation potential

(Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)

7.5 Western Africa

Western Africa is the largest regional grouping containing more than 18 countries[20] and spanning more than 8 million km^2. Therefore, it covers not only almost 30 percent of all African countries but also the same amount of the total area of the African continent. In general, the climatic conditions are dry and shaped by two major seasons. Consequently, average annual precipitation is rather low 311 mm, with a stark contrast between the north (25 mm) and the south (1600 mm) (Siebert and Frenken 2014; Frenken 2005). Most of the almost 372 million inhabitants of this region still live in rural areas. However, the Western African region is the fastest growing area on the continent with growth rates as high as 7%. Therefore, urban areas are expected to grow in the future which in turn will increase treated wastewater production potential (AfDB 2017). Currently, this potential is still quite low with seven percent of total potential or 1,93 billion m^3/year in absolute values. The highest potential is concentrated with 1,45 billion m^3/year in Nigeria which makes up around 75 percent of the regions treated wastewater potential. This trend continues also on the city level with Lagos (0,16 *10^9 m^3/year*) and Kano (0,04 *10^9 m^3/year*) respectively showing the highest wastewater production potential. The lowest potential ranges from 0,00 to 0,01 m^3/year in almost all of the smaller cities (less than one million people) in this region. The region principally produces Maize (16 million tons produced/year) and Sorghum (10 million tons produced/ year), with an irrigation demand of around 10 billion m^3/year. On a country level, the highest irrigation water need is observed in Nigeria with 5 billion m^3/year for Maize (5,5 *10^9 m^3/year*) and Sorghum (2,4 *10^6 m^3/year*), while the lowest irrigation water need is unsurprisingly found in the smaller countries like Guinea-Bissau or Mauritania. Consequently, the highest potential for wastewater irrigation can be observed in these two countries with 1066 and 161 percent respectively. However, since grain production in these countries is very small, these levels should be disregarded. Therefore, the highest effective levels are found in Senegal (33%), Nigeria (25%). The lowest potential is primarily found in Togo (2%) but also in Mali (3%), Ghana (4%) and Niger (4%).

[20] Benin, Burkina Faso, Cameroon, Cape Verde, Chad, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo.

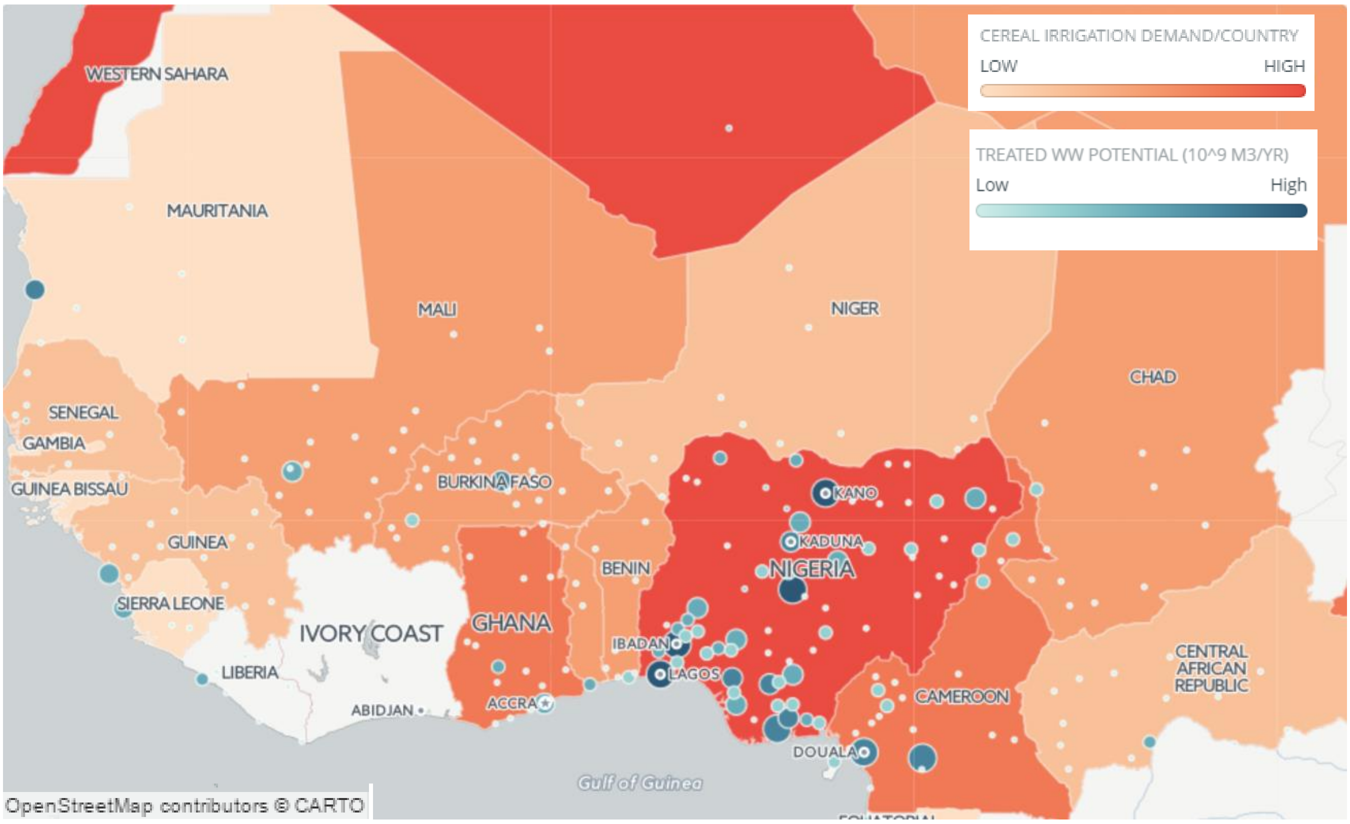

Figure 21: Western African Wastewater Irrigation Potential

(Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)

7.6 Southern Africa

The Southern Region compromises nine countries[21] and spans an area of 4,7 million km^2. This is largely made up by South Africa, Namibia and Mozambique (over 60 percent). While the smaller countries of this region are mainly landlocked, the three big countries all dispose of access to the ocean. The climate is as diverse as the landscape ranging from the semi-arid Kalahari Desert to the temperate mountains of Lesotho to the subtropical and tropical plains in the rest of the Southern region. Consequently, annual precipitation levels vary from high in more tropical zones of Mozambique (2.000 mm) to very low in the dry zones of the Kalahari Desert (100 mm) (Siebert and Frenken 2014). The Southern African region possesses high municipal wastewater production potential. In general, the region makes up almost 20 percent of total potential of the African continent or 3,31 billion m^3/year in absolute values. Especially, thanks to South Africa who would be able to produce 2,73 billion m^3 treated wastewater per year or percent of the total regional wastewater. The highest potential in South Africa is clearly found in Johannesburg (0,70 *billion* m^3*/year)*, but higher production can also be observed in Cape Town (0,22 billion m^3*/year)* and Durban (0,15 *billion* m^3*/year).* Almost 30 percent of the areas equipped for cultivation (around 30 million ha) is used by larger industrial and smaller individual farmers (Frenken 2005). Since the region mainly produces Maize (23 million tons produced per year), its irrigation demand is also highest for this crop with almost 20 billion m3/year. However, there is also a smaller Wheat production amounting to a bit more than 1 million tons produced per year. Overall, the region's irrigation water need for cereal crops amounts to 22 billion m3/year. Consequently, the highest potential for wastewater irrigation can be observed in South Africa (39%) and Botswana (26%). The South African potential is mainly caused by high wastewater production possibilities and improved access to sanitation but also due to rising water scarcity levels. However, South Africa also has the highest and most active grain cultivation amounting to more than 60 percent of the total cereal production in the region. On the contrary, the lowest potential can be found in Lesotho, Malawi and Mozambique with around 2 percent.

[21] Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia and Zimbabwe.

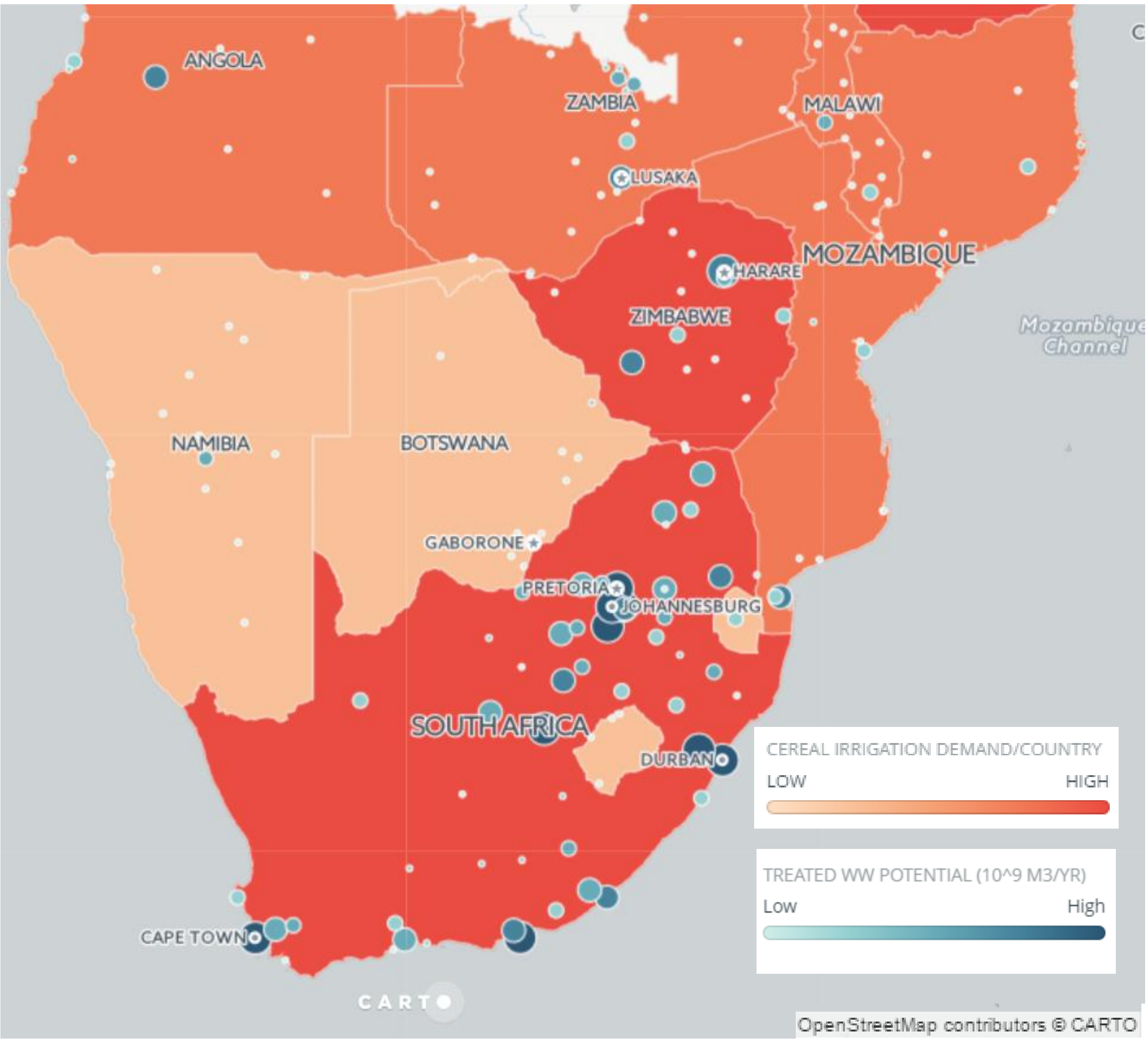

Figure 22: Southern Africa Wastewater Irrigation Potential

(Source: own depiction of analysed data with CARTO. "CARTO Builder." Analysis Tool. Last modified 2017. Accessed June 1 2017. https://limarie.carto.com/.)

7.7 Implications for the SDGs and 'Goal six'

In general, Africa still counts among the regions with the least access to improved sanitation with levels as low as 2,9 percent in rural Togo and 16,4 percent in urban South Sudan. If we consider the total percentage values of this indicator, 17 out of 47 Sub-Saharan African countries lie below the 21 percent mark. While Northern Africa counts among the regions with the biggest developments in terms of access to improved sanitation since the 1990s, the countries of Sub-Saharan Africa are on the other end of this scale. There, almost 700 million people are still without proper access to sanitation infrastructure (WHO and UNICEF 2015). Access to sanitation is important because it directly plays into the wastewater potential of a country. For this reason, the findings of this quantitative analysis show that the biggest treated wastewater potential can be found in the Northern African region but also in South Africa. Unsurprisingly, this is directly proportional to their treated wastewater irrigation potential. On the one hand, because these areas are counted among the agricultural centres of the continent, but also because they are heavily suffering from physical water scarcity. Consequently, an expansion of adequate wastewater treatment infrastructure in these regions could significantly alleviate water stress and increase food security. This is particularly applicable in these areas, because some countries (e.g. Algeria, Egypt, South Africa and Tunisia) have already invested in wastewater treatment infrastructure. However, the direct reuse of the treated effluent for irrigational purposes is still very limited. Therefore, increasing treated wastewater irrigation can also play an important role in addressing the issue of food security. Especially since, irrigation is now being reduced to a minimum in some parts due to local water infrastructure being largely unable to keep up with the rising demand. With an agricultural water abstraction as high as 80 percent of total freshwater withdrawal, new solutions to satisfy this rising demand are critical. Thus, increasing the amount of efficient wastewater treatment plants and establishing a functioning legal reuse scheme could make a significant difference in terms of water availability in these countries. (United Nations 2017; WWAP 2017b)

Finding and financing new clean water sources will play a major role in ensuring sustainable development for Africa and its population. Consequently, the advance of treated wastewater reuse regimes will be an important topic for cooperation and development all over the African Continent. With special efforts from the African Union (AU) but also from national NGOs and international organizations, the first priority should be expanding access to improved sanitation all over the continent. According to the JMP proposal, possible target values for increasing sanitation infrastructure should at least cover 50 percent of the total population by 2030. (WHO 2015)

In target 6.2 of 'Goal six' of the SDGs the UN calls for universal *"[...] access to adequate and reasonable sanitation and hygiene for all and end open defecation"*(United Nations 2017, Goal 6, Target 6.2). However, under current circumstances, the possibility of achieving universal access to improved sanitation (100 %) by 2030 seems is very low. According to the last JMP report of 2015, only 97 countries are living in situations where access to improved sanitation levels exceed the 90 percent mark, while 47 countries (37 located on the African continent) are still below the 50 percent line (WHO 2015). Similar results were found in the quantitative analysis of this thesis, especially with the 10 Sub-Saharan African countries[22] who were classified with the lowest treated wastewater production potential. In general, access to sanitation levels in these 10 countries range from around 6 percent in South Sudan to 41 percent in Malawi. Municipal water withdrawal in these countries is rather small compared to other highly populated countries with more than 500 million m^3/year in Tanzania and as little as 20 million m^3/year in Lesotho. However, some of these low potential countries have very high irrigation water needs. Especially, Tanzania (11 billion m^3/year) who has the highest irrigation water demand on the African continent. Among the other nine countries, Mozambique, Malawi, Uganda and South Sudan also show higher irrigation needs ranging from three to one billion m^3/year. Therefore, ensuring universal access to improved sanitation and consequently increasing potential wastewater production is key in these regions. To this end, three different scenarios of changes in access to improved sanitation were elaborated to compare the deviations in wastewater production and ultimately wastewater irrigation potential. While scenario number one illustrates the changes under a 50 percent increase of current access to improved sanitation values, scenario number two shows deviations under universal access as laid out by Target 6.2 of the SDGs. The third scenario observes changes to wastewater production and irrigation potential under a uniform level of 50 percent access to improved sanitation in all 10 countries as suggested by the JMP. The biggest limitation to this observation is the actuality of data. While the JMP data on access to sanitation is from 2015, the secondary data for municipal water withdrawal as extracted from AQUASTAT is based on latest values only. Although no level is older than 2000, the African continent has witnessed significant population growth over the last 10 years. Therefore, if one corrects the values to current population levels, the wastewater production and irrigation potential might be slightly higher than the levels presented in this study. Nonetheless, similar trends of increased wastewater production and wastewater irrigation can be observed.

