Water Resources, Water Quality and Human Health in Regions of Extreme Stress: Middle East
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Abstract

Water is the most important natural resource in the Arab World and will only become more important in the future. Water demand generally rises in conjunction with population increase and economic growth. Water shortage and scarcity will add a layer of political uncertainty in the region and potential conflicts may appear in several countries and may expand to more countries that share the same water source or groundwater aquifer. The symptoms and influences of climate change in the Arab region have been expressed in extreme harsh environments affecting all components and levels of societies and economies. Elevated poverty, food and water scarcity, migration and instability, flooding and catastrophes, diseases and mortality, are all real examples. This review aims to summarize the multi-disciplinary issues of the water crisis in the Arab World; to review the recent available data and information describing the status of water in the region; to highlight the urgency for synergy and integration in all scales and levels; and to propose scientific and affordable mitigation measures and solutions for the survival of the existing and coming generations.

Keywords: Water; Climate change; Food security; Poverty; Health; Conflict

Water as an Important Resource

Water always has been the key element of life on Planet Earth, and it always will be. It is the top priority for all cultures, religions, civilizations and social communities. Water influences every aspect of human life and plays a key role in every nation’s progress. Water availability and water quality have a direct relationship with the food system and nutrition, urban development and expansion, financial livelihood, and community health and hygiene [1].

The limited natural resources are experiencing growing scarcity, depletion and outright disappearance in several parts of the earth. Loss of land quality and pollution resulting from population pressures, urbanization, industrialization and economic expansion present a threat to the continued function of the earth’s surface, particularly in arid, semi-arid and tropical regions where a long history of chemical decomposition of rocks has made the land surface environment especially vulnerable [2].

A very complex reality emerges when we realize that seven billion people rely on the incredibly limited fresh water resource that is not unavailable due to its permanent location in the ground or atmosphere. This available fresh water accounts for 1% of all fresh water and is distributed disproportionately throughout the globe. The varying spatial distribution of fresh water, resulting from multifaceted systems of rainfall in space and time, fundamentally impacts the ecosystems and infrastructures on which the livelihood of humans rely [3]. Consequently, water and sanitation are now treasured as fundamental human rights. In spite of continuous efforts by the United Nations, 884 million people do not have reliable access to clean water and 2.6 billion lack basic sanitation [4].

As a moving resource, water links mountains to lowlands and urban populations to rural upland dwellers. Its management brings to light the strengths and weaknesses of governing systems at all levels and the relationships between nations that share water resources [1].

Water is a key element for political stability. Conflicts and even wars over water rights and allocation have happened in the past and could still potentially occur in many areas. The Middle East and the Nile Basin are good examples of water volatile regions.

Water can serve as a good medium for engaging citizens in participatory planning and governance around watershed protection and water management, encouraging greater transparency of local and national institutions, and promoting more equitable access to water and related services. Financing water-related infrastructure is a way to develop innovative, pro-poor and more sophisticated financial markets [1].

Although current global withdrawals are less than the resources available, a substantial number of people (more than two billion) live in water-stressed regions due to the disproportional allocation of renewable freshwater [5].

The developing world is most impacted by issues relating to water supply and contamination, with some of the most severe aquifer reduction occurring in the Middle East, South Asia and North Africa. However, these issues are not limited to the developing world and are problems also faced by high-income countries. Many developed cities face these problems due to an old and decaying water infrastructure that withdraws groundwater at unsustainable rates [4].

Water stress is as old as time, but in the past water scarcity found relief through import/export commerce. However this solution may soon cease to exist, a recent report of McKinsey and Company [6] found that within two decades, collective water demands will exceed expected supply by 40%. That shortage will drive up food prices, disrupt energy, constrict trade, create refugees and undermine authorities. Consequently, the term “Water-Food-Energy Nexus” has recently become current-mainly as a policy tool-to integrate these elements. Water infuses not only our ground beef patty, lettuce, cheese,
populations have been enriched by a combination of global trends. These trends include food price instability, increase in the number and severity of weather-related disasters, and an escalation of existing political conflicts. In 2007 and 2008, the number of hungry citizens increased by more than 115 million worldwide as a direct consequence of the increase in food and fuel prices throughout the globe. The World Bank estimated that between June 2010 and February 2011 an additional 44 million people were added to the list of those living in extreme poverty [10].

