Chapter

Water Demand and Salinity

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Abstract

The fresh water constitute only 3% of the total water on earth out of which underground water constitute 29 and <1% is in the form of lakes and rivers on the earth surface. Considering the rapidly increasing human population and demand for diverse food items crop production must increase substantially. At the same time arable land and good quality irrigation water resources are being depleted at faster rate particularly in the arid, semi-arid and tropical regions. Over the years the salinization of soil and water has steadily increased due to various causes and the increase in food production has essentially depends on this degrading resources. Since the balance between water demand and water availability has reached critical level in many regions of the world a sustainable approach to water resources and salinity management has become imperative. This chapter highlights global water resources, its demand and supply, salinity and its causes, effect of climate change and its management for sustainable use.

Keywords: water resources, demand, salinity, aquifers, climate change

1. Introduction

Water is the most important resource essential for sustenance of life on earth and drive the economic development of human society. Nearly 97% of the total water on earth is in oceans in the form of saline water and only the remaining 3% is fresh water. Out of this, nearly 70% of fresh water is in the form of ice present in the polar region and higher mountain ranges. Underground water constitutes 27% of fresh water and only <1% is in the form of surface water present in lakes and rivers. Rapid changes in human lifestyle coupled with urbanization and industrialization has created pressure on the limited fresh water resources. Further, the impending climate change has favoured salinization of both land and water across many parts of the world [1].

The projection given by FAO indicated increase of food requirements as a result of burgeoning population by 20% in developed countries and 60% in developing countries. In other words food requirements are increasing quicker than crop production. Hence, there is urgent need to improve alternative agricultural strategies [2, 3]. Among the many reasons affecting agricultural productivity in the tropical region, salinity and associated factors, like waterlogging and/or drought exaggerated by climate change have contributed significantly. The increase in saline areas has been directly attributed to both water and soil salinity problems. In the coastal areas inundation of low-lying areas by sea water and sea water intrusion into the fresh water aquifers contribute to the coastal salinization.

Since the balance between water demand and water availability has reached critical levels in many regions of the world and increased demand for water and food production is likely in the future, a sustainable approach to water resource use and salinity management has become imperative [4]. A number of approaches have been developed to combat the salinity problems and increase the food grain production, based on specific types of site, regional and global problems. This chapter highlights concepts of water resources, its availability, human demand and use of fresh water, the effect of climate change and other factors on salinity and water resources in the future and also discusses the ways to manage this precious natural resource.

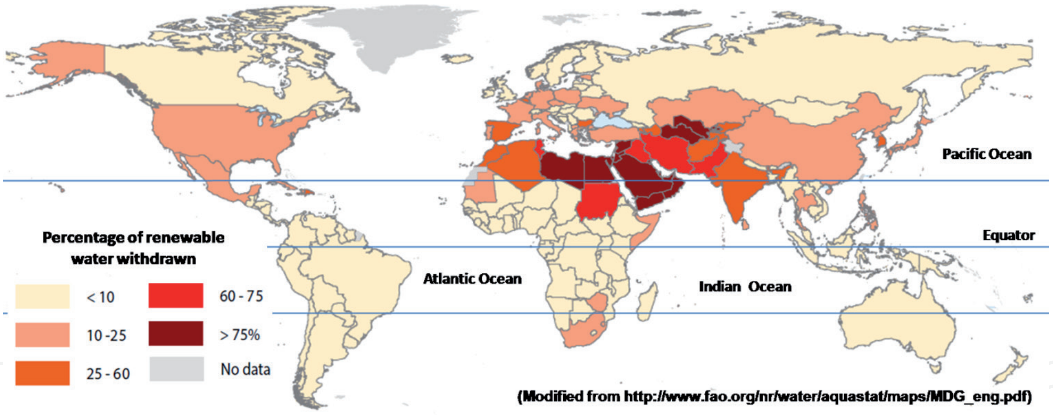
2. Global water resources

The concept of water resources encompasses qualitative socio-economic and environmental dimensions besides its quantitative and physical aspects. The source of all forms of water either directly or indirectly is precipitation, often used interchangeable with total rainfall in literatures. However, with reference to water resources, precipitation is considered as gain, evapotranspiration is viewed as loss and human use including for agriculture is described as demand. When the resources are contaminated by human activities or turned into saline by natural means, the fresh water resources get reduced which intensify the water demand. At the same time part of the rainfall after reaching the ground get evapotranspired or moves to the fresh water resources (surface and ground water).