[22] Lowest to highest: Tanzania, South Sudan, Benin, Eritrea, Chad, Malawi, Uganda, Lesotho, Mozambique, Togo.

To this end, Figure 23 shows that heightened access to sanitation clearly increases the wastewater irrigation potential of all 10 countries. While the increase of 50 percent of actual levels reflects the differences in sanitation development for each country, the 50 percent mark of the JMP offers a more uniform picture mainly influenced by differences in municipal water withdrawal. Unsurprisingly, the biggest change and the highest irrigation potential levels can be observed under the 100 percent access to sanitation scenario. While the levels in Tanzania are rising only moderately from one percent with actual levels (15.6%) to five percent with universal access (100%), the biggest increase can be observed for Togo. There, levels would rise from two percent under actual conditions to 21 percent under the SDG scenario. Other countries with similar increases are Chad (from to 13%), South Sudan (1% from to 13%), Benin (1% from to 12%), Mozambique (2% from to 11%) and Uganda (2% from to 10%). On the other hand, the increase in irrigation potential is much lower in countries with already higher access to sanitation levels like Lesotho (30%) or Malawi (41%). There, wastewater irrigation potential only increases a few percent points from 2 percent under the current situation to around 6 and 4 percent respectively under the SDG 100 scenario.

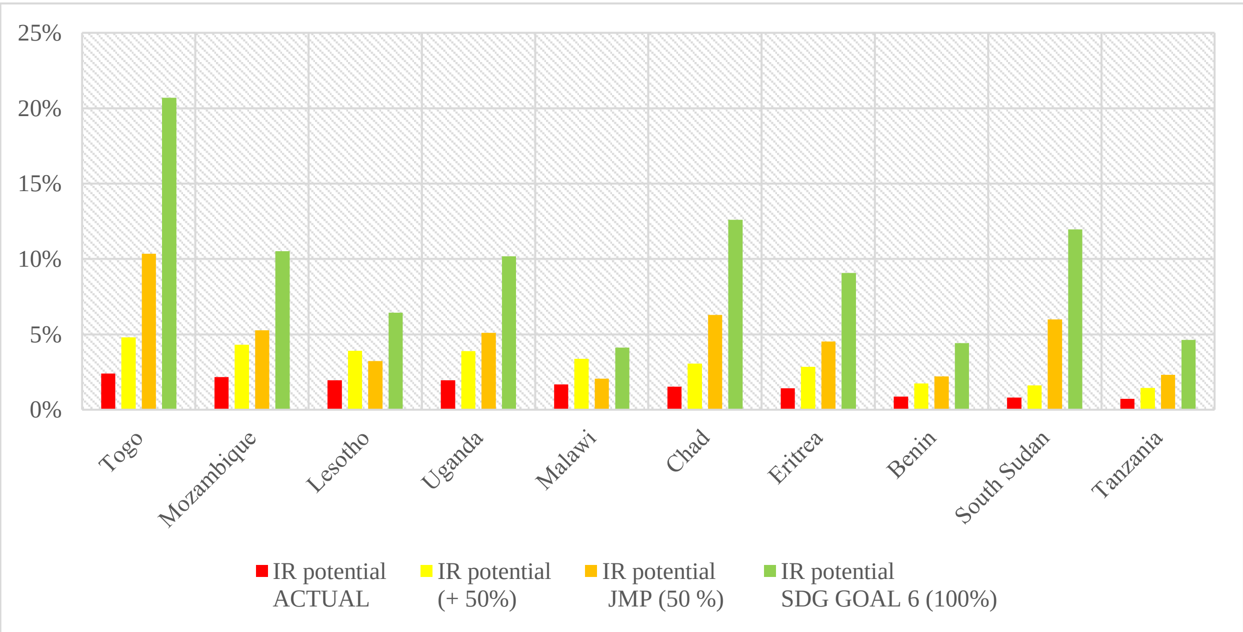

Figure 23: Changes to Wastewater Irrigation Potential
(Source: own depiction)

Therefore, a significant increase in relevant water infrastructure in terms of access to improved sanitation, in line with the goals and targets of the SDGs, could have an impact even in these ‘low’ potential countries. However, the problem will not be solved by access to sanitation alone. The sewer system needs to be interlinked with efficient and environmentally and financially sustainable treatment options to ensure safe wastewater discharge and prevent further pollution of local water bodies. This is particularly important, because thus far the topic of water quality has been a neglected issue in the development agenda. However, direct discharge of untreated municipal, agricultural and industrial wastewater significantly contributes to a deterioration of water quality due to pollution with pathogens, heavy metals and other toxins. For this reason, the SDGs and especially ‘Goal six’ have finally called for action in this regard. Apart from ensuring mere access to sanitation, these goals also aim at reducing water pollution and increase water quality with a variety of measures. There is even a specific target under Goal 6 calling for a reduction of untreated effluent discharge by 50 percent and an increase of reuse and recycling schemes by the same amount (United Nations 2017). These are ambitious goals by global standards but especially in the African context. Accordingly, the cost factor of measures to facilitate these target values should not be underestimated. Since, lacking funds have been huge limiting factors of the development of an efficient and functioning wastewater treatment infrastructure and capacity in African countries.

The WHO will be a key player in this regard. With its principle of ‘fit-to-purpose’ wastewater management solutions, they can offer a variety of treatment and non-treatment options to make wastewater reuse a possibility for developing countries. Therefore, new investment models and increased technology transfer is needed to achieve the SDG targets of Goal six. A key factor in this regard could be ‘TrackFin’. A tool developed by the WHO and UN Water, under the umbrella of the ‘Global Analysis and Assessment of Sanitation and Drinking Water’ (GLAAS), to compile evidence-based information on investments, funding opportunities and financing gaps. It is currently used by five African countries[23] with further expansion planned in the next years (UN Water and WHO 2015). Should this be successful, supplementary investments in irrigation infrastructure could also increase food security and therefore bring significant benefits under the Goal two of the SDGs. Especially, since studies show that global food demand is expected to rise by around 60 percent until 2050, mainly due to population growth and alimentation changes in developing regions in Africa and Asia. (IWA 2017; WWAP 2017a)

[23] Burkina Faso, Ghana, Madagascar, Mali, Morocco.

8 Conclusion and Discussion of Results

The overall aim of this investigation was to assess the global wastewater potential based on municipal wastewater discharge and access to improved sanitation as quantitative data for access to wastewater treatment. The second aim of this study was to highlight the enormous potential of treated wastewater for being a renewable, sustainable and available agricultural water source for irrigation of the most important dry cereal crops. The third aim was to look at the special case of Africa by investigating wastewater and irrigation potential with regards to fulfilling the targets set by 'Goal six' of the SDGs.

The most obvious finding to emerge from this study is that potential wastewater production is highest in highly populated areas with increased access to improved sanitation. The difference between developed and developing countries is still more than evident. While the countries and cities with the highest wastewater potential are mainly located in the developed world or in transition economies, the lowest potential is primarily found in developing countries and especially on the African continent especially since they have very low level of access to improved sanitation. In terms of agricultural reuse of treated wastewater for irrigation of cereal crops, a similar trend towards lowest potential in Western and Eastern African Countries can be observed. However, the highest potential is much more spread out and less dependent on the level of development. With seven out of ten highest potential countries in subtropical and tropical climates, the findings show that wastewater irrigation potential does not only depend on climatic conditions but also on the available amount of treated wastewater and access to improved sanitation as well as the specific irrigation water demand. However, the generalisability of these results is subject to certain limitations. For instance, the assumption that access to sanitation always means access to wastewater treatment. Furthermore, that wastewater treatment produces an effluent of quality standards suitable to be used for wastewater irrigation. Lastly, that only dry cereal crop irrigation was investigated which excludes many water intensive wet grains like rice or vegetables and fruits. Notwithstanding the fact that this analysis is completely based on potential wastewater, it still offers valuable insights into the future of irrigation in cultivation agriculture. In terms of data availability, a huge gap was detected for actual wastewater figures. Especially, in the Global South were data on wastewater collection, treatment and reuse is still almost non-existent. This is mainly, due to lacking infrastructure in big parts of Africa and Asia but also because these regions are still heavily relying on direct and indirect reuse of untreated wastewater for agriculture. Therefore, greater efforts are needed to ensure more stringent legal regulations and policy enforcement, but also additional studies focussing on increasing wastewater treatment capacities in developing countries.

The results of this study indicate that the global potential for wastewater collection and treatment is much higher than the current level. While the differences between actually treated wastewater and potentially treated wastewater are low in developed countries (like the US or Germany), they are very pronounced in the Global South. However, the possibilities for alleviating water stress in already dry areas would be immense. In general, this study finds that combining global total irrigation demand for dry cereal cultivation and global treated wastewater potential, wastewater irrigation could make up for almost 66 percent of total grain irrigation. Consequently, the results support the idea that wastewater treatment and its reuse can and will be a major factor in future sustainable water supply. The principal theoretical implication of this study is that access to improved sanitation and wastewater treatment needs to be expanded, especially in the developing countries. Furthermore, national and supranational guidelines and best practices need to be communicated and enforced more stringently to counteract public weariness. A public information campaign like the one laid out in honour of the 'World Water Day 2017' needs to be enforced to stress the importance of this topic.

For future practice, there is an urgent need to develop internationally standardized wastewater reuse-schemes that go hand in hand with a vast expansion of wastewater treatment investments. To reach the target set by 'Goal six' of the SDGs, a key policy priority should be long-term capacity building and strengthening treatment infrastructure globally but especially in the Global South. Ensuring appropriate reuse-systems, treatment services and technological support for wastewater should be a priority in developing countries. Especially, the African continent needs renewed investment in wastewater to be able to keep up with growing water demand but also with increasing physical water scarcity levels. Continued efforts are also needed to decrease economic water scarcity to a minimum by improving access to sanitation and increasing access to treated wastewater recycling schemes. Unless governments adopt reuse-schemes and increase efforts for wastewater treatment and access to improved sanitation, the targets in terms of ensuring clean water and sanitation under 'Goal six' will not be attained.

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Potential Wastewater of selected countries

Country	Continent	population	MWC (10^9 m3/year)	MWC (m3/year)	MWC (m3/capita/year)	SANpoptotal (%)	potWW country (m3/year)
Afghanistan	Asia	32.527.000	0,2034	203.400.000	6,25	31,9	64.884.600
Albania	Europe	2.897.000	0,5613	561.300.000	193,75	93,2	523.131.600
Algeria	Africa	39.667.000	1,0872	1.087.200.000	27,41	87,6	952.387.200
Angola	Africa	25.022.000	0,3195	319.500.000	12,77	51,6	164.862.000
Argentina	Americas	43.417.000	5,8	5.800.000.000	133,59	96,4	5.591.200.000
Armenia	Asia	3.018.000	0,843	843.000.000	279,32	89,5	754.485.000
Australia	Oceania	23.969.000	1,851	1.851.000.000	77,22	100	1.851.000.000
Austria	Europe	8.545.000	0,72	720.000.000	84,26	100	720.000.000
Azerbaijan	Asia	9.754.000	0,521	521.000.000	53,41	89,3	465.253.000
Bahamas	Americas	388.000	0,031	31.000.000	79,90	92	28.520.000
Bahrain	Asia	1.377.000	0,1779	177.900.000	129,19	99,2	176.476.800
Bangladesh	Asia	160.996.000	3,6	3.600.000.000	22,36	60,6	2.181.600.000
Barbados	Americas	284.200	0,02	20.000.000	70,37	96,2	19.240.000
Belarus	Europe	9.496.000	0,547	547.000.000	57,60	94,3	515.821.000
Belgium	Europe	11.299.000	0,7093	709.300.000	62,78	99,5	705.753.500
Belize	Americas	359.300	0,0114	11.400.000	31,73	90,5	10.317.000
Benin	Africa	10.880.000	0,041	41.000.000	3,77	19,7	8.077.000
Bhutan	Asia	774.800	0,017	17.000.000	21,94	50,4	8.568.000
Bolivia	Americas	10.725.000	0,136	136.000.000	12,68	50,3	68.408.000
Bosnia and Herzegovina	Europe	3.810.000	0,3218	321.800.000	84,46	94,8	305.066.400
Botswana	Africa	2.262.000	0,0878	87.800.000	38,82	63,4	55.665.200
Brazil	Americas	207.848.000	17,21	17.210.000.000	82,80	82,8	14.249.880.000
Bulgaria	Europe	7.150.000	1,07	1.070.000.000	149,65	86	920.200.000
Burkina Faso	Africa	18.106.000	0,3756	375.600.000	20,74	19,7	73.993.200
Burundi	Africa	11.179.000	0,0431	43.100.000	3,86	48	20.688.000
Cabo Verde	Africa	520.500	0,0016	1.600.000	3,07	72,2	1.155.200
Cambodia	Asia	15.578.000	0,098	98.000.000	6,29	42,4	41.552.000
Cameroon	Africa	23.344.000	0,2468	246.800.000	10,57	45,8	113.034.400
Canada	Americas	35.940.000	5,878	5.878.000.000	163,55	99,8	5.866.244.000
Central African Republic	Africa	4.900.000	0,0601	60.100.000	12,27	21,8	13.101.800
Chad	Africa	14.037.000	0,1037	103.700.000	7,39	12,1	12.547.700
Chile	Americas	17.948.000	1,267	1.267.000.000	70,59	99,1	1.255.597.000
China	Asia	1.407.306.000	75,01	75.010.000.000	53,30	76,5	57.382.650.000
Colombia	Americas	48.229.000	2,606	2.606.000.000	54,03	81,1	2.113.466.000
Comoros	Africa	788.500	0,0048	4.800.000	6,09	35,8	1.718.400
Congo	Africa	4.620.000	0,0637	63.700.000	13,79	15	9.555.000
Costa Rica	Americas	4.808.000	0,76	760.000.000	158,07	94,5	718.200.000
Croatia	Europe	4.240.000	0,5079	507.900.000	119,79	97	492.663.000
Cuba	Americas	11.390.000	1,7	1.700.000.000	149,25	93,2	1.584.400.000