Water and Climate Change

Water changes with the climate and changing the elements of the water cycle may directly and indirectly affect the climate. According to Allan [13] a change in rainfall intensity due to increased atmospheric concentrations of anthropogenic greenhouse gases may increase the risk of damage from flooding.

The climate system puts a cap on the circulation rate of available freshwater resources. Water, a naturally circulating resource, is continuously recharged. For this reason the cycle of water should be the primary emphasis in water resources assessments even though the water reserves in natural and artificial reservoirs help to increase available water resources for human society. The global hydrological fluxes according to Oki and Kanae [6] are shown in Figure 1.

The issue of how the hydrological cycle will change as the climate changes is complicated. However, with warming, the main prospect is for the atmosphere’s water holding capacity to increase and for an associated increase in water vapor [11]. The changes directly impact soil moisture and runoff, and make both floods and droughts more likely. Global changes to the climate have increased the frequency and the intensity of natural disasters that rare floods and droughts are now more consistent. International agencies declared the drought occurring in the Horn of Africa in 2011 as the worst in 60 years. Super-storm Sandy that recently slammed into New York and a number of other

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**Figure 1:** Global hydrological fluxes (1000 km3/year) and storages (1000 km3) with natural and anthropogenic cycles are synthesized from various sources.
states along the east coast of the US cause what is said to be a 100 year flood, the second in two years (citation).

Climate models are typically limited by their resolution to adequately represent processes at the level of cloud formation. This results in inconsistency in models of the relationship between rainfall extremes and warming in the tropics [14,15]. Intense rainfall is intrinsically local, but is driven by atmospheric moisture from further locations that might have contributed to more moderate rainfall in another place. Therefore, rapid increases in precipitation intensity in one region may result in a decrease in other regions [16].

On the other hand, according to [5], water cycles are expected to be accelerated by climate change. This would decrease the rate in which the number of people living under water stress; however, it is important to keep in mind the changes to seasonal weather patterns and the increased likelihood of extreme events may offset this effect. Preparation efforts should focus on reducing current vulnerability.

This vulnerability can be seen by current stresses on the climate system and the impact on the earth’s land surface. The impact includes rising surface temperatures, increasing frequency of flooding and drought, changes in natural ecosystems and pole-ward shifts in the distribution of several species.

Climate change may affect all components of any ecosystem including living organisms [17-19] estimated the consequences of climate change on the phylogenetic varieties of plant, bird and mammal groups across Europe. The study concluded that the vulnerability of species to climate change clusters weakly across phylogenies. Such a phylogenetic signal in species vulnerabilities does not lead to higher loss of evolutionary history than expected with a model of random extinctions. This is because vulnerable species have neither fewer nor closer relatives than the remaining clades. Reductions in phylogenetic diversity will be greater in southern Europe, and gains are expected in regions of high latitude or altitude. However, losses will not be offset by gains and the tree of life faces a trend towards homogenization across the continent. Similar studies are almost absent in the developing countries with minimal case studies on the regional and global scale interactions. What is evident is that unusual weather and climate extremes can have devastating consequences not only on humanity but also on the environment and other species [20,21].

Planting modified crops which are drought-resistant could allow farmers to use less water and fertilizer. If poor countries are unable to effectively exploit the use of genetically modified crops, vulnerable populations could be more at risk. Developing countries, especially in Africa, must look to adopting technologies that enable them to produce a higher quantity and quality food with less input of resources in order to survive the droughts, wars and other major causes of famine [10]. Indeed, without the scientific advances that occurred in the latter half of the twentieth century, the poor nations would be in a much more difficult situation than they are now [10]. The technologies utilized during the Green Revolution enabled developing nations to import cheaper grains and grow high-yield seed varieties. The crop technologies prevented crop yields in developing countries from being 23.5% lower and prices between 35% and 66% higher in 2000 then would have occurred without the Green Revolution. Caloric intake would have been 14.4% less, and the number of malnourished children would have been nearly 8% more. In other words, the Green Revolution improved the nutritional status of up to 42 million preschool children in developing countries [22]. These tools assisted poor nations in the last century, but were inadequate to prepare the agricultural system for anticipated difficulties caused by rising populations and loss of land productivity due to ecological disruptions from environmental degradation and frequent droughts [10].

