Water Security, The Nexus Of Water, Food, Population Growth and Energy

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Abstract: Issues causing increased water stress and availability throughout the world are complex. The importance of supply-side issues arising from increasing urbanization, causing localized levels of water stress, is described. Further, while the world population has doubled over the last 50 years, water use has tripled. Water use rates have increased (from 400km^3 per year per billion people in 1965, to the current level of 600km^3 per year per billion people in 2015), as a result of population growth with its associated food and energy implications, and dietary shifts of populations.

Water demands in 2025 are projected to be 1500km^3 per year, or 60% more than volumes in 2015. The findings in a case study in the Zambezi River basin indicate that while climate change is projected as 25% of the projected impact to future water security issues, 75% of water security issues are attributable to population increases (and its related food, energy, and changing dietary habits) and hence, population increases represent a greater threat to water security.

Keywords: Water security, population growth, energy usage, water demands, water stress.

1. INTRODUCTION

The challenges in the 21st century in relation to water security are ominous. Water is renewable but also finite and is a prerequisite for life [1]. Issues of water security have already been identified as one of the most difficult issues facing the world, by T. Boone Pickens who claims 'Water is the New Oil' [2]. While water security issues will unquestionably intensify, and there is considerable awareness that issues of water security already exist, the view of many politicians and professionals is primarily toward blaming 'climate change' for the challenges. The 'blame game' is partly adopted since it is easy for politicians to criticize a few select countries, particularly wealthy nations, as being responsible for climate change and hence causing issues such as droughts, floods, etc. In reality, however, issues of water security are much more complicated than being simply attributable to climate change alone. As will be demonstrated below, while there is no question that climate change is contributing to issues of deteriorating water security, the issues are much more complex than this narrow view.

To comprehend the issues, it is essential to understand the nexus of water, food, population growth and energy [3, 4, 5, 6, 7] as is schematically depicted in Figure **1**. It is acknowledged there are additional dimensions impacting water security (e.g. land degradation, environmental quality implications, etc.); however, they will not be explicitly considered in this paper. The components in Figure **1** are inter-linked and of immense importance to water security as will be demonstrated herein.

Generalizing the security issues throughout the world is very difficult as conditions and circumstances vary, and hence, vulnerability assessments have consistently been developed at the country or regional level [8]. Water security issues are very different, for example, in the Middle East, as opposed to North America, as opposed to Africa. Further, as time progresses, innovations may change efficiencies of water needs in relation to the generation of electricity, for example. Hence, the approach utilized herein will be to employ specific examples to demonstrate some of the impacts which influence the nexus of water, food, energy, population and climate change, as they impact water security, with the intent to demonstrate global trends on the basis of current information.

2. MAGNITUDES OF FACTORS INFLUENCING WATER SECURITY

Factors impacting water security include (a) burgeoning populations, (b) massive migration of people from rural areas to urban centers, (c) increasing standards of living in some regions, (d) increasing energy demands, (e) intensifying agriculture, (f) increasing industrialization, (g) increasing per capita water consumption, and (h) increasing global temperatures and rainfall intensities. However, these factors are intertwined and will be considered in relation to the nexus of the factors reflected in Figure **1**.