There are several reports on global total fresh water resources which are estimated with reference to a particular year, and may vary with the progress of time as it is depend on several dynamic components. The total freshwater resources spread across the world are estimated to be in the order of 43,750 km^3 $year^{-1}$. At the continental level on an average America has the largest share of the world's total freshwater resources with 45%, followed by Asia (28%), Europe (16%), and Africa (9%) [5]. Due to uneven distribution of population and water resources, continent wise estimation of water resource per inhabitant showed that America has highest amount with 24,000 m^3 $year^{-1}$ followed by Europe (9300 m^3 $year^{-1}$), Africa (5000 m^3 $year^{-1}$) and Asia (3400 m^3 $year^{-1}$) [6]. At the regional level, tropical humid region has fairly good IPWR per capita due to good amount of annual rainfall and water resources. However at the country level, countries located in the Arabian Gulf and Northern Africa (Morocco, Algeria, Bahrain, Jordan, Kuwait, Libyan Arab Jamahiriya, Maldives, Malta, Qatar, Saudi Arabia, United Arab Emirates and Yemen) are having very low total renewable water resources (TRWR) of 500 m^3 per inhabitant. In terms of internal renewable resources (IRWR), the threshold of 1000 m^3 per inhabitant is considered as water stress, which showed that countries located in North Africa and the Middle East are at the most critical stress level with values ranging from 0 to 1000 m^3 $year^{-1}$ per person.

3. Global water withdrawal

Water is withdrawn from the available resources for various purposes which creates the demand. In other words, to understand the relation between supply and demand, the ratio between water withdrawal by agriculture, municipalities and industries over total renewable water resources is used. This also indicates the level of human pressure on water resources. Arid and semi-arid regions in Asia and Africa have maximum withdrawal of more than 90% of renewable water as given in



(Modified from http://www.fao.org/nr/water/aquastat/maps/MDG_eng.pdf)

Figure 1.
Percentage of renewable water resources withdrawn.

Figure 1. In these areas surface flow is seasonal due to less rainfall. As a consequence this region exploits more ground water resources than other region.

Agriculture accounts for roughly 70% of total freshwater withdrawals globally and for over 90% in the majority of Least Developed Countries (LDCs) [7]. If remedial measures to improve the efficiency are not seriously implemented, by 2050 global agricultural water consumption is projected to increase by about 20%. Globally, some 38% of irrigated areas depend on groundwater [8] which has contributed to a 10-fold increase of groundwater abstraction for agricultural irrigation over the last 50 years. Conversely, almost half of the world's population depends on groundwater for drinking consequently salinization or overexploitation will affect the freshwater availability for domestic purpose.

4. Characterizing salinity

In the context of global water resources, demand and salinity, it is imperative to define salinity as it various in intensity and the severity is different based on the intended purpose. **Salinity** is a measure of the content of salts in soil or water. Salts are highly soluble in surface and groundwater and can be transported with water movement. There are two kinds of salinity viz., primary and secondary salinity.

- **Primary salinity** is produced by natural processes such as weathering of rocks or wind and rain depositing salt over thousands of years. Nevertheless, the distribution of salt deposits in the world natural region is uneven, and the impacts of salinity vary due to different topography and the age of the landscapes.