The health of human societies cannot be separated from all others. Climatic conditions affect human well-being both directly and indirectly. The direct impacts such as the physical effects of climatic extremes such as temperature and indirect impacts such as their influence on air pollutant concentrations, agricultural, marine and freshwater systems, and on infectious diseases vectors and pathogens have been frequently experienced [23].

Infectious disease occurrence varies seasonally which implies an association with climatic factors. However, this is not sufficient to prove a causal link between infectious disease and climate. To do these non-climatic factors must be considered and data must span numerous seasons and account for seasonal fluctuations [23].

The interaction between major types of global environmental change, including climate change, and human health is shown in Figure 2. There are suggestions that anthropogenic sources of global warming inducing agents may cause increases in heavy precipitation due to the exponential increase in atmospheric water-holding capacity with temperature [24,16]. The current models underestimate observation based increases in heavy precipitation with warming and, thus, underestimate potential future impacts [3]. There are high spatial variability in precipitation and sparse observation networks in many regions causing uncertainties in the estimates of area means of extreme precipitation [25].

Although drought is seen by many as the problem of most concern due to climate change, the attention it receives is lacking [26]. Extreme widespread droughts will occur simultaneously with sea level rise and salt-water intrusion threatening some of the lushest agricultural regions in the world. Meanwhile, ocean acidification, warming and overfishing may severely deplete the food available from the sea. According to Romm [26], the result of anthropogenic global warming that will affect the most people the near future is extended or permanent drought over large parts of currently habitable or arable land. This is a potentially irreversible drastic change in climate that will threaten food security as precipitation patterns are expected to shift, and will expand the dry subtropics. Precipitation pattern changes will likely result in extreme quantities which is only cause runoff rather than alleviate drought. Expected land warming will cause greater evaporation, drying the land. Once the ground is dry, the Sun’s energy goes into the soil, leading to a further increase in air temperature [26].

Deterioration of Water Quality Associated with Deterioration of Human Health

Environmental quality, including water quality, and human health have an intricate link. The future of risk management will primarily focus on quantitatively smaller risks impacting larger population groups. A shift from simply preventing disease to understanding the inter-relatedness of impacts on human health while sustaining human physical and mental well-being will occur in the realm of public health and its related sciences [27].

Water infrastructure in several regions in the world is flawed in such ways as to contaminate the water supply. Some nations like Pakistan and Bangladesh have about 70% of residents connected to a water supply but it is estimated that less than 20% are connected to a water
supply that is reliably free from chemical or sewage contamination. Contaminated drinking water carries with it the single biggest concern of diarrhea which kills more than 4,000 children below the age of five every day. Children are an especially vulnerable population and exposure to contaminated water results in a number of health burdens. According to the notes of [4], the global burden of diarrheal and respiratory disease could be reduced by 25-50% through the simple practice of regular hand washing. Such a reduction in disease burden would significantly reduce mortality, especially among the under five years old children.

Palestine is a clear example of the link between water scarcity, water contamination and health impacts. The comprehensive studies of [28, 29] summarized and described all components of the health sector in the Palestinian territories. Their studies concluded that international efforts should focus on prevention of modifiable causes of insecurity, reinvigoration of international norms, support of Palestinian social resilience and institutions that protect them from threats, and that a political solution is needed to improve human security in the occupied Palestinian territories. Political solutions that improve Palestinian security will simultaneously reduce threats to physical, mental, and social health. Some human-security threats can be mitigated by technical health-sector solutions such as production of clean drinking water and sanitation infrastructure. However, most threats require solutions extending beyond the scope of the health and environmental sectors to solutions involving social and political aspects. Social solutions should focus to strengthen social networks as sources of resilience and the capacity of the public and environmental health sector to provide support. Political solutions should address and reduce the threats posed by water and environmental contamination, weapons, destruction of homes, torture, humiliation, and restrictions on movement and on the economy. The political solution to the Palestinian conflict could integrate health through the identification and communication between human security threats and health conditions [28].

The failure to develop strategies to mitigate emerging or re-emerging infectious diseases in this context probably stems from ignorance and financial considerations. Reliable analysis of environmental and societal health risks is essential for their prevention and control, which depend on evidence-based guidance for health policy and planning. It is also crucial to optimize integrated surveillance systems to allow timely responses to public-health threats [30].