Country	Continent	population	MWC (10^9 m3/year)	MWC (m3/year)	MWC (m3/capita/year)	SANpoptotal (%)	potWW country (m3/year)
Cyprus	Europe	1.165.000	0,0841	84.100.000	72,19	100	84.100.000
North Korea	Asia	25.155.000	0,9028	902.800.000	35,89	81,9	739.393.200
Democratic Republic of the Congo	Africa	77.267.000	0,4649	464.900.000	6,02	28,7	133.426.300
Denmark	Europe	5.669.000	0,36	360.000.000	63,50	99,6	358.560.000
Djibouti	Africa	887.900	0,016	16.000.000	18,02	47,4	7.584.000
Dominican Republic	Americas	10.528.000	0,855	855.000.000	81,21	84	718.200.000
Ecuador	Americas	16.144.000	1,293	1.293.000.000	80,09	84,7	1.095.171.000
Egypt	Africa	91.508.000	9	9.000.000.000	98,35	94,7	8.523.000.000
El Salvador	Americas	6.127.000	0,474	474.000.000	77,36	75	355.500.000
Equatorial Guinea	Africa	845.100	0,0158	15.800.000	18,70	74,5	11.771.000
Eritrea	Africa	5.228.000	0,031	31.000.000	5,93	15,7	4.867.000
Estonia	Europe	1.313.000	0,06	60.000.000	45,70	97,2	58.320.000
Ethiopia	Africa	99.391.000	0,81	810.000.000	8,15	28	226.800.000
Fiji	Oceania	892.100	0,0253	25.300.000	28,36	91,1	23.048.300
Finland	Europe	5.503.000	0,415	415.000.000	75,41	97,6	405.040.000
France	Europe	64.395.000	5,481	5.481.000.000	85,12	98,7	5.409.747.000
Gabon	Africa	1.725.000	0,0847	84.700.000	49,10	41,9	35.489.300
Gambia	Africa	1.991.000	0,0412	41.200.000	20,69	58,9	24.266.800
Georgia	Asia	4.000.000	0,358	358.000.000	89,50	86,3	308.954.000
Germany	Europe	80.689.000	5,409	5.409.000.000	67,04	99,2	5.365.728.000
Ghana	Africa	27.410.000	0,235	235.000.000	8,57	14,9	35.015.000
Greece	Europe	10.955.000	1,293	1.293.000.000	118,03	99	1.280.070.000
Grenada	Americas	106.800	0,012	12.000.000	112,36	98	11.760.000
Guatemala	Americas	16.343.000	0,835	835.000.000	51,09	63,9	533.565.000
Guinea	Africa	12.609.000	0,2248	224.800.000	17,83	20,1	45.184.800
Guinea-Bissau	Africa	1.844.000	0,0341	34.100.000	18,49	20,8	7.092.800
Guyana	Americas	767.100	0,0613	61.300.000	79,91	83,7	51.308.100
Haiti	Americas	10.711.000	0,19	190.000.000	17,74	27,6	52.440.000
Honduras	Americas	8.075.000	0,315	315.000.000	39,01	82,6	260.190.000
Hungary	Europe	9.855.000	0,5945	594.500.000	60,32	98	582.610.000
Iceland	Europe	329.400	0,081	81.000.000	245,90	98,8	80.028.000
India	Asia	1.311.051.000	56	56.000.000.000	42,71	39,6	22.176.000.000
Indonesia	Asia	257.564.000	13,99	13.990.000.000	54,32	60,8	8.505.920.000
Iran	Asia	79.109.000	6,2	6.200.000.000	78,37	90	5.580.000.000
Iraq	Asia	36.423.000	4,3	4.300.000.000	118,06	85,6	3.680.800.000
Ireland	Europe	4.688.000	0,628	628.000.000	133,96	90,5	568.340.000
Israel	Asia	8.064.000	0,712	712.000.000	88,29	100	712.000.000
Italy	Europe	59.798.000	9,451	9.451.000.000	158,05	99,5	9.403.745.000
Jamaica	Americas	2.793.000	0,288	288.000.000	103,11	81,8	235.584.000
Japan	Asia	126.573.000	15,41	15.410.000.000	121,75	100	15.410.000.000
Jordan	Asia	7.595.000	0,2913	291.300.000	38,35	98,6	287.221.800
Kazakhstan	Asia	17.625.000	0,878	878.000.000	49,82	97,5	856.050.000

Country	Continent	population	MWC (10^9 m3/year)	MWC (m3/year)	MWC (m3/capita/year)	SANpoptotal (%)	potWW country (m3/year)
Kenya	Africa	46.050.000	1,186	1.186.000.000	25,75	30,1	356.986.000
Kuwait	Asia	3.892.000	0,4483	448.300.000	115,18	100	448.300.000
Kyrgyzstan	Asia	5.940.000	0,224	224.000.000	37,71	93,3	208.992.000
Laos	Asia	6.802.000	0,13	130.000.000	19,11	70,9	92.170.000
Latvia	Europe	1.970.000	0,1593	159.300.000	80,86	87,8	139.865.400
Lebanon	Asia	5.851.000	0,38	380.000.000	64,95	80,7	306.660.000
Lesotho	Africa	2.135.000	0,02	20.000.000	9,37	30,3	6.060.000
Liberia	Africa	4.503.000	0,0802	80.200.000	17,81	16,9	13.553.800
Libya	Africa	6.278.000	0,7	700.000.000	111,50	96,6	676.200.000
Lithuania	Europe	2.878.000	0,1499	149.900.000	52,08	92,4	138.507.600
Luxembourg	Europe	567.100	0,0408	40.800.000	71,94	97,6	39.820.800
Madagascar	Africa	24.235.000	0,395	395.000.000	16,30	12	47.400.000
Malawi	Africa	17.215.000	0,1431	143.100.000	8,31	41	58.671.000
Malaysia	Asia	30.331.000	3,902	3.902.000.000	128,65	96	3.745.920.000
Maldives	Asia	363.700	0,0056	5.600.000	15,40	97,9	5.482.400
Mali	Africa	17.600.000	0,107	107.000.000	6,08	24,7	26.429.000
Malta	Europe	418.700	0,0153	15.300.000	36,54	100	15.300.000
Mauritania	Africa	4.068.000	0,0954	95.400.000	23,45	40	38.160.000
Mauritius	Africa	1.273.000	0,214	214.000.000	168,11	93,1	199.234.000
Mexico	Americas	127.017.000	4,1184	4.118.400.000	32,42	85,2	3.508.876.800
Monaco	Europe	37.730	0,005	5.000.000	132,52	100	5.000.000
Mongolia	Asia	2.959.000	0,071	71.000.000	23,99	59,7	42.387.000
Montenegro	Europe	625.800	0,0964	96.400.000	154,04	95,9	92.447.600
Morocco	Africa	34.378.000	1,063	1.063.000.000	30,92	76,7	815.321.000
Mozambique	Africa	27.978.000	0,372	372.000.000	13,30	20,5	76.260.000
Myanmar	Asia	53.897.000	3,323	3.323.000.000	61,65	79,6	2.645.108.000
Namibia	Africa	2.459.000	0,073	73.000.000	29,69	34,4	25.112.000
Nepal	Asia	28.514.000	0,1476	147.600.000	5,18	45,8	67.600.800
Netherlands	Europe	16.925.000	1,217	1.217.000.000	71,91	97,7	1.189.009.000
New Zealand	Oceania	4.529.000	0,81	810.000.000	178,85	77	623.700.000
Nicaragua	Americas	6.082.000	0,286	286.000.000	47,02	67,9	194.194.000
Niger	Africa	19.899.000	0,0617	61.700.000	3,10	10,9	6.725.300
Nigeria	Africa	182.202.000	5	5.000.000.000	27,44	29	1.450.000.000
Norway	Europe	5.211.000	0,838	838.000.000	160,81	98,1	822.078.000
Oman	Asia	4.491.000	0,134	134.000.000	29,84	96,7	129.578.000
Pakistan	Asia	188.925.000	9,65	9.650.000.000	51,08	63,5	6.127.750.000
Panama	Americas	3.929.000	0,581	581.000.000	147,87	75	435.750.000
Papua New Guinea	Asia	7.619.000	0,2235	223.500.000	29,33	18,9	42.241.500
Paraguay	Americas	6.639.000	0,362	362.000.000	54,53	88,6	320.732.000
Peru	Americas	31.377.000	1,254	1.254.000.000	39,97	76,2	955.548.000
Philippines	Asia	100.699.000	6,235	6.235.000.000	61,92	73,9	4.607.665.000
Poland	Europe	38.612.000	2,292	2.292.000.000	59,36	97,2	2.227.824.000
Portugal	Europe	10.350.000	0,9105	910.500.000	87,97	99,7	907.768.500

Country	Continent	population	MWC (10^9 m3/year)	MWC (m3/year)	MWC (m3/capita/year)	SANpoptotal (%)	potWW country (m3/year)
Qatar	Asia	2.235.000	0,174	174.000.000	77,85	98	170.520.000
South Korea	Asia	50.293.000	6,924	6.924.000.000	137,67	100	6.924.000.000
Moldova	Europe	4.069.000	0,146	146.000.000	35,88	76,4	111.544.000
Romania	Europe	19.511.000	0,98	980.000.000	50,23	79,1	775.180.000
Russia	Europe	143.457.000	13,4	13.400.000.000	93,41	72,2	9.674.800.000
Rwanda	Africa	11.610.000	0,0614	61.400.000	5,29	61,6	37.822.400
Saint Lucia	Americas	185.000	0,0125	12.500.000	67,57	90,5	11.312.500
Saudi Arabia	Asia	31.540.000	2,13	2.130.000.000	67,53	100	2.130.000.000
Senegal	Africa	15.129.000	0,098	98.000.000	6,48	47,6	46.648.000
Seychelles	Africa	96.470	0,009	9.000.000	93,29	98,4	8.856.000
Sierra Leone	Africa	6.453.000	0,111	111.000.000	17,20	13,3	14.763.000
Singapore	Asia	5.604.000	1,078	1.078.000.000	192,36	100	1.078.000.000
Slovakia	Europe	5.426.000	0,3058	305.800.000	56,36	98,8	302.130.400
Slovenia	Europe	2.068.000	0,164	164.000.000	79,30	99,1	162.524.000
South Africa	Africa	54.490.000	4,185	4.185.000.000	76,80	66,4	2.778.840.000
South Sudan	Africa	12.340.000	0,193	193.000.000	15,64	6,7	12.931.000
Spain	Europe	46.122.000	5,308	5.308.000.000	115,09	99,9	5.302.692.000
Sri Lanka	Asia	20.715.000	0,805	805.000.000	38,86	95,1	765.555.000
Suriname	Americas	543.000	0,0493	49.300.000	90,79	79,2	39.045.600
Swaziland	Africa	1.287.000	0,0413	41.300.000	32,09	57,5	23.747.500
Sweden	Europe	9.779.000	1,019	1.019.000.000	104,20	99,3	1.011.867.000
Switzerland	Europe	8.299.000	0,917	917.000.000	110,50	99,9	916.083.000
Syria	Asia	18.502.000	1,475	1.475.000.000	79,72	95,7	1.411.575.000
Tajikistan	Asia	8.482.000	0,647	647.000.000	76,28	95	614.650.000
Thailand	Asia	67.959.000	2,739	2.739.000.000	40,30	93	2.547.270.000
Macedonia	Europe	2.078.000	0,2317	231.700.000	111,50	90,9	210.615.300
Timor-Leste	Asia	1.185.000	0,099	99.000.000	83,54	40,6	40.194.000
Togo	Africa	7.305.000	0,1407	140.700.000	19,26	11,6	16.321.200
Trinidad and Tobago	Americas	1.360.000	0,2376	237.600.000	174,71	91,5	217.404.000
Tunisia	Africa	11.254.000	0,496	496.000.000	44,07	91,6	454.336.000
Turkey	Asia	78.666.000	6,2	6.200.000.000	78,81	94,9	5.883.800.000
Uganda	Africa	39.032.000	0,328	328.000.000	8,40	19,1	62.648.000
Ukraine	Europe	44.824.000	3,266	3.266.000.000	72,86	95,9	3.132.094.000
United Arab Emirates	Asia	9.157.000	0,617	617.000.000	67,38	97,6	602.192.000
Tanzania	Africa	53.470.000	0,527	527.000.000	9,86	15,6	82.212.000
United States of America	Americas	321.774.000	62,09	62.090.000.000	192,96	100	62.090.000.000
Uruguay	Americas	3.432.000	0,41	410.000.000	119,46	96,4	395.240.000
Uzbekistan	Asia	29.893.000	4,1	4.100.000.000	137,16	100	4.100.000.000
Venezuela	Americas	31.108.000	5,123	5.123.000.000	164,68	94,4	4.836.112.000
Viet Nam	Asia	93.448.000	1,206	1.206.000.000	12,91	78	940.680.000
Zambia	Africa	16.212.000	0,29	290.000.000	17,89	43,9	127.310.000
Zimbabwe	Africa	15.603.000	0,425	425.000.000	27,24	36,8	156.400.000

Potential Wastewater of selected cities with more than 1.000.0000. inhabitants

Country	City	Population	MWC (m3/cap/yr)	SANpop rual (%)	SANpop urban (%)	potWW (m3/city/yr)	potWW (10^9 m3/ city/yr)
China	Guangzhou	48,600,000	53.30	63.7	86.6	2,243,286,730.82	2.24
Japan	Tokyo	39,800,000	121.75	100	100	4,845,567,380.09	4.85
China	Shanghai	31,100,000	53.30	63.7	86.6	1,435,518,875.07	1.44
Indonesia	Jakarta	28,900,000	54.32	47.5	72.3	1,134,929,000.17	1.13
India	Delhi	27,200,000	42.71	28.5	62.6	727,296,802.34	0.73
Pakistan	Karachi	25,100,000	51.08	51.1	83.1	1,065,399,841.21	1.07
South Korea	Seoul	24,800,000	137.67	100	100	3,414,296,224.13	3.41
Philippines	Manila	24,100,000	61.92	70.8	77.9	1,162,427,298.19	1.16
India	Mumbai	23,600,000	42.71	28.5	62.6	631,036,931.44	0.63
Mexico	Mexico City	22,300,000	32.42	74.5	88	636,288,698.36	0.64
United States of America	New York	22,200,000	192.96	100	100	4,283,745,734.58	4.28
Brazil	Sao Paulo	21,900,000	82.80	51.5	88	1,595,738,809.13	1.60
China	Beijing	20,700,000	53.30	63.7	86.6	955,473,977.94	0.96
Japan	Osaka	17,800,000	121.75	100	100	2,167,113,049.39	2.17
United States of America	Los Angeles	17,700,000	192.96	100	100	3,415,418,896.49	3.42
Nigeria	Lagos	17,600,000	27.44	25.4	32.8	158,417,580.49	0.16
Thailand	Bangkok	17,400,000	40.30	96.1	89.9	630,454,853.66	0.63
Egypt	Cairo	17,100,000	98.35	93.1	96.8	1,628,001,923.33	1.63
Argentina	Buenos Aires	16,000,000	133.59	98.3	96.2	2,056,189,971.67	2.06
Turkey	Istanbul	14,600,000	78.81	85.5	98.3	1,131,126,026.49	1.13
United Kingdom	London	14,500,000	90.64	99.6	99.1	1,302,482,956.30	1.30
Iran	Tehran	14,000,000	78.37	82.3	92.8	1,018,220,430.04	1.02
South Africa	Johannesb urg	13,100,000	76.80	60.5	69.6	700,259,790.79	0.70
Brazil	Rio de Janeiro	12,700,000	82.80	51.5	88	925,382,779.72	0.93
China	Tianjin	11,800,000	53.30	63.7	86.6	544,666,325.59	0.54
France	Paris	11,300,000	85.12	98.9	98.6	948,337,693.92	0.95
Congo	Kinshasa	10,900,000	13.79	5.6	20	30,057,575.76	0.03
India	Bangalore	10,800,000	42.71	28.5	62.6	288,779,612.69	0.29
Japan	Nagoya	10,500,000	121.75	100	100	1,278,353,203.29	1.28
Pakistan	Lahore	10,500,000	51.08	51.1	83.1	445,685,192.54	0.45
India	Chennai	10,300,000	42.71	28.5	62.6	275,410,186.18	0.28
China	Xiamen	10,100,000	53.30	63.7	86.6	466,197,448.17	0.47
Peru	Lima	10,100,000	39.97	53.2	82.5	333,013,194.38	0.33
Bangladesh	Dhaka	9,899,167	22.36	62.1	57.7	127,720,873.14	0.13
United States of America	Chicago	9,800,000	192.96	100	100	1,891,022,891.84	1.89
India	Kolkata	9,709,196	42.71	28.5	62.6	259,612,764.86	0.26
Colombia	Bogota	9,500,000	54.03	67.9	85.2	437,350,224.97	