- **Secondary salinity** occurs due to the accumulation of salt from the primary source. This may be due to extensive land clearing and unjust land use practices. This is mostly observed in the form of 'dryland salinity' or 'irrigation-induced salinity.' Dryland salinity occurs due to the replacement of deep-rooted native plants by shallow-rooted plants having less water requirement. In addition, farmers apply excess irrigation water once the irrigation water is made available to them. Consequently this leads to raising the water table and bringing salt to the surface where it can be left behind as the water evaporates. On the other hand, irrigation-induced salinity occurs when excess water applied to crops travels past the root zone to groundwater, raising the water table and salt to the surface. Salt may also be transported across surface and groundwater systems.

Water class	Electrical conductivity (dS/m)	Salt concentration (mg/l)	Type of water
Non-saline	<0.7	<500	Drinking and irrigation water
Slightly saline	0.7–2	500–1500	Irrigation water
Moderately saline	2–10	1500–7000	Primary drainage water and groundwater
Highly saline	10–25	7000–15,000	Secondary drainage water and groundwater
Very highly saline	25–45	1 5000–35,000	Very saline groundwater
Brine	>45	>45,000	Seawater

Table 1.
Classification of saline waters.

The term salinity used herein refers to the total dissolved concentration of inorganic ions (Na, Ca, Mg, K, HCO_3, SO_4 and Cl) in irrigation, drainage and ground waters. Individual concentrations of these cations and anions in a unit volume of water can be expressed either on a chemical equivalent basis ($mmol_c$/l) or on a mass basis (mg/l). The total salt concentration in water is expressed either in terms of the sum of either the cations or anions ($mmol_c$/l) or the sum of cations plus anions (mg/l). But for analytical convenience, salinity is measured as electrical conductivity (EC) expressed in units of (dS/m) [6]. As the solubility of salt vary at different temperature, EC values are always expressed at a standard temperature of 25°C to enable comparisons. This also helps to back convert EC into total salt concentration which is 1 dS/m = 10 $mmol_c$/l = 700 mg/l. In spite of certain shortcomings, EC is a fair indicator of salinity as plants are mainly sensitive to total salt concentration rather than to the proportions of individual salt constituents. At the same time, for comparison purposes, 'soil salinity', is commonly expressed in terms of the electrical conductivity of an extract of a saturated paste (EC_e; in dS/m) made using a sample of the soil. Normally due to the involvement of different modifying factors rigid water quality classifications are not advised but for the purpose of identifying the levels of water salinities water classification scheme is used.

In terms of total salt concentration, which is the major water quality factor generally limiting the use of waters for crop production and other purposes, water classes are defined (**Table 1**). As per this scheme, only very hardy and tolerant crops can be successfully grown with waters having salinity of 10 dS/m in EC or more. Many drainage waters, including shallow ground waters underlying irrigated lands, fall in the range of 2–10 dS/m in EC. Such waters have good potential for selected crop production with suitable salinity management practices. Reuse of second-generation drainage waters for irrigation in selected locations is sometimes possible particularly for purposes of reducing drainage volume in preparation for ultimate disposal or treatment. Such waters will generally have ECs in the range 10–25 dS/m. Very highly saline waters (25–45 dS/m in EC) and brine (>45 dS/m in EC) are beyond the scope of these guidelines and their uses for crop production are therefore not discussed herein. In summary water having EC more than 10 are not recommended for irrigation and water with EC value <10 are used with suitable salinity management methods.

5. Status of saline land and water

The availability of fresh water for farming is an essential condition for achieving satisfactory and profitable yields, both in terms of unit yields and quality. In coastal regions due to excessive withdrawal of ground water, high evapotranspiration, rise of saline ground water and sea water intrusion pose major challenge. The most common reasons for the increase in salt-affected lands are the mismanagement of irrigated areas. Increase in groundwater pumping results in the intrusion of seawater into the fresh water aquifers. In certain region/islands due to the exhaustion of fresh water aquifers the overlying saline water layers mix with fresh water, resulting in the increase of salinity in the groundwater. In the dry region, high rates of irrigation water application and inadequate or absence of drainage systems has resulted in the movement and deposition of salt on the surface of the soil profile favoured by high evapotranspiration rates. As a result nearly 5–10% of the existing fresh water resources are getting salinized. The critical values of renewable fresh water resources and economic water scarcity and salinization indicate the necessity for regional water use policy and appropriate water management strategies at various levels.