Water: Challenges of Scientific Research and Policy

Water is vital to all life and should be treated with great care. The scientific world is vastly important for framing the setting for effective water policies that ensure sustainability, efficiency and equity in access and use of the scarce water resources available to Arab states [31]. The linkage between science and policy can make a significant contribution in improving both water governance “as a process” of decision-making and power sharing and water management “as a result of that process” [32].

The United Nations Educational, Scientific and Cultural Organization (UNESCO) Institute of Statistics have reported the Arab world to be severely lacking in science and technology, especially when compared to other developing countries and the developed world [33]. The inadequate research system in the Arab region includes a lack of water research and scientific innovation.

Research is needed within the framework of global understanding, regional cooperation and local actions. Ranking national needs based on what is available should include how to protect the available resources, how to increase their quality and improve their quality, and how to plan future scenarios based on the different variables.

Given the unstable situation of the water sector in the Arab region, including Palestine, the region should have become, in theory, water “Silicon Valley”, becoming a hub for and leading the way in cutting-edge water science, innovative solutions, and new pathways to address the region’s water challenges. However, this has not been seen in the
current research efforts. Despite some progress, the regional overall knowledge index remains one of the lowest in the world [34]. As a result, demand for water research is not yet a systematic component of the water policy approach even among government agencies that provide funding to research organizations [31]. Underfunded, understaffed, and poorly performing research organizations continue to dominate the regional water research landscape with only a few bright research efforts [35].

Research on water sciences is still limited on scale and topic depending on priorities of each government of several developing countries. Many governments in developing nations have acknowledged the lack of quality research organizations and their important roles in water resource management plans. This has led the governments to seek outside consultant expertise due to the weak vigor of the region’s water departments at national universities and research centers. The high demand for key water policy documents by policymakers combined with the weak state of water research centers make the debate on linking water research to policy a top priority.

In the research world seniority plays an important role for funding and support and, as a result, young researchers are having difficulty bringing their own research ideas to fruition. Although the generation of scientific understanding is an exercise in rational thinking and objective analysis, the behavior of stakeholders in many regions of the Arab world is far more driven by existing power structures. Consequently, scientific knowledge alone is not sufficient to enable sustainable development [31]. A study by Taylor et al. [35] revealed that water research organizations in the Middle East and North Africa (MENA) region are faced with the following constraints:

a) Lack of a critical mass of competent researchers in the region due to inadequate education structures, compelling career opportunities, and limited partnership with international research communities and professional growth opportunities.

b) Ineffective management and leadership in research organizations.

c) Limited networking between researchers and policy communities.

d) Lack of an internal research strategy and agenda for actions.

e) Inexperience water managers and professionals who are unable to adopt practices that serve water sustainability, such as rainwater harvesting.

According to the recommendations of Laamrani et al. [31], research can contribute to better governance of water resources in at least three ways: i) by encouraging open inquiry and debate, ii) by empowering people with the knowledge to hold governments accountable, and iii) by enlarging the array of policy options and solutions available to the policy process. The study concluded that the region has technical competences in the water sector on an individual level but that there is a current gap between institutionalization of science and innovation. Consequently, the intention is to shed some light on how research and policy in the Arab region, including Palestine, can mutually guide and feed each other to work in harmony.

**Water and environment in Palestine: past and present**

This section describes and reviews the major findings of more than 15 years of research on water and environment in Palestine concentrating on the Gaza Strip. All governments and societies face the issue of environmental protection. The environment in Palestine, both natural and infrastructure, suffers from considerable stresses. Occupation, the shortage and pollution of resources, high population growth and insufficient job opportunities, have resulted in many environmental hazards. Inadequate water quantity and quality limit the economic development of Palestine. Israeli security pretexts and frequent closures of Palestinian territories cause disruption of economic and municipal activities and aggravate the existing pollution throughout Palestine. Additionally, the effects of global climate change on the Gaza Strip extend beyond water to affect soil, agriculture, and seashores. Disease outbreaks in hospital archives reveal large increases in diseases linked to water scarcity, sanitation, chemical and microbial contamination. For more than a century the Gaza Strip, along with the historic Palestinian, has been considered a particularly volatile area, both politically and environmentally [36]. It remains a theatre for wars and conflicts, as well as a thoroughfare for invasions between west and east. Due to its location as a crossroads, the area has carried an extra load of geopolitical changes remained concerns to many.