Country	City	Population	MWC (m3/cap/yr)	SANpop rual (%)	SANpop urban (%)	potWW (m3/city/yr)	potWW (10^9 m3/ city/yr)
India	Hyderabad	9,200,000	42.71	28.5	62.6	245,997,447.85	0.25
China	Hangzhou	8,450,000	53.30	63.7	86.6	390,036,478.92	0.39
China	Shantou	8,150,000	53.30	63.7	86.6	376,189,029.96	0.38
China	Wuhan	8,100,000	53.30	63.7	86.6	373,881,121.80	0.37
United States of America	San Francisco	7,700,000	192.96	100	100	1,485,803,700.73	1.49
India	Ahmedabad	7,650,000	42.71	28.5	62.6	204,552,225.66	0.20
United States of America	Boston	7,550,000	192.96	100	100	1,456,859,472.80	1.46
Angola	Luanda	7,450,000	12.77	22.5	88.6	84,282,777.16	0.08
United States of America	Philadelphi a	7,350,000	192.96	100	100	1,418,267,168.88	1.42
China	Hong Kong	7,300,000	53.30	63.7	86.6	336,954,591.25	0.34
Canada	Toronto	7,200,000	163.55	99	100	1,177,562,604.34	1.18
Chile	Santiago	7,150,000	70.59	90.9	100	504,738,689.55	0.50
Iraq	Baghdad	7,000,000	118.06	83.8	86.4	714,010,378.06	0.71
Singapore	Singapore	6,950,000	192.36		100	1,336,920,057.10	1.34
Saudi Arabia	Riyadh	6,900,000	67.53	100	100	465,979,708.31	0.47
Malaysia	Kuala Lumpur	6,800,000	128.65	95.9	96.1	840,684,105.37	0.84
United States of America	Dallas	6,750,000	192.96	100	100	1,302,490,257.14	1.30
United States of America	Houston	6,350,000	192.96	100	100	1,225,305,649.31	1.23
Spain	Madrid	6,250,000	115.09	100	99.8	717,849,399.42	0.72
United States of America	Miami	6,200,000	192.96	100	100	1,196,361,421.37	1.20
Indonesia	Bandung	6,050,000	54.32	47.5	72.3	237,588,942.94	0.24
China	Wenzhou	5,950,000	53.30	63.7	86.6	274,641,070.95	0.27
India	Surat	5,900,000	42.71	28.5	62.6	157,759,232.86	0.16
United States of America	Detroit	5,700,000	192.96	100	100	1,099,880,661.58	1.10
United States of America	Atlanta	5,600,000	192.96	100	100	1,080,584,509.62	1.08
Kenya	Nairobi	5,350,000	25.75	29.7	31.2	42,989,602.61	0.04
China	Harbin	5,300,000	53.30	63.7	86.6	244,638,264.88	0.24
Egypt	Alexandria	5,250,000	98.35	93.1	96.8	499,825,151.90	0.50
Myanmar	Rangoon	5,250,000	61.65	77.1	84.3	272,868,012.13	0.27
China	Chongqing	5,214,014	53.30	63.7	86.6	240,669,309.06	0.24
Jordan	Amman	5,200,000	38.35	98.9	98.6	196,649,553.65	0.20
Italy	Milan	5,150,000	158.05	99.6	99.5	809,881,379.81	0.81
Mexico	Guadalajar a	5,050,000	32.42	74.5	88	144,092,283.71	0.14
Australia	Sydney	4,975,000	77.22	100	100	384,193,124.45	0.38
Brazil	Belo H	4,950,000	82.80	51.5	88	360,680,689.73	0.36

Country	City	Population	MWC (m3/cap/yr)	SANpop rual (%)	SANpop urban (%)	potWW (m3/city/yr)	potWW (10^9 m3/ city/yr)
China	Zhengzhou	4,800,000	53.30	63.7	86.6	221,559,183.29	0.22
Indonesia	Surabaya	4,775,000	54.32	47.5	72.3	187,518,545.88	0.19
Mexico	Monterrey	4,750,000	32.42	74.5	88	135,532,346.06	0.14
Turkey	Ankara	4,750,000	78.81	85.5	98.3	368,003,330.54	0.37
Ghana	Accra	4,700,000	8.57	8.6	20.2	8,139,693.54	0.01
Sri Lanka	Colombo	4,700,000	38.86	96.7	88.1	160,910,620.32	0.16
Spain	Barcelona	4,650,000	115.09	100	99.8	534,079,953.17	0.53
Germany	Berlin	4,550,000	67.04	99	99.3	302,874,906.74	0.30
China	Dongguan	4,528,000	53.30	63.7	86.6	209,004,162.90	0.21
China	Changsha	4,525,000	53.30	63.7	86.6	208,865,688.41	0.21
Australia	Melbourne	4,500,000	77.22	100	100	347,511,368.85	0.35
United States of America	Phoenix	4,400,000	192.96	100	100	849,030,686.13	0.85
Saudi Arabia	Jeddah	4,375,000	67.53	100	100	295,458,148.38	0.30
China	Shenzhen	4,291,796	53.30	63.7	86.6	198,101,420.13	0.20
China	Taiyuan	4,275,000	53.30	63.7	86.6	197,326,147.62	0.20
Nigeria	Kano	4,275,000	27.44	25.4	32.8	38,479,270.26	0.04
Italy	Naples	4,250,000	158.05	99.6	99.5	668,348,711.50	0.67
Morocco	Casablanca	4,225,000	30.92	65.5	84.1	109,869,049.25	0.11
Bangladesh	Chittagong	4,224,611	22.36	62.1	57.7	54,506,708.05	0.05
United States of America	Seattle	4,175,000	192.96	100	100	805,614,344.23	0.81
United Arab Emirates	Dubai	4,150,000	67.38	95.2	98	274,035,055.15	0.27
United States of America	Tampa	4,150,000	192.96	100	100	800,790,306.24	0.80
China	Shenyeng	4,149,596	53.30	63.7	86.6	191,537,729.32	0.19
Brazil	Porto Alegre	4,075,000	82.80	51.5	88	296,924,002.16	0.30
China	Kunming	4,050,000	53.30	63.7	86.6	186,940,560.90	0.19
Pakistan	Faisalabad	4,050,000	51.08	51.1	83.1	171,907,145.69	0.17
South Africa	Cape Town	4,050,000	76.80	60.5	69.6	216,492,530.74	0.22
China	Chengdu	4,036,718	53.30	63.7	86.6	186,327,488.18	0.19
China	Fuzhou	4,025,000	53.30	63.7	86.6	185,786,606.82	0.19
China	Jinan	4,025,000	53.30	63.7	86.6	185,786,606.82	0.19
Pakistan	Rawalpindi	3,950,000	51.08	51.1	83.1	167,662,524.81	0.17
India	Pune	3,803,872	42.71	28.5	62.6	101,711,174.34	0.10
Brazil	Recife	3,775,000	82.80	51.5	88	275,064,566.41	0.28
China	Nanchang	3,750,000	53.30	63.7	86.6	173,093,111.95	0.17
Dominican Republic	Santo Domingo	3,750,000	81.21	75.7	86.2	262,517,809.65	0.26
Algeria	Algiers	3,725,000	27.41	82.2	89.8	91,681,709.23	0.09
Venezuela	Caracas	3,725,000	164.68	69.9	97.5	598,112,884.95	0.60
Japan	Yokohama	3,697,894	121.75	100	100	450,210,918.13	0.45

Country	City	Population	MWC (m3/cap/yr)	SANpop rual (%)	SANpop urban (%)	potWW (m3/city/yr)	potWW (10^9 m3/ city/yr)
Brazil	Fortaleza	3,625,000	82.80	51.5	88	264,134,848.54	0.26
China	Xian	3,617,406	53.30	63.7	86.6	166,972,816.46	0.17
India	Jaipur	3,600,000	42.71	28.5	62.6	96,259,870.90	0.10
Italy	Rome	3,600,000	158.05	99.6	99.5	566,130,673.27	0.57
United States of America	Denver	3,600,000	192.96	100	100	694,661,470.47	0.69
Ethiopia	Addis Ababa	3,550,000	8.15	28.2	27.2	7,869,283.94	0.01
Syria	Damascus	3,525,000	79.72	95.1	96.2	270,338,274.24	0.27
Indonesia	Medan	3,450,000	54.32	47.5	72.3	135,484,603.83	0.14
China	Ningbo	3,425,000	53.30	63.7	86.6	158,091,708.91	0.16
China	Zibo	3,425,000	53.30	63.7	86.6	158,091,708.91	0.16
Greece	Athens	3,400,000	118.03	98.1	99.2	398,085,842.08	0.40
Senegal	Dakar	3,400,000	6.48	33.8	65.4	14,403,648.62	0.01
Ukraine	Kiev	3,400,000	72.86	92.6	97.4	241,292,289.84	0.24
China	Nanjing	3,383,005	53.30	63.7	86.6	156,153,296.85	0.16
China	Wuxi	3,350,000	53.30	63.7	86.6	154,629,846.67	0.15
Brazil	Curitiba	3,325,000	82.80	51.5	88	242,275,412.80	0.24
China	Hechi	3,275,189	53.30	63.7	86.6	151,176,708.33	0.15
China	Nanning	3,275,000	53.30	63.7	86.6	151,167,984.43	0.15
Nigeria	Ibadan	3,250,000	27.44	25.4	32.8	29,253,246.40	0.03
Netherlands	Rotterdam	3,175,000	71.91	99.9	97.5	222,592,355.98	0.22
United States of America	Orlando	3,175,000	192.96	100	100	612,652,824.65	0.61
Afghanistan	Kabul	3,160,266	6.25	27	45.1	8,912,655.49	0.01
Brazil	Brasilia	3,139,979	82.80	51.5	88	228,793,897.27	0.23
Uganda	Kampala	3,125,000	8.40	17.3	28.5	7,484,243.70	0.01
Brazil	Salvador	3,081,422	82.80	51.5	88	224,527,154.00	0.22
United Kingdom	Birmingham	3,075,000	90.64	99.6	99.1	276,216,213.15	0.28
United States of America	Cleveland	3,075,000	192.96	100	100	593,356,672.70	0.59
United States of America	Minneapolis	3,075,000	192.96	100	100	593,356,672.70	0.59
Mali	Bamako	3,050,000	6.08	16.1	37.5	6,953,480.11	0.01
Cameroon	Yaounde	3,025,000	10.57	26.8	61.8	19,764,404.56	0.02
Mexico	Puebla	3,025,000	32.42	74.5	88	86,312,704.60	0.09
Canada	Montreal	3,017,278	163.55	99	100	493,476,908.29	0.49
Cameroon	Douala	3,000,000	10.57	26.8	61.8	19,601,062.37	0.02
United Kingdom	Manchester	3,000,000	90.64	99.6	99.1	269,479,232.34	0.27
India	Kanpur	2,992,624	42.71	28.5	62.6	80,019,333.30	0.08
Turkey	Izmir	2,975,000	78.81	85.5	98.3	230,486,296.49	0.23
Nigeria	Abuja	2,950,000	27.44	25.4	32.8	26,552,946.73	0.03
India	Haora	2,934,655	42.71	28.5	62.6	78,469,308.73	0.08

Country	City	Population	MWC (m3/cap/yr)	SANpop rual (%)	SANpop urban (%)	potWW (m3/city/yr)	potWW (10^9 m3/ city/yr)
Australia	Brisbane	2,900,000	77.22	100	100	223,951,771.04	0.22
Haiti	Port-au-Prince	2,900,000	17.74	19.2	33.6	17,284,660.63	0.02
India	Indore	2,875,000	42.71	28.5	62.6	76,874,202.45	0.08
China	Changchun	2,860,210	53.30	63.7	86.6	132,022,039.92	0.13
China	Huizhou	2,850,000	53.30	63.7	86.6	131,550,765.08	0.13
Nepal	Kathmandu	2,850,000	5.18	43.5	56	8,261,541.70	0.01
Iran	Isfahan	2,800,000	78.37	82.3	92.8	203,644,086.01	0.20
Philippines	Quezon City	2,761,720	61.92	70.8	77.9	133,207,415.68	0.13
China	Chenzhou	2,750,000	53.30	63.7	86.6	126,934,948.76	0.13
Ghana	Kumasi	2,750,000	8.57	8.6	20.2	4,762,586.65	0.00
United States of America	Cincinnati	2,750,000	192.96	100	100	530,644,178.83	0.53
South Africa	Durban	2,729,000	76.80	60.5	69.6	145,878,547.26	0.15
Egypt	El Giza	2,681,863	98.35	93.1	96.8	255,326,205.97	0.26
Colombia	Medellin	2,648,489	54.03	67.9	85.2	121,928,132.63	0.12
China	Dalian	2,601,153	53.30	63.7	86.6	120,064,444.64	0.12
Ecuador	Quito	2,600,000	80.09	80.7	87	181,167,368.68	0.18
Hungary	Budapest	2,600,000	60.32	98.6	97.8	153,393,668.19	0.15
India	Bhilai	2,600,000	42.71	28.5	62.6	69,521,017.87	0.07
India	Lucknow	2,583,505	42.71	28.5	62.6	69,079,960.49	0.07
China	Anshan	2,550,000	53.30	63.7	86.6	117,703,316.12	0.12
Philippines	Cebu	2,550,000	61.92	70.8	77.9	122,995,419.52	0.12
Portugal	Lisbon	2,550,000	87.97	99.8	99.6	223,428,782.61	0.22
Canada	Vancouver	2,525,000	163.55	99	100	412,964,663.33	0.41
Venezuela	Maracaibo	2,525,000	164.68	69.9	97.5	405,432,224.03	0.41
India	Coimbatore	2,500,000	42.71	28.5	62.6	66,847,132.57	0.07
United States of America	Washington , D.C.	2,445,216	192.96	100	100	471,832,595.05	0.47
China	Zhangzhou	2,434,799	53.30	63.7	86.6	112,385,849.57	0.11
China	Guiyang	2,416,816	53.30	63.7	86.6	111,555,787.32	0.11
Netherlands	Amsterdam	2,400,000	71.91	99.9	97.5	168,258,788.77	0.17
Germany	Stuttgart	2,350,000	67.04	99	99.3	156,429,896.89	0.16
India	Nagpur	2,341,009	42.71	28.5	62.6	62,595,895.59	0.06
United States of America	Portland	2,325,000	192.96	100	100	448,635,533.01	0.45
United States of America	Salt Lake City	2,325,000	192.96	100	100	448,635,533.01	0.45
Poland	Warsaw	2,300,000	59.36	96.7	97.5	133,114,316.79	0.13
China	Lanzhou	2,282,609	53.30	63.7	86.6	105,361,038.71	0.11
China	Qingdao	2,254,122	53.30	63.7	86.6	104,046,131.12	0.10
Mozambique	Maputo	2,250,000	13.30	10.1	42.4	12,684,537.85	0.01
Ecuador	Guayaquil	2,233,014	80.09	80.7	87	155,595,873.31	0.16