As discussed above the salinity level, both soil and water, has been increasing in many of the regions particularly in the tropics and arid regions though the processes of occurrence of salt affected soils are different. Salinity can be found in different altitudes, from territories below sea level, e.g. the district of the Dead Sea, to mountains rising over 5000 m as the Tibetan Plateau of the Rocky Mountains [9]. Older estimates [10] suggest that 10% of the total arable land is affected by salinity and sodicity, extending over more than 100 countries occupying different proportions of their territory. The description of the types of salt-affected soils, causes of formation and hypothetical salinization cycle has been reported by many researchers [11].

Due to the non-availability of updated information or lack of compilation of regional level assessments the current extent of salt-affected soils are unknown. Based on the FAO/UNESCO Soil Map of the World, Massoud [12] made an estimate of 880 M ha of salt-affected soils of which 36% are in developing countries. These are the potential areas where land can be leased for food production or alternate energy sources using suitable technologies which are currently available. However, Balba [13] gave a global estimate of only 600 M ha as salt-affected soils which included 340 M ha in Asia, 140 M ha in Australia, 60 M ha in South America 30 M ha in Africa, 26 M ha in North America and 1 M ha in Europe. The recent estimate quoted 954.8 M ha of salt-affected soils which is much higher than the previous estimates [14].

Similar to that of soils, the availability of freshwater is a major limiting factor for sustainable agriculture and other developmental activities. In certain regions of the world the water crisis is so severe than the availability of land. Unlike soils, there are several assessments and projection for future water requirements and availability. Global assessment of water availability and projections found decrease in water availability in the developing regions with increasing population pressure [15, 16]. The assessment grouped the water scarcity into physical water scarcity, approaching physical water scarcity and economic water scarcity to understand the water shortage which includes all purpose of water (**Figure 2**). Physical water scarcity means water resource development is approaching or has exceeded sustainable limits. Here water availability is related to water demand which implies that dry areas are not necessarily water scarce. This physical scarcity analysis showed that more than 75% of river flows are withdrawn for agriculture, industry and domestic purposes. In approaching physical water scarcity nearly 60% of river flows are withdrawn and these basins may experience physical water scarcity in the future. The situation may get worsen with more withdrawal to produce more food. Whereas in economic water scarcity even though water in nature is available locally to meet human demands factors such as human, institutional and financial capital limits access to water. The tropical developing region mostly faces the challenges of water scarcity. Economic water scarcity is the major limits for production in sub-Saharan Africa while physical water scarcity limits the production in South Asia.