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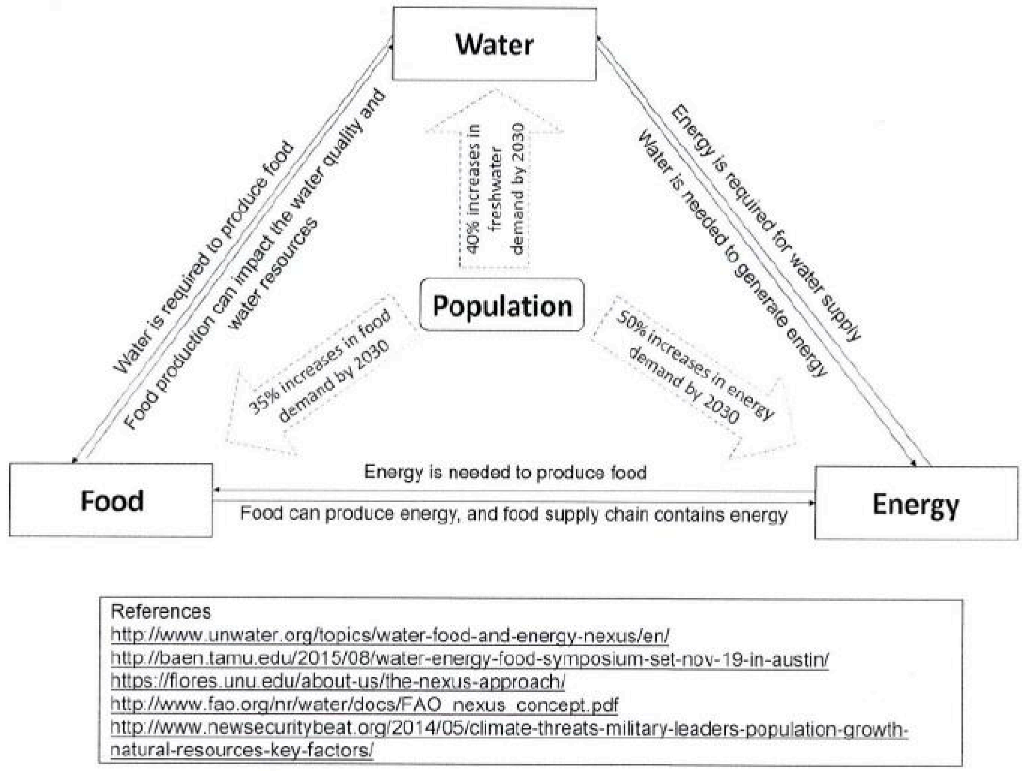

Figure 1: Nexus perspective in terms of water availability.

2.1. Water Consumption and Climate Change Effects on Water Security

While the degree of water stress can be characterized in many ways, one of the most useful is by characterizing the numbers of people at various levels of water availability. Two-thirds of the world's population were experiencing water shortages during the 1980s [9]. Currently, more than a billion people lack ready access to water and 2.7 billion experience water scarcity (defined as <1000m^3/capita/year [9]) at least one month a year and by 2025, two-thirds of the world's population will be facing water shortages [10]. In 2100, it is projected that one-half of the world's population of 11 billion will be under water stress [11, 12]. These examples of various measures of water stress demonstrate both the extensive spatial dimensions and increasing severity of water supply security projected for the world's population in years to come.

As the examples described above indicate, water shortages are geographically widespread and projected to intensify. One of the contributing factors leading to this stress is that the vast majority of the human population utilizes much greater volumes than the 20L of domestic water / day needed to survive for drinking and sanitation [13]. Consider the information listed in Table **1**, which describe examples of water usage in three megacities (defined as cities with more than 10 million). The intent, as examples only, is to demonstrate water usage in large cities is large relative to survival and, because of their large populations, have large implications to individual watersheds. Recognizing that there are 336 cities in the world with populations of more than one million [14], and 35

Table 1: Domestic Water Use in Three Cities

	Population	Domestic Water Use/Capita	Domestic Water Use in the Listed City (MLD)
Mexico City, Mexico	21 million	364 L/cap/day	7520
Buenos Aires, Argentina	12 million	378-400 L/cap/day	4555
Shanghai, China	23 million	411 L/cap/day	9420

Ref: extracted from [10].

megacities [15], these results indicate the enormous magnitude of water delivered to cities.

In 2006, UNEP [16] indicated more people were living in cities than in rural areas and that by 2050, 70% of the world's population will live in urban centers. This will require the delivery of massive quantities of water to selected areas (i.e. locations of the large cities influence the potential for supply-side threats; if withdrawals exceed the ability of nearby surface water sources, or the rate of replenishment of local groundwater aquifers, regional water security issues will develop). Hence, huge amounts of water are being moved to many cities, requiring significant energy, while simultaneously potentially depleting water supplies for surrounding regions. These actions reduce the availability of freshwater for all uses and are not distributed equally across the globe.