Country	City	Population	MWC (m3/cap/yr)	SANpop rual (%)	SANpop urban (%)	potWW (m3/city/yr)	potWW (10^9 m3/ city/yr)
Germany	Munich	2,225,000	67.04	99	99.3	148,109,157.69	0.15
Colombia	Cali	2,216,418	54.03	67.9	85.2	102,036,937.99	0.10
China	Shijianzhua ng	2,204,737	53.30	63.7	86.6	101,766,610.23	0.10
Japan	Sapporo	2,202,893	121.75	100	100	268,197,649.81	0.27
China	Baotou	2,200,000	53.30	63.7	86.6	101,547,959.01	0.10
Japan	Okayama	2,200,000	121.75	100	100	267,845,433.07	0.27
Mexico	Toluca	2,200,000	32.42	74.5	88	62,772,876.07	0.06
China	Xiangtan	2,183,454	53.30	63.7	86.6	100,784,226.04	0.10
China	Nanchong	2,174,000	53.30	63.7	86.6	100,347,846.77	0.10
Syria	Aleppo	2,170,132	79.72	95.1	96.2	166,431,131.85	0.17
Qatar	Doha	2,150,000	77.85	98	98	164,034,899.33	0.16
United States of America	Las Vegas	2,150,000	192.96	100	100	414,867,267.09	0.41
China	Jilin	2,138,988	53.30	63.7	86.6	98,731,757.16	0.10
Brazil	Manaus	2,125,000	82.80	51.5	88	154,837,669.84	0.15
Nigeria	Port Harcourt	2,125,000	27.44	25.4	32.8	19,127,122.64	0.02
Sweden	Stockholm	2,125,000	104.20	99.6	99.3	219,881,110.03	0.22
China	Taizhou	2,100,000	53.30	63.7	86.6	96,932,142.69	0.10
India	Agra	2,100,000	42.71	28.5	62.6	56,151,591.36	0.06
India	Chandigarh	2,100,000	42.71	28.5	62.6	56,151,591.36	0.06
United Kingdom	Leeds	2,100,000	90.64	99.6	99.1	188,635,462.64	0.19
Japan	Fukuoka	2,092,144	121.75	100	100	254,714,188.97	0.25
Cuba	Havana	2,082,458	149.25	89.1	94.4	293,409,007.76	0.29
Uzbekistan	Tashkent	2,081,014	137.16	100	100	285,423,256.28	0.29
Austria	Vienna	2,065,500	84.26	100	100	174,038,619.08	0.17
Australia	Perth	2,025,000	77.22	100	100	156,380,115.98	0.16
Belgium	Brussels	2,025,000	62.78	99.4	99.5	126,484,718.78	0.13
Colombia	Barranquilla	2,025,000	54.03	67.9	85.2	93,224,653.22	0.09
United States of America	Sacramento	2,025,000	192.96	100	100	390,747,077.14	0.39
Azerbaijan	Baku	2,007,150	53.41	86.6	91.6	98,204,248.25	0.10
China	Nantong	1,980,000	53.30	63.7	86.6	91,393,163.11	0.09
China	Suzhou	1,964,000	53.30	63.7	86.6	90,654,632.50	0.09
France	Lyon	1,960,000	85.12	98.9	98.6	164,490,431.87	0.16
Congo	Brazzaville	1,950,000	13.79	5.6	20	5,377,272.73	0.01
Indonesia	Bekasi	1,949,165	54.32	47.5	72.3	76,545,463.14	0.08
Bolivia	La Paz	1,940,000	12.68	27.5	60.8	14,957,083.45	0.01
United States of America	Kansas City	1,940,000	192.96	100	100	374,345,347.98	0.37
United States of America	San Diego	1,938,570	192.96	100	100	374,069,413.00	0.37
Congo	Lubumbash	1,930,000	13.79	5.6	20	5,322,121.21	0.01

Country	City	Population	MWC (m3/cap/yr)	SANpop rual (%)	SANpop urban (%)	potWW (m3/city/yr)	potWW (10^9 m3/ city/yr)
Bolivia	Santa Cruz	1,920,000	12.68	27.5	60.8	14,802,886.71	0.01
Brazil	Campinas	1,911,277	82.80	51.5	88	139,264,789.22	0.14
Congo	Mbuji-Mayi	1,910,000	13.79	5.6	20	5,266,969.70	0.01
India	Patna	1,878,960	42.71	28.5	62.6	50,241,235.28	0.05
Pakistan	Saidu	1,860,310	51.08	51.1	83.1	78,963,106.72	0.08
Romania	Bucharest	1,842,097	50.23	63.3	92.2	85,308,039.84	0.09
United Kingdom	Liverpool	1,840,000	90.64	99.6	99.1	165,280,595.83	0.17
Uruguay	Montevideo	1,840,000	119.46	92.6	96.6	212,339,860.14	0.21
El Salvador	San Salvador	1,830,000	77.36	60	82.4	116,656,451.77	0.12
China	Urumqi	1,829,612	53.30	63.7	86.6	84,451,529.26	0.08
China	Yangzhou	1,820,000	53.30	63.7	86.6	84,007,857.00	0.08
South Africa	Benoni	1,795,672	76.80	60.5	69.6	95,987,549.55	0.10
United States of America	Austin	1,790,000	192.96	100	100	345,401,120.04	0.35
Brazil	Belem	1,787,368	82.80	51.5	88	130,236,186.47	0.13
Germany	Frankfurt	1,787,332	67.04	99	99.3	118,975,387.43	0.12
Lebanon	Beirut	1,779,062	64.95	80.7	80.7	93,243,403.34	0.09
China	Shuyang	1,770,000	53.30	63.7	86.6	81,699,948.84	0.08
Iran	Shiraz	1,760,000	78.37	82.3	92.8	128,004,854.06	0.13
Germany	Hamburg	1,748,058	67.04	99	99.3	116,361,077.74	0.12
Israel	Tel Aviv-Yafo	1,745,179	88.29	100	100	154,088,225.20	0.15
China	Tangshan	1,737,974	53.30	63.7	86.6	80,221,687.50	0.08
China	Hefei	1,711,952	53.30	63.7	86.6	79,020,559.78	0.08
Turkey	Adana	1,700,000	78.81	85.5	98.3	131,706,455.14	0.13
Belarus	Minsk	1,691,069	57.60	95.2	94.1	91,663,739.80	0.09
Morocco	Rabat	1,680,376	30.92	65.5	84.1	43,697,352.31	0.04
China	Wanxian	1,680,000	53.30	63.7	86.6	77,545,714.15	0.08
United States of America	Columbus	1,680,000	192.96	100	100	324,175,352.89	0.32
India	Bhopal	1,663,457	42.71	28.5	62.6	44,478,932.24	0.04
Benin	Cotonou	1,650,000	3.77	7.3	35.6	2,213,547.79	0.00
France	Marseille	1,650,000	85.12	98.9	98.6	138,474,088.05	0.14
China	Xuzhou	1,645,096	53.30	63.7	86.6	75,934,609.62	0.08
Japan	Sendai	1,643,781	121.75	100	100	200,126,924.46	0.20
Iran	Tabriz	1,640,000	78.37	82.3	92.8	119,277,250.38	0.12
United Kingdom	Glasgow	1,640,000	90.64	99.6	99.1	147,315,313.68	0.15
Japan	Kyoto	1,632,320	121.75	100	100	198,731,571.50	0.20
India	Aurangaba d	1,630,000	42.71	28.5	62.6	43,584,330.43	0.04
China	Taian	1,629,000	53.30	63.7	86.6	75,191,647.83	0.08
United States of America	Irvine	1,611,303	192.96	100	100	310,919,475.38	0.31

Country	City	Population	MWC (m3/cap/yr)	SANpop rual (%)	SANpop urban (%)	potWW (m3/city/yr)	potWW (10^9 m3/ city/yr)
Malaysia	George Town	1,610,101	128.65	95.9	96.1	199,056,811.58	0.20
China	Haikou	1,606,808	53.30	63.7	86.6	74,167,305.87	0.07
India	Ludhiana	1,597,184	42.71	28.5	62.6	42,706,868.23	0.04
Brazil	Goiania	1,596,597	82.80	51.5	88	116,335,698.42	0.12
Indonesia	Palembang	1,595,250	54.32	47.5	72.3	62,646,902.68	0.06
Japan	Hiroshima	1,594,420	121.75	100	100	194,117,325.18	0.19
Sierra Leone	Freetown	1,590,000	17.20	6.9	22.8	6,235,815.90	0.01
India	Vadodara	1,582,738	42.71	28.5	62.6	42,320,598.76	0.04
India	Kalyan	1,576,614	42.71	28.5	62.6	42,156,850.03	0.04
Tunisia	Tunis	1,570,476	44.07	79.8	97.4	67,416,317.53	0.07
Venezuela	Valencia	1,569,526	164.68	69.9	97.5	252,014,422.51	0.25
Venezuela	Valencia	1,569,526	164.68	69.9	97.5	252,014,422.51	0.25
Zimbabwe	Harare	1,557,406	27.24	30.8	49.3	20,913,637.90	0.02
China	Luoyang	1,552,790	53.30	63.7	86.6	71,673,934.21	0.07
Indonesia	Denpasar	1,550,000	54.32	47.5	72.3	60,869,894.47	0.06
Madagascar	Antananariv o	1,544,216	16.30	8.7	18	4,530,379.93	0.00
China	Luzhou	1,537,000	53.30	63.7	86.6	70,945,096.82	0.07
United States of America	Pittsburgh	1,535,267	192.96	100	100	296,247,453.27	0.30
United Kingdom	Sheffield	1,530,000	90.64	99.6	99.1	137,434,408.49	0.14
Japan	Kobe	1,528,478	121.75	100	100	186,089,023.57	0.19
Poland	Katowice	1,527,362	59.36	96.7	97.5	88,397,282.23	0.09
Nigeria	Benin City	1,520,000	27.44	25.4	32.8	13,681,518.31	0.01
New Zealand	Auckland	1,510,000	178.85	100	100	270,059,615.81	0.27
China	Suzhou	1,496,545	53.30	63.7	86.6	69,077,768.32	0.07
China	Handan	1,494,659	53.30	63.7	86.6	68,990,714.03	0.07
Guinea	Conakry	1,494,000	17.83	11.8	34.1	9,082,818.56	0.01
Panama	Panama City	1,490,000	147.87	58	83.5	183,978,404.17	0.18
Pakistan	Multan	1,479,615	51.08	51.1	83.1	62,804,047.25	0.06
Dominican Republic	Santiago	1,471,007	81.21	75.7	86.2	102,977,476.17	0.10
Cambodia	Phnom Penh	1,466,000	6.29	30.5	88.1	8,125,016.56	0.01
Mexico	Tijuana	1,464,728	32.42	74.5	88	41,793,267.83	0.04
China	Datong	1,462,839	53.30	63.7	86.6	67,521,961.28	0.07
Iraq	Basra	1,460,000	118.06	83.8	86.4	148,922,164.57	0.15
Ukraine	Donetsk	1,460,000	72.86	92.6	97.4	103,613,747.99	0.10
Pakistan	Gujranwala	1,448,735	51.08	51.1	83.1	61,493,308.32	0.06
Bangladesh	Khulna	1,447,669	22.36	62.1	57.7	18,678,091.67	0.02
China	Liuzhou	1,436,030	53.30	63.7	86.6	66,284,507.08	0.07
China	Fushun	1,435,323	53.30	63.7	86.6	66,251,873.26	0.07
United States of America	Baltimore	1,432,946	192.96	100	100	276,503,437.63	0.28

Country	City	Population	MWC (m3/cap/yr)	SANpop rual (%)	SANpop urban (%)	potWW (m3/city/yr)	potWW (10^9 m3/ city/yr)
Turkey	Bursa	1,425,544	78.81	85.5	98.3	110,443,145.23	0.11
China	Suining	1,425,000	53.30	63.7	86.6	65,775,382.54	0.07
Pakistan	Hyderabad	1,422,665	51.08	51.1	83.1	60,386,735.66	0.06
China	Yantai	1,417,666	53.30	63.7	86.6	65,436,858.57	0.07
China	Xinyang	1,411,944	53.30	63.7	86.6	65,172,741.56	0.07
Saudi Arabia	Ad Damman	1,411,656	67.53	100	100	95,333,775.52	0.10
Bahrain	Manama	1,410,000	129.19	99.2	99.2	180,706,091.50	0.18
China	Luan	1,408,227	53.30	63.7	86.6	65,001,171.67	0.07
India	Faridabad	1,394,000	42.71	28.5	62.6	37,273,961.12	0.04
India	Allahabad	1,390,000	42.71	28.5	62.6	37,167,005.71	0.04
Venezuela	Maracay	1,390,000	164.68	69.9	97.5	223,188,432.24	0.22
India	Nasik	1,381,248	42.71	28.5	62.6	36,932,987.27	0.04
Philippines	Angeles	1,380,000	61.92	70.8	77.9	66,562,227.03	0.07
Argentina	Cordoba	1,374,467	133.59	98.3	96.2	176,635,328.86	0.18
Japan	Kawasaki	1,372,025	121.75	100	100	167,041,195.59	0.17
China	Jinxi	1,369,623	53.30	63.7	86.6	63,219,281.94	0.06
United States of America	San Antonio	1,364,905	192.96	100	100	263,374,142.88	0.26
Saudi Arabia	Makkah	1,354,312	67.53	100	100	91,461,146.48	0.09
Ireland	Dublin	1,350,000	133.96	92.9	89.1	161,132,636.52	0.16
United Kingdom	Nottingham	1,350,000	90.64	99.6	99.1	121,265,654.55	0.12
Mexico	Ciudad Juarez	1,343,000	32.42	74.5	88	38,319,987.53	0.04
Indonesia	Semarang	1,342,042	54.32	47.5	72.3	52,703,196.72	0.05
Ukraine	Kharkiv	1,338,063	72.86	92.6	97.4	94,960,083.89	0.09
South Africa	Pretoria	1,338,000	76.80	60.5	69.6	71,522,717.56	0.07
Germany	Mannheim	1,337,587	67.04	99	99.3	89,037,700.63	0.09
India	Amritsar	1,330,000	42.71	28.5	62.6	35,562,674.53	0.04
India	Asansol	1,328,000	42.71	28.5	62.6	35,509,196.82	0.04
United States of America	Harrisburg	1,320,000	192.96	100	100	254,709,205.84	0.25
India	Meerut	1,310,592	42.71	28.5	62.6	35,043,726.87	0.04
Australia	Adelaide	1,310,000	77.22	100	100	101,164,420.71	0.10
Philippines	Davao	1,307,252	61.92	70.8	77.9	63,053,336.53	0.06
Mexico	Leon	1,301,313	32.42	74.5	88	37,130,527.13	0.04
Zambia	Lusaka	1,297,720	17.89	35.7	55.6	12,906,758.75	0.01
India	Vishakhapa tnam	1,296,089	42.71	28.5	62.6	34,655,933.28	0.03
France	Lille	1,290,000	85.12	98.9	98.6	108,261,559.75	0.11
United Arab Emirates	Abu Dhabi	1,290,000	67.38	95.2	98	85,181,981.00	0.09
United States of America	San Jose	1,281,471	192.96	100	100	247,274,591.45	0.25