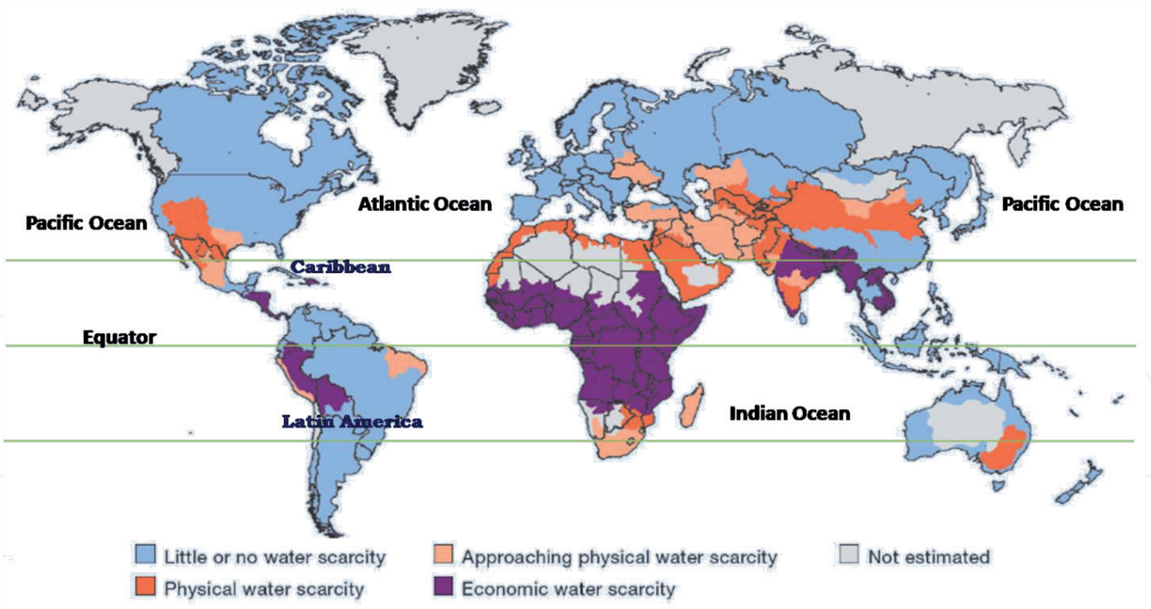


Figure 2.
Areas of physical and economical water scarcity at the basin level in 2007 [16].

In contrast to the crisis, some countries have developed technologies to utilize the saline water. For example, in Israel, farmers carryout crop production with unconventional water resources irrigation and desalination plants have been installed to get fresh water from saline water. In some tropical regions of Asia technologies have been developed to address this issue and we can find agriculture practices based on alternative plant species, most of them are halophytes, which are able to tolerate high temperatures and/or low water availability [17]. Similar attempts are being made in some of the South Asian countries to meet the challenges but in many cases these are at experimental stage.

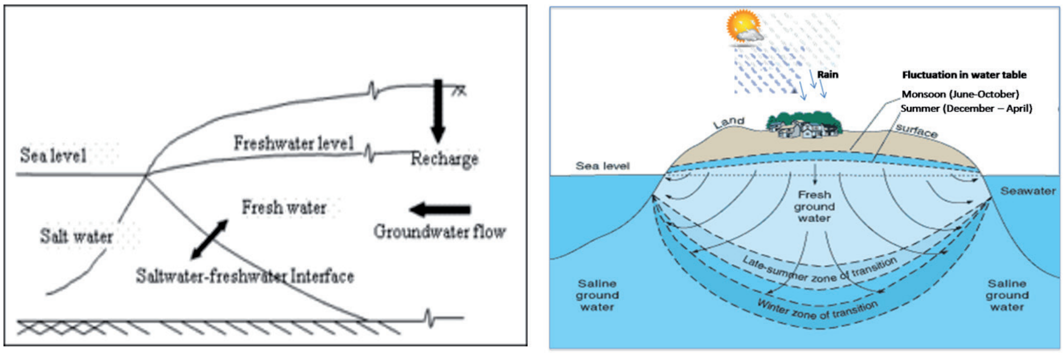
6. Factors affecting aquifer and salinization

6.1 Land subsidence

Large scale withdrawal of ground water (over exploitation), especially from the artesian aquifers can sometimes result in local land subsidence due to compression of the aquifers. Land subsidence poses serious problems to buildings, other structures and affects the equilibrium of freshwater-sea water interface region. Sometimes this causes inundation of low lying areas, resulting in sea water ingress. The subsidence depends on the nature of sub surface formations, their extent, magnitude and duration of the artesian pressure decline.

6.2 Sea water intrusion

This is one of the most serious emerging problems in the coastal regions. When groundwater is pumped out of coastal aquifers which is in hydraulic connection with the sea due to gradients salt water from the sea may flow towards the well (**Figure 3**). There is a dynamic equilibrium in the seawater-fresh water interface which gets disturbed due to over exploitation of ground water or reduced freshwater recharge. This result in movement of salt water into freshwater aquifers under the influence of groundwater development or by over exploitation which is known



Coastal areas Island

Figure 3.
Fresh water-salt water interface.

as seawater intrusion. Sometime there is a propensity to point out the occurrence of any saline water along the coastal zone to sea water intrusion. But there may be many reasons for the occurrence of salinity. In order to avoid mistaken diagnoses of seawater intrusion as evidenced by temporary increases of total dissolved salts, chloride-bicarbonate ratio as a criterion to evaluate the intrusion.