Moderating these volumes of water delivered to cities is typically difficult since demand is insufficiently controlled due to inadequate pricing procedures (including many regional issues of zero pricing) and challenges implicit in legislation. Demand for water is going to increase but supply of water will not.

2.2. Population Growth Effects on Water Security

The planet's increasing populations are impacting demand-side concerns on water security. Over a 41 year period from 1965 to 2006 (e.g. see Figure **2**), the human population increased from 3 billion to 6.5 billion. As [1] reported, the renewable water supply per capita has dropped by 58% since 1950, as the world population increased from 2.5 to 6 billion (from 1950 to 2000). The dramatic growth of population as apparent from Figure **2**, Shows the approximate doubling of the human population; what is not widely appreciated is that during this period when populations have doubled, water use has more than tripled, due to increases in population, energy and food. The consumption of water has changed from approximately 400km^3 per year per billion people (in 1965) to 600km^3 per year per billion people in 2006 (as estimated from the values reported in [17]. As illustrated in Figure **3**, the majority of water use occurs in the agricultural sector. Although the growth in water use as a percentage in agriculture is decreasing (due to domestic and industry demands increasing), and as [17] indicates, agriculture will continue to represent the largest fraction of the world's water use.

The ramifications of water availability are apparent when realizing the human population is expected to increase from 6.6 billion in 2008, to 8 billion in 2025, to 9.7 billion by 2050 [18] (accounting for decreased numbers of children per woman (2.82 to 2.16) as well as the improvement in life expectancy (65 to 76 years)) [19]. This equates to a 60% increase in demand for supplied water by 2025 or, equivalently, to approximately 1500km^3 of water per year, or as much water as used for all purposes in the world outside of

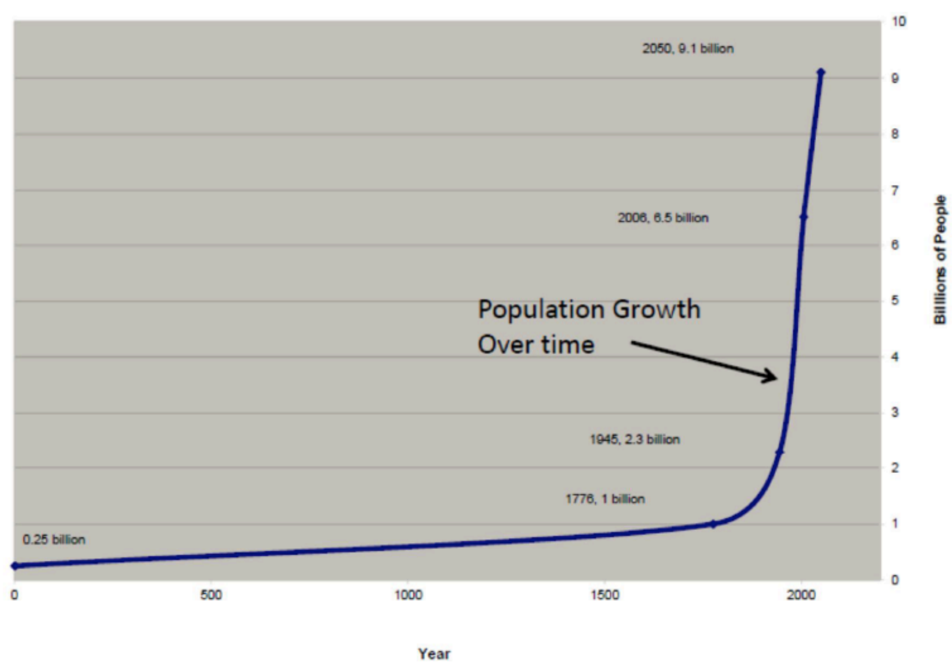

Figure 2: Population vs Time.