The Gaza Strip has only one source of water for the population and it is a groundwater. Therefore contamination of the groundwater can have catastrophic consequences. The threatening contamination is primarily caused by the aquifer’s susceptibility to surface-derived contamination due to the high permeability of sands and gravels in the area.

The coastal aquifer is the primary drinking water source for up to 1.5 million people in Gaza. This aquifer is currently contaminated and is also not recharging adequately. Over time it might replenish, allowing it once again to become a significant source of water irrespective of its quality. Yet for this to become a reality, a stable peace with Israel, a stable Palestinian government, and the political will to adapt new technologies and governance structures for sustainable water and sanitation systems. Until then Gazans will continue to be deprived of this basic necessity essential to good health and high quality of life and to life itself [37]. Based on long term-research in the Middle East, Figure 3 summarizes the general framework of research on water issues.

Because of the water needs of the growing population, the recent drought, and the lack of alternative natural water sources, desalination of seawater are some of the options for water self-sufficiency in Gaza as well as in several countries of the Middle East.

**Water and Soil**

Soil is strongly linked to the availability of water; when water is limited, dust storms disrupt the limited soil. The general interactions between soil and surrounding environmental elements are shown in Figure 4. Soil is fundamental to the Earth’s ‘critical zone,’ the thin surface between the tree canopy and the aquifers. Additionally, soil organisms create particles that bind with decaying biomass and living microbes to form larger aggregates [38]. According to the recommendation of Banwart [38], research collaboration is required to manage the planet’s threatened soil resources for food production and much more.

Much of the current research aims at intensifying agricultural systems for a growing, hungry world. These research aims have largely ignored the question of how soils will cope with pressure due to population demand and abused intensified uses. Our planet’s soils are under threat, as witnessed in the past decade by dust-bowl conditions in northwest China, the desertification of grasslands in Inner Mongolia and massive dust storms across north-central Africa. Soil losses in some locations around the world exceed of 50 tons per hectare annually, up
to 100 times faster than the rate of soil formation [39]. These figures bring to light the fact with we are losing up to half a centimeter of this resource per year [38].

It is necessary to prioritize attention on the actions and research needs necessary to overcoming the key constraints to wastewater treatment and reuse in Arab countries.

Global growth in human population and wealth brings with it an expected 50% increase in food demand by 2030 and a doubling by 2050. This will require a major intensification of agricultural production [39]. Scientists need to develop a predictive framework for soil loss and degradation to systematically evaluate and implement potential solutions [38].

At least 60% (by mass) of fertile soil consists of particulates sized 0.25-10 mm. These aggregates provide a good balance of mineral and organic nutrients which are processed by microbes into forms useful for plants. The pores within and between soil aggregates retain sufficient moisture for biological growth, facilitate drainage and allow oxygen to reach plant roots [38]. The desertification scale of the world is shown in Figure 5.

A global network of research field sites, Critical Zone Observatories, has been established in the past four years. Multidisciplinary teams focus on the fundamentals of soil production and degradation, and aim to create quantitative, predictive models. This program has enormous potential. It can and should be accelerated, with stronger collaboration between national programs and strong links to policy-makers [38].

Soil does far more than support farming and forestry. It stores carbon, filters water, transforms nutrients and sustains biodiversity [40]. It is unclear how these essential roles will respond to agricultural intensification and other human-driven changes, and how they might be enhanced in tandem with farming or how this will affect humanity.

Recent studies on soil/water interaction highlighted hot topics to be investigated. The recent study of Braudeau [41] showed oil to be present at all organization scales of the natural environment; from soil aggregates and water at the micro scale within the soil, which is represented by a pedon at a local place in the field, to agro- or eco-systems at the watershed scale (Figure 6). To each scale of organization, there is a corresponding mapping work leading to specific geographic information system (GIS) and data base. At the same time, water is present everywhere in the environment. However, for modeling, we have to make a distinction between what we call “free water”, or water in its liquid state, of which the principal driving force is gravity; and on the other hand, “thermodynamic water” is linked in energetic
equilibrium with other basic components of the local environment (solid particles and air) [41].

According to Braude [41], the problem is how to model the water cycle in the environment based on these two states of water as well as through the natural multi-scaled organization (Figure 6). In contrast to free water, which is well known and modelled by hydrologists, the thermodynamic aspect of water is poorly known, especially in the soil medium. This is an issue because water in soil is mainly in equilibrium and cannot be neglected because of its direct

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**Figure 5:** World Atlas of Desertification.