6.3 Upcoming of saline water

This phenomenon occurs due to the local rise of the interface between fresh and saline water. This happens when an aquifer having underlying layer of saline water is pumped by a well penetrating only the upper freshwater portion of the aquifer. This rise in interface layer below the well due to excess removal of water is called upcoming of saline water. Generally the interface lies near horizontal at the start of pumping which rises to progressively higher levels with continued pumping of water until eventually it reaches the well. At that point it necessitates closing of the well because of the degrading influence of the saline water. When pumping is stopped, the denser saline water tends to settle downward and to return to its former position. In such areas, the rainwater tend to float over saline water as a thin lens and in such conditions the saline water rises by 40 units for every unit of the fresh water withdrawn. Because of this very fragile ground water system of small islands the fresh water needs to be skimmed to prevent upcoming.

6.4 Geogenic salinity

This kind of salinity is a common water quality problem observed in the coastal aquifers. In these aquifers, the salinity is caused because of leaching of salts in the aquifer material. In certain areas the formation water gets freshened regularly due to the leaching effect. This happens mostly for the water soluble salts only.

6.5 Sea level rise (SLR)

The observed and projected increase in mean sea level due to global warming poses a serious threat to the coastal aquifers particularly located in the small islands. The projected SLR will drive the fresh water-seawater interface more towards inland along coastal aquifers and consequently submerge the lowlying areas with saline sea water. This will result in direct salinization of shallow coastal aquifers. Water resources of the small islands located in the tropical region (Indian Ocean and Polynesian islands) will be significantly affected by the rise in sea level and with the change in rainfall pattern the negative effect will be even greater.

7. Climate change and future water demand

Water has become a scarce natural commodity due to its declining availability and increase in demand for various purposes. This has created huge pressure on the available fresh water resources around the globe. Several reports state that the magnitude of stress on water resources is expected to increase as a consequence of climate change, population growth, economic development and land-use change including urbanization [18]. In consequence several studies were carried out focusing on the assessment of global water demand and its availability. In reality water demand has reached critical levels in several parts of the world, particularly in countries with very limited water availability. Many researchers have concluded that besides climate change, misuse of water, over exploitation and limited infrastructures for water supply are the major reasons for water scarcity.

Globally water consumption for all sectors amounts to 9% of total freshwater resources in the world with agriculture being the largest user, in turn accounting for approximately 70% of total water withdrawals which is equivalent to 2700 km^3 $year^{-1}$ [19]. Agricultural sector receives up to two-thirds of the total water withdrawals and accounts for almost 90% of the total water consumption in the world [5]. As more than 80% of global agricultural land is rainfed water demand is met mostly from the green water resource [16]. In Asia, Africa, Central and South America, the values for specific water withdrawal range from 50 to 100% which experiences great diversity in climatic conditions. Irrigation water withdrawals range between 96 km^3 in Sub-Saharan Africa and 708 km^3 in East Asia; the highest values for specific water withdrawal are observed in South Asia, with 913 km^3 [20].