Country	City	Population	MWC (m3/cap/yr)	SANpop rual (%)	SANpop urban (%)	potWW (m3/city/yr)	potWW (10^9 m3/ city/yr)
Iran	Ahvaz	1,280,000	78.37	82.3	92.8	93,094,439.32	0.09
India	Ghaziabad	1,270,095	42.71	28.5	62.6	33,960,883.54	0.03
India	Bareilly	1,270,000	42.71	28.5	62.6	33,958,343.34	0.03
Indonesia	Ujungpandang	1,262,000	54.32	47.5	72.3	49,559,875.37	0.05
China	Qiqihar	1,261,682	53.30	63.7	86.6	58,236,923.64	0.06
Pakistan	Peshawar	1,260,886	51.08	51.1	83.1	53,519,830.45	0.05
United States of America	St. Louis	1,259,958	192.96	100	100	243,123,410.28	0.24
Italy	Turin	1,258,631	158.05	99.6	99.5	197,930,448.73	0.20
India	Varanasi	1,258,202	42.71	28.5	62.6	33,642,878.36	0.03
China	Hohhot	1,250,238	53.30	63.7	86.6	57,708,689.62	0.06
United States of America	Long Beach	1,249,195	192.96	100	100	241,046,565.45	0.24
Bolivia	Cochabamba	1,240,000	12.68	27.5	60.8	9,560,197.67	0.01
China	Huainan	1,239,327	53.30	63.7	86.6	57,205,057.91	0.06
Oman	Muscat	1,230,000	29.84	94.7	97.3	35,709,165.00	0.04
Iraq	Mosul	1,228,467	118.06	83.8	86.4	125,305,455.30	0.13
China	Maoming	1,217,715	53.30	63.7	86.6	56,207,487.68	0.06
China	Ganzhou	1,216,134	53.30	63.7	86.6	56,134,511.63	0.06
Libya	Tripoli	1,209,199	111.50	95.7	96.8	130,511,825.80	0.13
Iran	Qom	1,200,000	78.37	82.3	92.8	87,276,036.86	0.09
Turkey	Antalya	1,200,000	78.81	85.5	98.3	92,969,262.45	0.09
Nigeria	Kaduna	1,191,296	27.44	25.4	32.8	10,722,853.98	0.01
India	Rajkot	1,179,941	42.71	28.5	62.6	31,550,268.98	0.03
China	Linyi	1,176,334	53.30	63.7	86.6	54,297,416.73	0.05
Indonesia	Cilacap	1,174,964	54.32	47.5	72.3	46,141,893.35	0.05
Myanmar	Mandalay	1,167,000	61.65	77.1	84.3	60,654,660.98	0.06
China	Zaozhuang	1,164,332	53.30	63.7	86.6	53,743,426.46	0.05
Norway	Oslo	1,160,000	160.81	98.3	98	182,812,972.56	0.18
Germany	Essen	1,157,801	67.04	99	99.3	77,070,081.30	0.08
India	Jabalpur	1,157,584	42.71	28.5	62.6	30,952,468.44	0.03
Indonesia	Serang	1,140,000	54.32	47.5	72.3	44,768,825.61	0.04
United Kingdom	Southampton	1,140,000	90.64	99.6	99.1	102,402,108.29	0.10
China	Changzhou	1,138,009	53.30	63.7	86.6	52,528,405.13	0.05
China	Xianyang	1,126,000	53.30	63.7	86.6	51,974,091.75	0.05
Malawi	Lilongwe	1,120,000	8.31	39.8	47.3	4,403,639.62	0.00
Morocco	Agadir	1,120,000	30.92	65.5	84.1	29,125,049.74	0.03
China	Zhanjiang	1,113,895	53.30	63.7	86.6	51,415,347.18	0.05
Indonesia	Bandar Lampung	1,110,000	54.32	47.5	72.3	43,590,698.62	0.04
United States of America	Indianapolis	1,104,641	192.96	100	100	213,153,205.95	0.21

Country	City	Population	MWC (m3/cap/yr)	SANpop rual (%)	SANpop urban (%)	potWW (m3/city/yr)	potWW (10^9 m3/ city/yr)
United States of America	Fort Lauderdale	1,103,781	192.96	100	100	212,987,259.04	0.21
India	Madurai	1,101,954	42.71	28.5	62.6	29,464,986.05	0.03
Togo	Lome	1,100,850	19.26	2.9	24.7	5,237,197.80	0.01
Nigeria	Onitsha	1,100,000	27.44	25.4	32.8	9,901,098.78	0.01
China	Nanyang	1,097,766	53.30	63.7	86.6	50,670,862.17	0.05
Armenia	Yerevan	1,097,742	279.32	78.2	96.2	294,973,969.11	0.29
Kazakhstan	Almaty	1,096,256	49.82	98.1	97	52,972,333.90	0.05
Argentina	Rosario	1,094,784	133.59	98.3	96.2	140,692,742.62	0.14
United States of America	Ft. Worth	1,090,830	192.96	100	100	210,488,214.40	0.21
Mexico	Aguascalie ntes	1,090,000	32.42	74.5	88	31,101,106.78	0.03
Ukraine	Odessa	1,090,000	72.86	92.6	97.4	77,355,469.39	0.08
Denmark	Kobenhavn	1,085,000	63.50	99.6	99.6	68,625,436.58	0.07
Central African Republic	Bangui	1,080,000	12.27	7.2	43.6	5,775,487.35	0.01
Argentina	Mendoza	1,070,000	133.59	98.3	96.2	137,507,704.36	0.14
India	Kochi	1,061,848	42.71	28.5	62.6	28,392,597.61	0.03
Kuwait	Kuwait	1,061,532	115.18	100	100	122,272,557.97	0.12
Brazil	Santos	1,060,201	82.80	51.5	88	77,251,318.78	0.08
Nigeria	Aba	1,060,000	27.44	25.4	32.8	9,541,058.82	0.01
India	Srinagar	1,057,928	42.71	28.5	62.6	28,287,781.31	0.03
Georgia	Tbilisi	1,052,628	89.50	75.9	95.2	89,688,116.11	0.09
China	Baoding	1,051,326	53.30	63.7	86.6	48,527,277.07	0.05
India	Warangal	1,034,690	42.71	28.5	62.6	27,666,423.84	0.03
Pakistan	Abbottabad	1,032,323	51.08	51.1	83.1	43,818,197.62	0.04
Bulgaria	Sofia	1,029,913	149.65	83.7	86.8	133,782,097.61	0.13
China	Ankang	1,025,000	53.30	63.7	86.6	47,312,117.27	0.05
China	Zhuhai	1,023,000	53.30	63.7	86.6	47,219,800.94	0.05
Congo	Pointe-Noire	1,020,000	13.79	5.6	20	2,812,727.27	0.00
France	Bordeaux	1,020,000	85.12	98.9	98.6	85,602,163.52	0.09
Canada	Calgary	1,012,661	163.55	99	100	165,621,072.84	0.17
Chile	Valparaiso	1,010,000	70.59	90.9	100	71,298,751.95	0.07
Saudi Arabia	Medina	1,010,000	67.53	100	100	68,208,623.97	0.07
Guatemala	Guatemala	1,009,469	51.09	49.3	77.5	39,971,402.23	0.04
India	Sholapur	1,009,056	42.71	28.5	62.6	26,981,000.08	0.03
Brazil	Vitoria	1,008,328	82.80	51.5	88	73,471,603.74	0.07
China	Neijiang	1,006,427	53.30	63.7	86.6	46,454,821.70	0.05
India	Vijayawada	1,005,793	42.71	28.5	62.6	26,893,751.20	0.03
Brazil	Maceio	1,000,215	82.80	51.5	88	72,880,451.73	0.07
China	Maanshan	1,000,121	53.30	63.7	86.6	46,163,748.32	0.05
China	Anyang	1,000,000	53.30	63.7	86.6	46,158,163.19	0.05

Irrigation Water Demand

Region	Country	Agroecological Zone	Crop	Production (t)	Area harvested (ha)	Yield (hg/ha)	IRdemand crop (mm/year)	IRdemand (m3/ha)	Irdemand per crop (m3/year)	IR total (m3/year)	pot WW (m3/year)	pot WW irrigation
Central Africa	Angola	Tropics, warm	Maize	1,686,869	1,624,186	10,386	96.70	967.00	1,570,587,862	1,718,395,848	164,862,000	10%
Central Africa	Angola	Tropics, warm	Sorghum	48,133	198,844	2,421	36.20	362.00	71,981,528			
Central Africa	Angola	Tropics, warm	Millet	43,056	195,934	2,197	38.70	387.00	75,826,458			
Central Africa	Cameroon	Tropics, warm	Maize	1,600,000	799,254	20,019	96.70	967.00	772,878,618	1,045,990,604	113,034,400	11%
Central Africa	Cameroon	Tropics, warm	Sorghum	1,150,000	754,453	15,243	36.20	362.00	273,111,986			
Central Africa	Central African Republic	Tropics, warm	Maize	172,989	109,334	15,822	96.70	967.00	105,725,978	123,455,652	13,101,800	11%
Central Africa	Central African Republic	Tropics, warm	Sorghum	51,169	48,977	10,447	36.20	362.00	17,729,674			
Central Africa	Chad	Tropics, warm	Millet	694,751	1,103,180	6,298	38.70	387.00	426,930,660	823,452,790	12,547,700	2%
Central Africa	Chad	Tropics, warm	Sorghum	921,662	1,095,365	8,414	36.20	362.00	396,522,130			
Central Africa	Gabon	Tropics, warm	Maize	43,079	27,267	15,799	96.70	967.00	26,367,189	26,367,189	35,489,300	135%
Eastern Africa	Burundi	Tropics, warm	Maize	127,829	97,242	13,145	248.60	2,486.00	241,743,612	282,770,700	20,688,000	7%
Eastern Africa	Burundi	Tropics, warm	Sorghum	22,354	32,254	6,931	127.20	1,272.00	41,027,088			
Eastern Africa	Comoros	Tropics, warm	Maize	6,524	3,129	20,850	248.60	2,486.00	7,778,694	7,778,694	1,718,400	22%
Eastern Africa	Djibouti	Tropics, warm	Maize	16	8	19,379	248.60	2,486.00	19,888	19,888	7,584,000	38134%
Eastern Africa	Eritrea	Tropics, warm	Sorghum	140,209	268,946	5,213	127.20	1,272.00	342,099,312	342,099,312	4,867,000	1%
Eastern Africa	Ethiopia	Tropics, warm	Maize	7,234,955	2,114,876	34,210	248.60	2,486.00	5,257,581,736	7,591,256,536	226,800,000	3%
Eastern Africa	Ethiopia	Tropics, warm	Sorghum	4,339,134	1,834,650	23,651	127.20	1,272.00	2,333,674,800			
Eastern Africa	Kenya	Tropics, warm	Maize	3,513,171	2,116,141	16,602	248.60	2,486.00	5,260,726,526	5,731,793,516	356,986,000	6%
Eastern Africa	Kenya	Tropics, warm	Sorghum	177,553	213,520	8,316	127.20	1,272.00	271,597,440			
Eastern Africa	Kenya	Tropics, warm	Wheat	328,637	147,210	22,324	135.50	1,355.00	199,469,550			
Eastern Africa	Madagascar	Tropics, warm	Maize	328,637	215,113	17,022	248.60	2,486.00	534,770,918	537,592,028	47,400,000	9%

Eastern Africa	Madagascar	Tropics, warm	Wheat	5,000	2,082	24,016	135.50	1,355.00	2,821,110			
Eastern Africa	Mauritius	Tropics, warm	Maize	625	69	90,580	248.60	2,486.00	171,534	171,534	199,234,000	116148%
Eastern Africa	Rwanda	Tropics, warm	Maize	583,096	233,150	25,009	248.60	2,486.00	579,610,900	754,163,644	37,822,400	5%
Eastern Africa	Rwanda	Tropics, warm	Sorghum	140,578	137,227	10,244	127.20	1,272.00	174,552,744			
Eastern Africa	South Sudan	Tropics, warm	Sorghum	990,000	724,500	13,665	127.20	1,272.00	921,564,000	1,612,672,000	12,931,000	1%
Eastern Africa	South Sudan	Tropics, warm	Maize	268,000	278,000	9,640	248.60	2,486.00	691,108,000			
Eastern Africa	Tanzania	Tropics, warm	Maize	6,737,197	4,146,000	16,250	248.60	2,486.00	10,306,956,000	11,390,036,016	82,212,000	1%
Eastern Africa	Tanzania	Tropics, warm	Sorghum	883,195	851,478	10,372	127.20	1,272.00	1,083,080,016			
Eastern Africa	Uganda	Tropics, warm	Maize	2,763,000	1,105,000	25,005	248.60	2,486.00	2,747,030,000	3,221,486,000	62,648,000	2%
Eastern Africa	Uganda	Tropics, warm	Sorghum	299,000	373,000	8,016	127.20	1,272.00	474,456,000			
Southern Africa	Botswana	Subtropics, warm/mod.	Maize	28,550	104,197	2,740	207.60	2,076.00	216,312,972	216,312,972	55,665,200	26%
Southern Africa	Lesotho	Subtropics, warm/mod.	Maize	90,072	132,727	6,786	207.60	2,076.00	275,541,252	310,646,868	6,060,000	2%
Southern Africa	Lesotho	Subtropics, warm/mod.	Wheat	12,592	13,832	9,104	253.80	2,538.00	35,105,616			
Southern Africa	Malawi	Subtropics, warm/mod.	Maize	2,776,277	1,676,213	16,563	207.60	2,076.00	3,479,818,188	3,479,818,188	58,671,000	2%
Southern Africa	Mozambique	Subtropics, warm/mod.	Maize	1,357,220	1,703,500	7,967	207.60	2,076.00	3,536,466,000	3,536,466,000	76,260,000	2%
Southern Africa	Namibia	Subtropics, warm/mod.	Maize	68,000	156,189	24,754	207.60	2,076.00	324,248,364	328,055,364	25,112,000	8%
Southern Africa	Namibia	Subtropics, warm/mod.	Wheat	10,000	1,500	66,667	253.80	2,538.00	3,807,000			
Southern Africa	South Africa	Subtropics, warm/mod.	Maize	14,250,000	2,688,200	53,009	207.60	2,076.00	5,580,703,200	7,053,444,360	2,778,840,000	39%
Southern Africa	South Africa	Subtropics, warm/mod.	Wheat	1,750,000	476,570	36,721	253.80	2,538.00	1,209,534,660			
Southern Africa	South Africa	Subtropics, warm/mod.	Barley	302,000	85,125	35,477	309.20	3,092.00	263,206,500			
Southern Africa	Swaziland	Subtropics, warm/mod.	Maize	81,623	87,164	9,364	207.60	2,076.00	180,952,464	181,911,828	23,747,500	13%
Southern Africa	Swaziland	Subtropics, warm/mod.	Wheat	683	378	18,088	253.80	2,538.00	959,364			
Southern Africa	Zambia	Subtropics, warm/mod.	Maize	3,350,671	1,205,202	27,802	207.60	2,076.00	2,501,999,352	2,589,519,744	127,310,000	5%
Southern Africa	Zambia	Subtropics, warm/mod.	Wheat	201,504	34,484	71,559	253.80	2,538.00	87,520,392			
Southern Africa	Zimbabwe	Subtropics, warm/mod.	Maize	1,456,000	2,283,803	6,375	207.60	2,076.00	4,741,175,028	4,741,175,028	156,400,000	3%

Western Africa	Benin	Tropics, warm	Maize	1,354,344	968,030	13,991	95.50	955.00	924,468,650	929,036,735	8,077,000	1%
Western Africa	Benin	Tropics, warm	Sorghum	100,249	101,513	9,875	4.50	45.00	4,568,085			
Western Africa	Burkina Faso	Tropics, warm	Sorghum	1,707,613	1,548,404	11,028	4.50	45.00	69,678,180	785,866,105	73,993,200	9%
Western Africa	Burkina Faso	Tropics, warm	Millet	972,539	1,192,006	8,159	0.00	0.00	0			
Western Africa	Burkina Faso	Tropics, warm	Maize	1,433,085	749,935	19,109	95.50	955.00	716,187,925			
Western Africa	Cabo Verde	Tropics, warm	Maize	1,065		2,018	95.50	955.00	0	0	1,155,200	#DIV/0!
Western Africa	Gambia	Tropics, warm	Millet	76,816	100,829	7,618	0.00	0.00	0	35,051,365	24,266,800	69%
Western Africa	Gambia	Tropics, warm	Maize	30,289	36,703	8,252	95.50	955.00	35,051,365			
Western Africa	Ghana	Tropics, warm	Maize	1,762,000	1,019,000	17,291	95.50	955.00	973,145,000	983,360,000	35,015,000	4%
Western Africa	Ghana	Tropics, warm	Sorghum	259,000	227,000	11,410	4.50	45.00	10,215,000			
Western Africa	Guinea	Tropics, warm	Maize	652,000	466,999	13,961	95.50	955.00	445,984,045	445,984,045	45,184,800	10%
Western Africa	Guinea-Bissau	Tropics, warm	Sorghum	14,000	14,784	9,470	4.50	45.00	665,280	665,280	7,092,800	1066%
Western Africa	Guinea-Bissau	Tropics, warm	Millet	10,000	7,563	13,222	0.00	0.00	0			
Western Africa	Mali	Tropics, warm	Millet	1,715,044	1,743,423	9,837	0.00	0.00	0	766,994,880	26,429,000	3%
Western Africa	Mali	Tropics, warm	Maize	1,744,026	803,136	21,715	95.50	955.00	766,994,880			
Western Africa	Mauritania	Tropics, warm	Sorghum	57,198	134,868	4,241	4.50	45.00	6,069,060	23,667,800	38,160,000	161%
Western Africa	Mauritania	Tropics, warm	Maize	12,565	18,428	6,818	95.50	955.00	17,598,740			
Western Africa	Niger	Tropics, warm	Millet	3,321,753	7,358,247	4,514	0.00	0.00	0	160,754,850	6,725,300	4%
Western Africa	Niger	Tropics, warm	Sorghum	1,425,980	3,572,330	3,992	4.50	45.00	160,754,850			
Western Africa	Nigeria	Tropics, warm	Maize	10,790,600	5,849,800	18,446	95.50	955.00	5,586,559,000	5,831,233,000	1,450,000,000	25%
Western Africa	Nigeria	Tropics, warm	Sorghum	6,741,100	5,437,200	12,398	4.50	45.00	244,674,000			
Western Africa	Senegal	Tropics, warm	Millet	408,993	715,996	5,712	0.00	0.00	0	139,774,755	46,648,000	33%
Western Africa	Senegal	Tropics, warm	Maize	178,732	146,361	12,212	95.50	955.00	139,774,755			
Western Africa	Sierra Leone	Tropics, warm	Millet	40,000	38,204	10,470	0.00	0.00	0	17,751,540	14,763,000	83%
Western Africa	Sierra Leone	Tropics, warm	Maize	38,000	18,588	20,444	95.50	955.00	17,751,540			