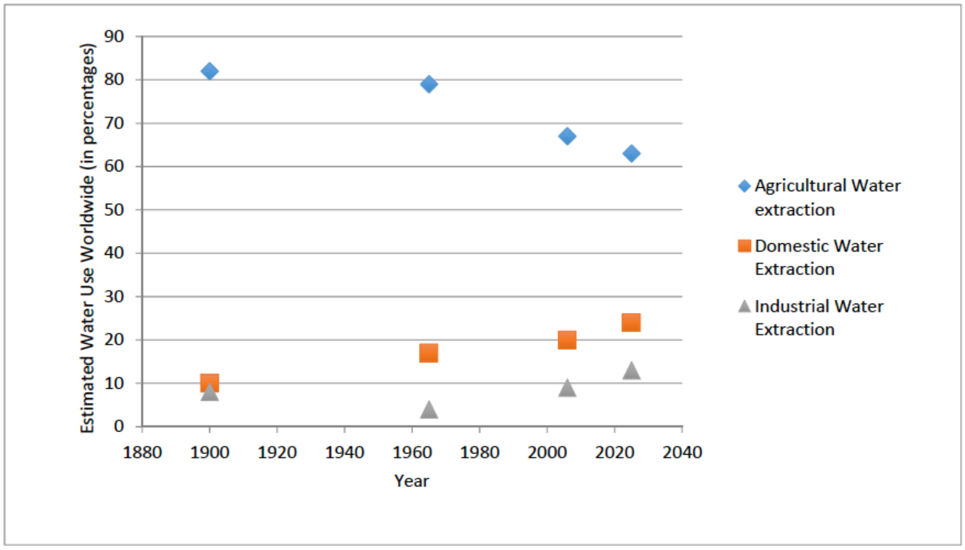

Figure 3: Estimated water use worldwide over time (based on information from Shiklomanov, 1999).

Asia [16]. Extending the water use needs for 2050, will require a 90% increase in water per year to be supplied.

FAO (as reported in [20]) indicated that water use has grown at twice the rate of population growth over the last century. To characterize these quantities in the global context, groundwater is providing approximately 50% of current potable water supplies, 40% of that being utilized by industry and 20% of water used for irrigation [20]. Reliance upon groundwater has grown explosively in the past 50 years in part due to electrification of the rural environment and the availability of diesel-powered pumps for tube wells [21]. The result has been increases in groundwater pumpage from 100-150km^3/yr in the 1970s to 950-1000km^3/yr in the early 2000s [21]. While reliance upon groundwater has been enormously helpful to meet water demands over the last five decades, reliance upon groundwater as a source of supply cannot continue at the current levels due to declining groundwater levels. Demands are outpacing groundwater supplies available as globally, only 2% of all precipitation goes to groundwater (e.g. see [22]).

Meeting the projected freshwater demands is clearly going to be difficult. Some of the important underlying bases for the projected water demands are further described below.

2.3. Food Effects on Water Security

Worldwide use of water for irrigation has been estimated as 70% [10, 17]. Climate change is altering hydrologic cycles through increasing evaporation/ evapotranspiration rates, and changes to the precipitation processes e.g. patterns, extremes, and intensities, and changing soil moisture and runoff levels [11, 23, 24, 25]. Hence, demands for water for irrigation are influenced by climate change as well as population, food and energy.

While discussion above has demonstrated that increases in population have resulted in heightened water needs, changes in dietary habits also have had a profound impact on irrigation water requirements. The importance of diet is evident since one kg of grain requires 2500L of water whereas 15500L of water is needed for one kg of beef [26]. The result is that when diets change to more water- intensive foods, water needs increase. The implications are profound if sectors of the population adopt the meaty American and European diets requiring 5000L of water/day, as opposed to primarily vegetarian- based African and Asian diets which require only 2000L/cap/day [27, 28].

To understand the implications of dietary change, consider the changes in the diet in China wherein meat consumption was 20kg per person per year in 1985, but has increased to 50kg per person in 2009 [27]. Assuming a population of 1.3 billion for China, this translates to 60km^3/yr of water for China alone, on the basis of changes in just meat consumption. This magnitude by itself equates to four percent of the water needed for the additional 2 billion people expected by 2025.