Analysis of factors affecting water supply and demand indicated that the water demand will be influenced by population growth, industrial development and

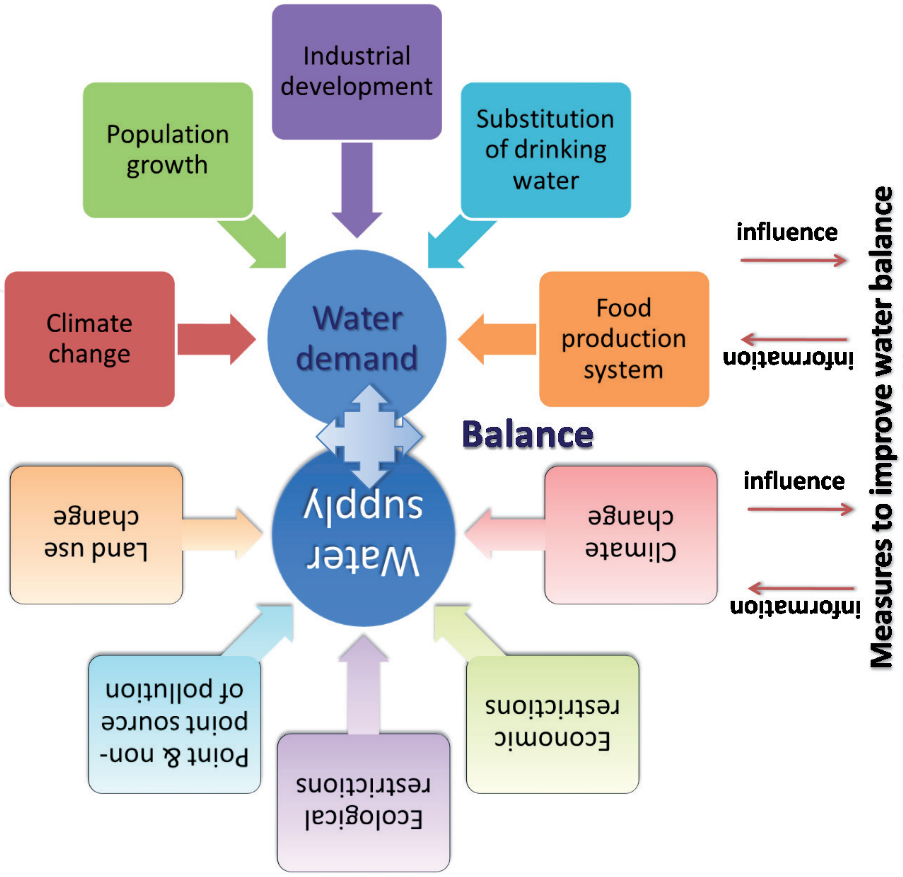


Figure 4.
Driving forces of future water supply and demand (modified from Hornbogen and Schultz [21]).

food production besides climate change. At the same time the water supply will be decided by land use change, ecological and economic restriction, pollution besides climate change (**Figure 4**). The balance between these two will decide the fresh water availability [21]. The future global water situation and development until 2025 was analysed with different scenarios. Under the business as usual scenario the present contrast in water situation between industrialized and developing countries is likely to continue in the future. Withdrawal of water from the available resources in most of the industrialized countries is projected to decline or will remain at the present level due to technological and efficient water management. Consequently the pressure on available freshwater resources will decline. In contrast withdrawal will continue to grow in developing countries due to urbanization and industrialization. Further, the push for development will also be expected to increase the salinity level. This will increase the pressure on the available freshwater resources by increasing severe water stress area from 36.4 to 38.6 million km^2. The increase will be significant in Southern Africa, Western Africa and South Asia which will be a limiting factor in the future for industrial and agricultural growth due to competition for water [15]. On an average globally 40% water deficit will be experienced by 2030 under a business-as-usual scenario.

8. Conclusions

In spite of efforts by various stakeholders and global level organizations, lots of gap still persists in our understanding of the global water resources and the emerging salinity problems. Meanwhile there are several disputes in utilizing and sharing this precious resource. Human activities have rendered water unusable at several places due to pollution, salinity and over exploitation. There should be proper regulations and monitoring which involve measures like precaution/prevention; control/restriction and remedial/restoration measures. Efforts should be made to study sea-level rise and sea water intrusion. In summary, the available information suggests that water security and the salinity will remain a challenge for many tropical countries today and in the future until suitable remedial measures are implemented and relevant technologies are developed.

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