Western Africa	Togo	Tropics, warm	Maize	833,044	696,588	11,959	95.50	955.00	665,241,540	679,809,795	16,321,200	2%
Western Africa	Togo	Tropics, warm	Sorghum	307,579	323,739	9,501	4.50	45.00	14,568,255			
Central America	Belize	Tropics, warm	Maize	69,169	18,926	36,547	173.60	1,736.00	32,855,536	36,219,712	10,317,000	28%
Central America	Belize	Tropics, warm	Sorghum	9,091	3,858	23,564	87.20	872.00	3,364,176			
Central America	Costa Rica	Tropics, warm	Maize	10,723	6,224	17,228	173.60	1,736.00	10,804,864	10,804,864	718,200,000	6647%
Central America	El Salvador	Tropics, warm	Maize	819,311	314,343	26,064	173.60	1,736.00	545,699,448	616,888,656	355,500,000	58%
Central America	El Salvador	Tropics, warm	Sorghum	140,808	81,639	17,248	87.20	872.00	71,189,208			
Central America	Guatemala	Tropics, warm	Maize	1,847,214	871,593	21,194	173.60	1,736.00	1,513,085,448	1,536,609,392	533,565,000	35%
Central America	Guatemala	Tropics, warm	Sorghum	47,051	26,977	17,441	87.20	872.00	23,523,944			
Central America	Honduras	Tropics, warm	Maize	609,312	363,343	16,770	173.60	1,736.00	630,763,448	658,784,296	260,190,000	39%
Central America	Honduras	Tropics, warm	Sorghum	38,000	32,134	11,825	87.20	872.00	28,020,848			
Central America	Mexico	Tropics, warm	Maize	23,273,257	7,060,275	32,964	173.60	1,736.00	12,256,637,400	15,076,922,214	3,508,876,800	23%
Central America	Mexico	Tropics, warm	Sorghum	8,394,057	2,013,909	41,680	87.20	872.00	1,756,128,648			
Central America	Mexico	Tropics, warm	Wheat	3,669,814	706,611	51,935	150.60	1,506.00	1,064,156,166			
Central America	Nicaragua	Tropics, warm	Maize	368,000	243,875	15,090	173.60	1,736.00	423,367,000	470,978,200	194,194,000	41%
Central America	Nicaragua	Tropics, warm	Sorghum	121,569	54,600	22,265	87.20	872.00	47,611,200			
Central America	Panama	Tropics, warm	Maize	134,701	54,920	24,527	173.60	1,736.00	95,341,120	95,341,120	435,750,000	457%
Arabian Peninsula	Kuwait	Subtropics, warm/mod	Maize	48,098	1,564	307,532	579.50	5,795.00	9,063,380	9,121,564	448,300,000	4915%
Arabian Peninsula	Kuwait	Subtropics, warm/mod	Wheat	56	14	40,000	415.60	4,156.00	58,184			
Arabian Peninsula	Oman	Subtropics, warm/mod	Sorghum	23,897	1,617	147,786	372.20	3,722.00	6,018,474	18,253,173	129,578,000	710%
Arabian Peninsula	Oman	Subtropics, warm/mod	Maize	9,793	1,445	67,772	579.50	5,795.00	8,373,775			
Arabian Peninsula	Oman	Subtropics, warm/mod	Wheat	3,403	929	36,631	415.60	4,156.00	3,860,924			
Arabian Peninsula	Qatar	Subtropics, warm/mod	Maize	179	3	596,667	579.50	5,795.00	17,385	25,697	170,520,000	663579%
Arabian Peninsula	Qatar	Subtropics, warm/mod	Wheat	15	2	25,000	415.60	4,156.00	8,312			
Arabian Peninsula	Saudi Arabia	Subtropics, warm/mod	Wheat	500,000	116,718	42,838	415.60	4,156.00	485,080,008	937,410,693	2,130,000,000	227%

Arabian Peninsula	Saudi Arabia	Subtropics, warm/mod	Sorghum	265,000	102,000	25,980	372.20	3,722.00	379,644,000			
Arabian Peninsula	Saudi Arabia	Subtropics, warm/mod	Maize	80,000	12,543	63,780	579.50	5,795.00	72,686,685			
Arabian Peninsula	United Arab Emirates	Subtropics, warm/mod	Sorghum	76,990	1,795	428,947	372.20	3,722.00	6,680,990	6,733,145	602,192,000	8944%
Arabian Peninsula	United Arab Emirates	Subtropics, warm/mod	Maize	259	9	282,542	579.50	5,795.00	52,155			
Central Asia	Kazakhstan	Temperate,cool	Wheat	12,996,900	11,923,000	10,901	14.20	142.00	1,693,066,000	2,806,325,842	856,050,000	31%
Central Asia	Kazakhstan	Temperate,cool	Barley	2,411,817	1,909,356	12,632	14.20	142.00	271,128,552			
Central Asia	Kazakhstan	Temperate,cool	Maize	663,994	125,710	52,820	669.90	6,699.00	842,131,290			
Central Asia	Kyrgyzstan	Temperate,cool	Wheat	572,734	339,027	16,893	14.20	142.00	48,141,834	686,395,768	208,992,000	30%
Central Asia	Kyrgyzstan	Temperate,cool	Barley	197,084	155,398	12,683	14.20	142.00	22,066,516			
Central Asia	Kyrgyzstan	Temperate,cool	Maize	556,142	91,982	60,462	669.90	6,699.00	616,187,418			
Central Asia	Tajikistan	Temperate,cool	Wheat	868,372	292,573	29,681	14.20	142.00	41,545,366	536,164,387	614,650,000	115%
Central Asia	Tajikistan	Temperate,cool	Maize	186,321	73,525	127,504	669.90	6,699.00	492,543,975			
Central Asia	Tajikistan	Temperate,cool	Barley	113,430	14,613	15,427	14.20	142.00	2,075,046			
Central Asia	Uzbekistan	Temperate,cool	Wheat	6,955,976	1,454,600	47,821	14.20	142.00	206,553,200	461,115,200	4,100,000,000	889%
Central Asia	Uzbekistan	Temperate,cool	Maize	411,630	38,000	108,324	669.90	6,699.00	254,562,000			
Eastern Asia	China	Temperate,cool	Maize	215,812,100	37,150,395	58,091	10.30	103.00	3,826,490,685	6,113,295,440	57,382,650,000	939%
Eastern Asia	China	Temperate,cool	Wheat	126,215,211	24,071,629	52,433	9.50	95.00	2,286,804,755			
Eastern Asia	Japan	Subtropics, very cold	Wheat	852,400	212,600	40,094	9.50	95.00	20,197,000	38,618,200	15,410,000,000	39903%
Eastern Asia	Japan	Subtropics, very cold	Barley	169,700	60,200	28,189	30.60	306.00	18,421,200			
Eastern Asia	Mongolia	Subtropics, very cold	Wheat	489,295	291,247	16,800	9.50	95.00	27,668,465	27,668,465	42,387,000	153%
Eastern Asia	South Korea	Subtropics, very cold	Barley	88,273	30,489	28,952	30.60	306.00	9,329,634	10,961,051	6,924,000,000	63169%
Eastern Asia	South Korea	Subtropics, very cold	Maize	82,008	15,839	51,776	10.30	103.00	1,631,417			
Southeast Asia	Cambodia	Tropics, warm	Maize	550,000	119,129	46,168	18.20	182.00	21,681,478	21,681,478	41,552,000	192%
Southeast Asia	Indonesia	Tropics, warm	Maize	19,008,426	3,837,019	49,540	18.20	182.00	698,337,458	698,337,458	8,505,920,000	1218%
Southeast Asia	Laos	Tropics, warm	Maize	1,412,440	243,385	58,033	18.20	182.00	44,296,070	44,296,070	92,170,000	208%

Southeast Asia	Malaysia	Tropics, warm	Maize	59,188	9,707	60,975	18.20	182.00	1,766,674	1,766,674	3,745,920,000	212032%
Southeast Asia	Philippines	Tropics, warm	Maize	7,770,603	2,611,432	29,756	18.20	182.00	475,280,624	475,280,624	4,607,665,000	969%
Southeast Asia	Thailand	Tropics, warm	Maize	4,804,670	1,131,728	42,454	18.20	182.00	205,974,496	205,974,496	2,547,270,000	1237%
Southern Asia	Afghanistan	Tropics, warm	Wheat	5,370,259	2,653,746	20,237	68.10	681.00	1,807,201,026	1,807,201,026	64,884,600	4%
Southern Asia	Bangladesh	Tropics, warm	Wheat	1,303,000	429,770	30,319	68.10	681.00	292,673,370	505,836,858	2,181,600,000	431%
Southern Asia	Bangladesh	Tropics, warm	Maize	2,124,000	307,152	69,151	69.40	694.00	213,163,488			
Southern Asia	Bhutan	Tropics, warm	Maize	74,370	24,651	30,169	69.40	694.00	17,107,794	18,684,309	8,568,000	46%
Southern Asia	Bhutan	Tropics, warm	Wheat	5,172	2,315	22,341	68.10	681.00	1,576,515			
Southern Asia	India	Tropics, warm	Wheat	95,850,000	30,470,000	31,457	68.10	681.00	20,750,070,000	27,175,122,000	22,176,000,000	82%
Southern Asia	India	Tropics, warm	Maize	23,670,000	9,258,000	25,567	69.40	694.00	6,425,052,000			
Southern Asia	Iran	Tropics, warm	Wheat	10,600,000	7,300,000	14,521	68.10	681.00	4,971,300,000	4,971,300,000	5,580,000,000	112%
Southern Asia	Maldives	Tropics, warm	Maize	140	44	40,000	69.40	694.00	30,536	35,436	5,482,400	15471%
Southern Asia	Maldives	Tropics, warm	Sorghum	50	35	11,364	14.00	140.00	4,900			
Southern Asia	Nepal	Tropics, warm	Maize	2,283,222	928,761	24,584	69.40	694.00	644,560,134	1,158,356,928	67,600,800	6%
Southern Asia	Nepal	Tropics, warm	Wheat	1,883,147	754,474	24,960	68.10	681.00	513,796,794			
Southern Asia	Pakistan	Tropics, warm	Wheat	25,979,399	9,199,318	28,241	68.10	681.00	6,264,735,558	7,057,604,186	6,127,750,000	87%
Southern Asia	Pakistan	Tropics, warm	Maize	4,936,747	1,142,462	43,211	69.40	694.00	792,868,628			
Southern Asia	Sri Lanka	Tropics, warm	Maize	241,144	67,159	35,906	69.40	694.00	46,608,346	46,608,346	765,555,000	1643%
Western Asia	Armenia	Subtropics, cool	Wheat	338,158	104,823	32,260	475.40	4,754.00	498,328,542	516,707,242	754,485,000	146%
Western Asia	Armenia	Subtropics, cool	Barley	200,552	66,539	30,141	0.00	0.00	0			
Western Asia	Armenia	Subtropics, cool	Maize	20,158	2,845	70,854	646.00	6,460.00	18,378,700			
Western Asia	Azerbaijan	Subtropics, cool	Wheat	1,449,100	604,429	23,975	475.40	4,754.00	2,873,455,466	3,116,209,346	465,253,000	15%
Western Asia	Azerbaijan	Subtropics, cool	Barley	681,759	335,802	20,302	0.00	0.00	0			
Western Asia	Azerbaijan	Subtropics, cool	Maize	203,596	37,578	54,180	646.00	6,460.00	242,753,880			
Western Asia	Cyprus	Subtropics, cool	Barley	2,720	18,939	1,436	0.00	0.00	0	29,165,790	84,100,000	288%

Western Asia	Cyprus	Subtropics, cool	Wheat	4,445	6,135	7,245	475.40	4,754.00	29,165,790			
Western Asia	Georgia	Subtropics, cool	Maize	347,200	151,000	22,993	646.00	6,460.00	975,460,000	1,166,095,400	308,954,000	26%
Western Asia	Georgia	Subtropics, cool	Wheat	50,200	40,100	12,519	475.40	4,754.00	190,635,400			
Western Asia	Georgia	Subtropics, cool	Barley	31,500	23,400	13,462	0.00	0.00	0			
Western Asia	Iraq	Subtropics, cool	Wheat	5,055,111	2,109,455	23,964	475.40	4,754.00	10,028,349,070	10,028,349,070	3,680,800,000	37%
Western Asia	Iraq	Subtropics, cool	Barley	1,277,796	1,145,814	11,152	0.00	0.00	0			
Western Asia	Israel	Subtropics, cool	Wheat	126,300	61,600	20,503	475.40	4,754.00	292,846,400	323,841,480	712,000,000	220%
Western Asia	Israel	Subtropics, cool	Maize	163,601	4,798	340,977	646.00	6,460.00	30,995,080			
Western Asia	Jordan	Subtropics, cool	Barley	38,873	38,139	10,192	0.00	0.00	0	109,427,572	287,221,800	262%
Western Asia	Jordan	Subtropics, cool	Wheat	27,452	23,018	11,926	475.40	4,754.00	109,427,572			
Western Asia	Lebanon	Subtropics, cool	Wheat	140,000	47,677	29,364	475.40	4,754.00	226,656,458	231,669,418	306,660,000	132%
Western Asia	Lebanon	Subtropics, cool	Barley	33,000	18,605	17,737	0.00	0.00	0			
Western Asia	Lebanon	Subtropics, cool	Maize	3,000	776	38,671	646.00	6,460.00	5,012,960			
Western Asia	Syria	Subtropics, cool	Wheat	2,024,332	1,287,886	15,718	475.40	4,754.00	6,122,610,044	6,281,655,244	1,411,575,000	22%
Western Asia	Syria	Subtropics, cool	Barley	600,104	1,220,559	4,917	0.00	0.00	0			
Western Asia	Syria	Subtropics, cool	Maize	67,080	24,620	27,246	646.00	6,460.00	159,045,200			
Western Asia	Turkey	Subtropics, cool	Wheat	19,000,000	7,820,750	24,294	475.40	4,754.00	37,179,845,500	41,415,428,480	5,883,800,000	14%
Western Asia	Turkey	Subtropics, cool	Barley	6,300,000	2,718,950	23,171	0.00	0.00	0			
Western Asia	Turkey	Subtropics, cool	Maize	5,950,000	655,663	90,748	646.00	6,460.00	4,235,582,980			
Eastern Europe	Belarus	Temperate,cool	Wheat	2,925,079	741,946	39,424	19.70	197.00	146,163,362	655,391,030	515,821,000	79%
Eastern Europe	Belarus	Temperate,cool	Barley	1,988,102	545,796	36,426	93.30	933.00	509,227,668			
Eastern Europe	Bulgaria	Temperate,cool	Wheat	5,347,078	1,267,914	42,172	19.70	197.00	249,779,058	775,997,751	920,200,000	119%
Eastern Europe	Bulgaria	Temperate,cool	Maize	3,137,478	408,404	76,823	79.80	798.00	325,906,392			
Eastern Europe	Bulgaria	Temperate,cool	Barley	852,231	214,697	39,695	93.30	933.00	200,312,301			
Eastern Europe	Hungary	Temperate,cool	Maize	9,315,100	1,191,420	78,185	79.80	798.00	950,753,160	1,438,804,920	582,610,000	40%