Shifts in dietary habits are almost impossible to reverse since they are a product of increasing wealth and urbanization [27]. The result is increased water needs cause significant implications to water security arising from food consumption.

2.4. Energy-Water Effects on Water Security

Energy needs a lot of water, and water needs a lot of energy. World energy consumption in 1965 was estimated as averaging 50GJ/cap in 1965 and 75GJ/cap in 2010 [29]. This equates to an increase of 50% over a 45 year period. Table **2** indicates projected energy and water demand if this energy demand growth rate continues and its concomitant increase in water use evolves, relative to water in 1965.

- Rising temperature: 2^{o}C over the next 100 years,
- Drying up of biomass during droughts,
- Rapid growth of crops and then wilting during the dry periods will occur,
- Overall, an intensification of the hydrologic cycle which exacerbates erosion and decreases infiltration rates.

As a result of the above, climate change is expected to affect water availability through impacts to the hydrologic processes. To assess the relative impacts of both population and climate change, Zhang *et al*. [31] considered the Zambezi River Basin in Africa. The eight countries sharing the Basin are: Angola, Namibia, Botswana, Zimbabwe, Zambia, Tanzania, Malawi and

Table 2: Water Use Implicit in Meeting Energy Consumption at the World Scale Relative to 1965

I	II	III	IV	V
Year	**Energy Consumption (gigajoules/capita)**	**World Population (billions)**	**Litres of Water Needed for Energy Production (25 gal/kwh^{+})**	**Relative to Water Needs in 1965**
1965	50*	3	3.93×10^{15}	1
2010	75*	6.5	12.8×10^{15}	3.3
2050	95**	9.5	23.6×10^{15}	6.0

Legend: *as per [29].

**Assumed as a rate of increase similar to the change from 1965 to 2010.

$^{+}$ Rated at 25 gal/kwh, primarily for cooling water [30].

Proviso: Improvements in technology will change the efficiency of energy needs for water but the essence of increased water demands is evident.

The results in column V of Table **2** demonstrate that increased world energy demand will involve approximately a six-fold increase in water needs in 2050 relative to 1965, arising from the combination of projected energy consumption per capita, and the growth in the world's population. The effect of the increased energy consumption per person accounts for 37% of the increase in water use whereas 63% of the increase in water use is due to population growth, on the basis of these estimates.

3. EXAMPLE OF ASSESSMENT OF IMPORTANCE OF POPULATION GROWTH RELATIVE TO CLIMATE CHANGE

There is no question that the climate is warming. For example, the 107 year long temperature record in Regina, Saskatchewan has demonstrated a clear indication of increase [31]. While there is no guarantee that these types of trends will continue, the predictions of many indicate the general hydrologic trends arising from climate change will include (e.g. see [31, 32]):

Moazambique, which cumulatively result in the Zambezi Basin having a population of 40 million in 2010 [32]. Global Climate Models and the Soil and Water Assessment Tool (SWAT) and the projected population growth rates [9, 19] (and see Figure **4**) for the eight countries in the Zambezi River Basin were used to investigate the importance of population growth, relative to that of climate change.

Using the Aridity Index and Falkenmark Water Stress Indicator, Zhang *et al*. [33] assessed the importance of the combinations of population growth and climate change. The results show that climate is 10% drier for the entire Zambezi Basin, arising from changes in both precipitation and potential evapotranspiration (water will become less available due to large decreases in the wet seasons (from 30 to 50%), and the dry season becoming nearly one month longer). There are exceptions, where Zimbabwe's climate will become 10% less arid for the entire Basin, arising from changes in both precipitation