Eastern Europe	Hungary	Temperate,cool	Wheat	5,261,890	1,112,730	47,288	19.70	197.00	219,207,810			
Eastern Europe	Hungary	Temperate,cool	Barley	1,274,710	288,150	44,238	93.30	933.00	268,843,950			
Eastern Europe	Poland	Temperate,cool	Wheat	11,628,670	2,338,782	49,721	19.70	197.00	460,740,054	1,001,983,554	2,227,824,000	222%
Eastern Europe	Poland	Temperate,cool	Maize	4,468,403	678,250	65,881	79.80	798.00	541,243,500			
Eastern Europe	Romania	Temperate,cool	Maize	11,988,553	2,504,419	47,870	79.80	798.00	1,998,526,362	2,891,599,607	775,180,000	27%
Eastern Europe	Romania	Temperate,cool	Wheat	7,584,814	2,107,813	35,984	19.70	197.00	415,239,161			
Eastern Europe	Romania	Temperate,cool	Barley	1,712,509	512,148	33,438	93.30	933.00	477,834,084			
Eastern Europe	Slovakia	Temperate,cool	Wheat	2,072,405	379,283	54,640	19.70	197.00	74,718,751	376,759,837	302,130,400	80%
Eastern Europe	Slovakia	Temperate,cool	Maize	1,814,113	216,186	83,914	79.80	798.00	172,516,428			
Eastern Europe	Slovakia	Temperate,cool	Barley	675,853	138,826	48,684	93.30	933.00	129,524,658			
Eastern Europe	Ukraine	Temperate,cool	Wheat	24,113,970	6,010,600	40,119	19.70	197.00	1,184,088,200	7,678,246,700	3,132,094,000	41%
Eastern Europe	Ukraine	Temperate,cool	Maize	28,496,810	4,626,900	61,589	79.80	798.00	3,692,266,200			
Eastern Europe	Ukraine	Temperate,cool	Barley	9,046,060	3,003,100	30,122	93.30	933.00	2,801,892,300			
Southern Europe	Albania	Subtropics, cool	Wheat	280,000	69,998	40,001	208.20	2,082.00	145,735,836	326,850,836	523,131,600	160%
Southern Europe	Albania	Subtropics, cool	Maize	380,000	55,000	69,091	329.30	3,293.00	181,115,000			
Southern Europe	Croatia	Subtropics, cool	Maize	2,046,966	252,567	81,046	329.30	3,293.00	831,703,131	1,191,081,409	492,663,000	41%
Southern Europe	Croatia	Subtropics, cool	Wheat	648,917	156,139	41,560	208.20	2,082.00	325,081,398			
Southern Europe	Croatia	Subtropics, cool	Barley	175,592	46,160	38,040	74.30	743.00	34,296,880			
Southern Europe	Greece	Subtropics, cool	Wheat	1,645,950	544,370	30,236	208.20	2,082.00	1,133,378,340	1,795,198,250	1,280,070,000	71%
Southern Europe	Greece	Subtropics, cool	Barley	470,190	182,590	25,751	74.30	743.00	135,664,370			
Southern Europe	Greece	Subtropics, cool	Maize	1,778,140	159,780	111,287	329.30	3,293.00	526,155,540			
Southern Europe	Italy	Subtropics, cool	Wheat	7,141,926	1,874,179	38,107	208.20	2,082.00	3,902,040,678	6,766,776,149	9,403,745,000	139%
Southern Europe	Italy	Subtropics, cool	Maize	9,239,545	869,947	106,208	329.30	3,293.00	2,864,735,471			
Southern Europe	Malta	Subtropics, cool	Wheat	15,056	3,100	48,569	208.20	2,082.00	6,454,200	6,830,158	15,300,000	224%
Southern Europe	Malta	Subtropics, cool	Barley	2,120	506	41,891	74.30	743.00	375,958			

Southern Europe	Portugal	Subtropics, cool	Maize	896,995	107,642	83,331	329.30	3,293.00	354,465,106	454,038,838	907,768,500	200%
Southern Europe	Portugal	Subtropics, cool	Wheat	98,794	47,826	20,657	208.20	2,082.00	99,573,732			
Southern Europe	Slovenia	Subtropics, cool	Maize	350,693	38,331	91,491	329.30	3,293.00	126,223,983			
Southern Europe	Slovenia	Subtropics, cool	Wheat	173,245	33,124	52,302	208.20	2,082.00	68,964,168	208,920,277	162,524,000	78%
Southern Europe	Slovenia	Subtropics, cool	Barley	89,700	18,482	48,534	74.30	743.00	13,732,126			
Southern Europe	Spain	Subtropics, cool	Barley	6,983,109	2,792,110	25,010	74.30	743.00	2,074,537,730			
Southern Europe	Spain	Subtropics, cool	Wheat	6,471,400	2,171,200	29,806	208.20	2,082.00	4,520,438,400	7,973,244,815	5,302,692,000	67%
Southern Europe	Spain	Subtropics, cool	Maize	4,776,190	418,545	114,114	329.30	3,293.00	1,378,268,685			
Western Europe	Austria	Temperate,cool	Wheat	1,804,018	304,645	59,217	166.60	1,666.00	507,538,570			
Western Europe	Austria	Temperate,cool	Maize	2,334,385	216,316	107,915	260.00	2,600.00	562,421,600	1,149,580,620	720,000,000	63%
Western Europe	Austria	Temperate,cool	Barley	845,705	145,825	57,994	54.60	546.00	79,620,450			
Western Europe	Belgium	Temperate,cool	Wheat	1,994,600	211,900	94,129	166.60	1,666.00	353,025,400			
Western Europe	Belgium	Temperate,cool	Maize	662,700	63,100	105,024	260.00	2,600.00	164,060,000	542,856,600	705,753,500	130%
Western Europe	Belgium	Temperate,cool	Barley	434,700	47,200	92,097	54.60	546.00	25,771,200			
Western Europe	France	Temperate,cool	Wheat	38,950,202	5,297,210	73,530	166.60	1,666.00	8,825,151,860			
Western Europe	France	Temperate,cool	Maize	18,343,420	1,825,221	100,500	260.00	2,600.00	4,745,574,600	14,534,059,376	5,409,747,000	37%
Western Europe	France	Temperate,cool	Barley	11,728,556	1,764,346	66,475	54.60	546.00	963,332,916			
Western Europe	Germany	Temperate,cool	Wheat	27,784,700	3,219,700	86,296	166.60	1,666.00	5,364,020,200			
Western Europe	Germany	Temperate,cool	Barley	11,562,800	1,573,700	73,475	54.60	546.00	859,240,200	7,474,640,400	5,365,728,000	72%
Western Europe	Germany	Temperate,cool	Maize	5,142,100	481,300	106,838	260.00	2,600.00	1,251,380,000			
Western Europe	Luxembourg	Temperate,cool	Wheat	77,943	12,665	61,541	166.60	1,666.00	21,099,890	25,640,972	39,820,800	155%
Western Europe	Luxembourg	Temperate,cool	Barley	45,962	8,317	55,262	54.60	546.00	4,541,082			
Western Europe	Netherlands	Temperate,cool	Wheat	1,304,054	142,212	91,698	166.60	1,666.00	236,925,192			
Western Europe	Netherlands	Temperate,cool	Barley	196,925	27,613	71,316	54.60	546.00	15,076,698	284,746,290	1,189,009,000	418%
Western Europe	Netherlands	Temperate,cool	Maize	173,066	12,594	137,419	260.00	2,600.00	32,744,400			

Western Europe	Switzerland	Temperate,cool	Wheat	550,826	88,350	62,346	166.60	1,666.00	147,191,100			
Western Europe	Switzerland	Temperate,cool	Barley	201,091	27,125	74,135	54.60	546.00	14,810,250	202,855,150	916,083,000	452%
Western Europe	Switzerland	Temperate,cool	Maize	138,474	15,713	88,127	260.00	2,600.00	40,853,800			
Australia	Australia	Subtropics, warm/mod.	Wheat	25,303,037	12,613,226	20,061	53.60	536.00	6,760,689,136			
Australia	Australia	Subtropics, warm/mod.	Barley	9,174,417	3,814,113	24,054	49.10	491.00	1,872,729,483	11,799,326,815	1,851,000,000	16%
Australia	Australia	Subtropics, warm/mod.	Sorghum	1,282,042	531,996	24,099	595.10	5,951.00	3,165,908,196			
New Zealand	New Zealand	Subtropics, cool	Barley	405,747	59,337	68,380	0.00	0.00	0			
New Zealand	New Zealand	Subtropics, cool	Wheat	413,497	47,931	86,269	0.00	0.00	0	26,891,172	623,700,000	2319%
New Zealand	New Zealand	Subtropics, cool	Maize	237,165	21,582	109,890	124.60	1,246.00	26,891,172			
Pacific Islands	Fiji	Tropics, warm	Maize	1,341	683	19,643	17.70	177.00	120,891	121,427	23,048,300	18981%
Pacific Islands	Fiji	Tropics, warm	Sorghum	26	8	32,297	6.70	67.00	536			
Pacific Islands	Papua New Guinea	Tropics, warm	Maize	12,481	2,256	55,329	17.70	177.00	399,312	478,305	42,241,500	8831%
Pacific Islands	Papua New Guinea	Tropics, warm	Sorghum	4,644	1,179	39,409	6.70	67.00	78,993			
Andean	Chile	Tropics, cool/cold/very cold	Maize	1,186,127	117,418	101,017	119.40	1,194.00	140,197,092	140,197,092	1,255,597,000	896%
Andean	Colombia	Tropics, cool/cold/very cold	Maize	1,803,039	505,751	35,651	119.40	1,194.00	603,866,694	606,276,732	2,113,466,000	349%
Andean	Colombia	Tropics, cool/cold/very cold	Sorghum	19,147	6,309	30,350	38.20	382.00	2,410,038			
Andean	Ecuador	Tropics, cool/cold/very cold	Maize	1,667,704	485,696	34,336	119.40	1,194.00	579,921,024	595,624,712	1,095,171,000	184%
Andean	Ecuador	Tropics, cool/cold/very cold	Barley	14,490	15,688	9,236	100.10	1,001.00	15,703,688			
Andean	Peru	Tropics, cool/cold/very cold	Maize	1,529,636	484,047	31,601	119.40	1,194.00	577,952,118	728,928,944	955,548,000	131%
Andean	Peru	Tropics, cool/cold/very cold	Barley	226,310	150,826	15,005	100.10	1,001.00	150,976,826			
Andean	Venezuela	Tropics, cool/cold/very cold	Maize	2,271,059	586,318	38,734	119.40	1,194.00	700,063,692	723,459,282	4,836,112,000	668%
Andean	Venezuela	Tropics, cool/cold/very cold	Sorghum	131,876	61,245	21,533	38.20	382.00	23,395,590			
Brazil	Brazil	Tropics, warm	Maize	79,881,614	15,432,909	51,761	1.70	17.00	262,359,453	2,419,752,598	14,249,880,000	589%
Brazil	Brazil	Tropics, warm	Wheat	6,261,895	2,834,945	22,088	76.10	761.00	2,157,393,145			
Southern Cone	Argentina	Subtropics, warm/mod.	Maize	33,087,165	4,836,655	68,409	190.20	1,902.00	9,199,317,810	13,739,873,310	5,591,200,000	41%

Southern Cone	Argentina	Subtropics, warm/mod.	Wheat	9,315,049	3,492,735	26,670	130.00	1,300.00	4,540,555,500			
Southern Cone	Argentina	Subtropics, warm/mod.	Sorghum	3,466,410		44,009	119.70	1,197.00	0			
Southern Cone	Bolivia	Subtropics, warm/mod.	Sorghum	1,229,286	472,170	26,035	119.70	1,197.00	565,187,490	1,458,572,106	68,408,000	5%
Southern Cone	Bolivia	Subtropics, warm/mod.	Maize	994,955	469,708	21,182	190.20	1,902.00	893,384,616			
Southern Cone	Paraguay	Subtropics, warm/mod.	Maize	3,200,000	800,000	40,000	190.20	1,902.00	1,521,600,000	2,249,600,000	320,732,000	14%
Southern Cone	Paraguay	Subtropics, warm/mod.	Wheat	840,000	560,000	15,000	130.00	1,300.00	728,000,000			
Southern Cone	Uruguay	Subtropics, warm/mod.	Wheat	1,076,000	167,400	26,967	130.00	1,300.00	217,620,000	466,972,200	395,240,000	85%
Southern Cone	Uruguay	Subtropics, warm/mod.	Maize	564,500	131,100	43,059	190.20	1,902.00	249,352,200			
Northern Africa	Algeria	Subtropics, warm/mod.	Wheat	2,436,197	1,651,311	14,753	202.90	2,029.00	3,350,510,019			19%
Northern Africa	Algeria	Subtropics, warm/mod.	Barley	939,401	791,843	11,863	199.20	1,992.00	1,577,351,256	4,927,861,275	952,387,200	
Northern Africa	Egypt	Subtropics, warm/mod.	Wheat	9,279,804	1,425,060	65,119	202.90	2,029.00	2,891,446,740			90%
Northern Africa	Egypt	Subtropics, warm/mod.	Maize	8,059,906	1,039,241	77,556	628.50	6,285.00	6,531,629,685	9,423,076,425	8,523,000,000	
Northern Africa	Libya	Subtropics, warm/mod.	Wheat	200,000	256,624	7,794	202.90	2,029.00	520,690,096			75%
Northern Africa	Libya	Subtropics, warm/mod.	Barley	95,000	189,635	5,010	199.20	1,992.00	377,752,920	898,443,016	676,200,000	
Northern Africa	Morocco	Subtropics, warm/mod.	Wheat	5,115,884	2,986,158	17,132	202.90	2,029.00	6,058,914,582			
Northern Africa	Morocco	Subtropics, warm/mod.	Barley	1,638,086	1,585,216	10,334	199.20	1,992.00	3,157,750,272			
Northern Africa	Morocco	Subtropics, warm/mod.	Maize	97,379	137,447	7,085	628.50	6,285.00	863,854,395	10,080,519,249	815,321,000	8%
Northern Africa	Tunisia	Subtropics, warm/mod.	Wheat	1,513,220	722,880	20,933	202.90	2,029.00	1,466,723,520			17%
Northern Africa	Tunisia	Subtropics, warm/mod.	Barley	772,540	574,650	13,444	199.20	1,992.00	1,144,702,800	2,611,426,320	454,336,000	
Northern America	United States of America	Temperate,cool	Maize	361,091,140.00	33,644,310.00	107,326.00	333.80	3,338.00	112,304,706,780		62,090,000,000	
Northern America	United States of America	Temperate,cool	Sorghum	10,987,910.00	2,590,420.00	42,417.00	162.40	1,624.00	4,206,842,080		62,090,000,000	
Northern America	United States of America	Temperate,cool	Wheat	55,147,120.00	18,771,550.00	29,378.00	224.40	2,244.00	42,123,358,200	158,634,907,060	62,090,000,000	39%