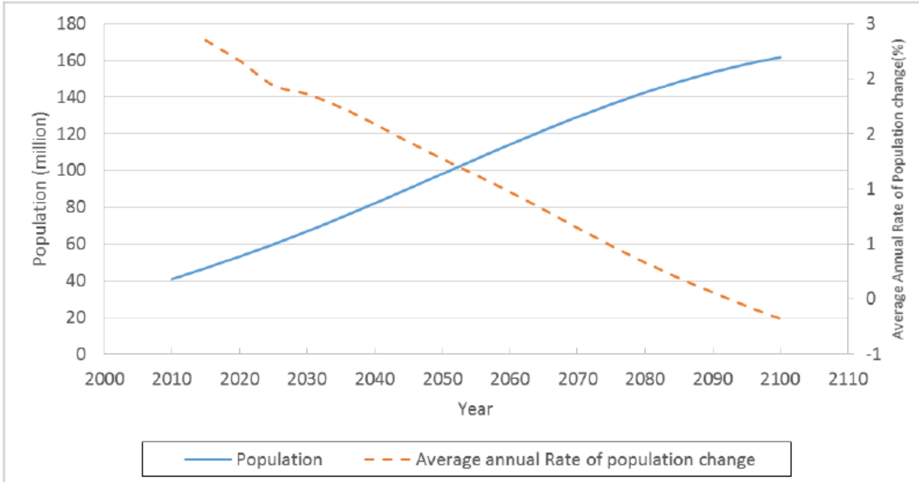

Figure 4: Population and average Annual Rate of Population Change for Zambezi River Basin.

and potential evapotranspiration where, for example, there will be 54% more water available for Zimbabwe, but the water availability per capita will still be reduced by 14%, with population as the dominant factor in the increasing water stress. Although low fertility rates were employed for population changes in the future (see [34]), the results still indicate that water stress is primarily due to population growth and, to a significantly lesser degree, as a result of climate change. The decreases in per capita water availability are twice as high as the basin reductions in water resources predicted under climate change alone. They also report that projected population growth will have approximately twice the impacts of climate change in the Zambezi Basin. Results of water stress show that per capita water availability will decline significantly in the future, with four out of the eight countries in the Zambezi River Basin in "stress" condition (less than 1,700m^3/yr) and one in "extreme scarcity" condition (less than 500m^3/yr) by the end of the 21st century. Increasing populations throughout the Zambezi River Basin are projected to decrease the number of people able to attain access to affordable water, thus increasing the risk of a lower quality of life. Given the combination of projected population growth and the increase from 400 to 600km^3/yr per billion people (from [17]), the population increases are projected to be three times as important as that of climate change, in terms of water stress.

The findings described above indicating that 75% of water scarcity is attributable to population increases, is consistent with the findings of others (e.g. see [8] which indicated that 80% of water scarcity is attributable to population increases, higher food and energy requirements leading to higher water requirements, and economic development.

The findings from the analyses are consistent; population growth has an overall, substantially greater influence than climate change, on water security.

4. SUMMARY THOUGHTS

This last segment of this paper is purposefully not entitled conclusions. Water security needs are clearly profound, but very complicated. Many dimensions will influence the future water security of the planet, with one of these being climate change. While climate change will increase the amount of water movement in the hydrologic cycle, in some regions the implications of climate change, with its impacts on intensification of the hydrologic cycle, lesser rates of infiltration for groundwater replenishment due to increasing rainfall intensities, increased temperatures increasing the evapotranspiration, etc., climate change will introduce major challenges to the nexus of water security.

Nevertheless, while climate change will influence future water security, it would be highly remiss to not recognize the enormous importance of population growth to future water security. Population growth will dramatically increase the need for food and energy, and there will be dietary changes which will involve increased demands for water. The result is that increased water demands for population, energy, food production and dietary preferences in the Zambezi River are estimated as 75% attributable to future water security issues, substantially exceeding the impacts of climate change on water security.

The Zambezi River Basin is the example used in this paper, to demonstrate the importance of population growth (along with the concomitant impacts with respect to food, energy and dietary changes) such that while climate change is important, population growth is of greater importance to future water security. However, the most important message from this paper is that water security is destined to become a crisis throughout the world; we must use water very wisely in the future and identify ways to do more, with less.

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