**Figure 6:** Scales of organization of the natural environment.
link to the climatic conditions for life, in soil and in air above the soil [41]. The soil medium is differentiated into horizontal layers, called soil horizons that have different structures, each of them characterized by their hydro-structural properties (Figure 7). These horizons, and their characteristic structure, result from the pedo-climate regime which is the direct product of two water cycles; one is the free water cycle, coming from the soil surface (rainfall) and going down by gravity, and the other is the thermodynamic water cycle, linked to the medium and going up through the continuum soil-plant- atmosphere [41].

Possible Solutions of Water Problems

General overview: treated wastewater as a promising solution

In many Arab countries, including Palestine, limited water resources pose severe constraints on economic and social development and threaten the livelihood of people [42]. Available surface water is declining and the over-exploitation of groundwater beyond natural recharge rates has lowered the water table and caused an increase in groundwater salinity, groundwater depletion, and ecological degradation [42]. In the last 30 years the countries of the region have witnessed water scarcity and deteriorated quality resulting in increased water stress. This looming crisis has prompted many governments to seek a more efficient use of water resources and to develop interventions that narrow the gap between supply and demand in the region [43].

One potential intervention strategy is to develop the nonconventional water resources, such as municipal wastewater. In most Arab countries, the agricultural system consumes the majority of the water resources, accounting for approximately 80% of the total water supply [44]. Therefore the extended reuse of reclaimed (treated) wastewater for irrigation and other purposes could contribute considerably to the reduction of ‘water stress’ and ‘water scarcity’ in the Arab countries as part of an Integrated Water Resources Management (IWRM) approach [45]. The greatest potential for water conservation may be through wastewater reuse for irrigation, as an alternative to traditional ground and surface water sources [44].

However there are economic, institutional, health, environmental, cultural and religious concerns that deter the sustainable and safe re-use and recycling of wastewater. Addressing these constraints will require support and dedication at all levels of governments, and from local, regional and international organizations to increase both the volume of wastewater treated and the proportion of treated wastewater that is reused. The threats caused by water scarcity and the need for protecting the environment and natural resources have already influenced many Arab countries to introduce wastewater treatment and reuse as an additional water resource in their national water resource management plans, but there is still substantial need to extend the scope of this practice [43].

Wastewater reuse: facts and figures

The Arab population in 2008 stood at about 343.8 million, with 55% located in urban areas. These populations produced around 10 billion m$^3$ of wastewater. The infrastructure of wastewater management (collection, treatment and disposal) is still very weak in most areas. The average coverage of the sewerage system is between 30 to 40% with some rural areas having no access to sewage systems that feed into treatment plants [42]. Consequently the relevant authorities are urged to devote serious effort and clear commitment to promoting the reuse of treated wastewater as an integral part of their water resources management [46]. Several projects in the Arab region have demonstrated that reuse of treated wastewater might be economically feasible and environmentally justifiable for industry, recreational areas, golf courses and forestry. These applications could increase the percentage of reused wastewater above what is used for agriculture and contribute to increasing the efficiency of water use at the national level [47]. To increase water availability, policy and decision makers should consider wastewater reuse as an integral component in the national water strategic plan [43]. The following Table 1 summarizes total water withdrawal; raw wastewater and treated wastewater in the different Arab countries.

Regional concerns, health impacts and environmental safety

While health aspects related to wastewater reuse in the region are the top priority, other areas of concerns such as culture, religion and economy must be addressed. According to Fatta et al. [48], the reuse of treated wastewater is hampered by concerns for human health and the
that have been irrigated with treated wastewater, which was attributed to water losses, salt levels in soil have tended to increase in some areas due to soil salinization, and phyto-toxicity [51]. Based on high evaporation rates and suspended solids in treated wastewater resulting in poor infiltration, fertility and productivity resulting soil clogging due to high content of salinity in the wastewater plant effluent.

In coastal cities, which discharge high loads of salt leading to increased additional burden on the quality of treated wastewater (ultimately to be diluted with untreated industrial streams into the sewage network causes an overloading and to lack of adequately trained staff without technical and practical skills in operation and maintenance [36].

Irrigation with inadequately treated wastewater poses serious public health risks, as wastewater is a major source of excreted pathogens, bacteria, viruses, protozoa, and helminthes (worms) that can cause gastro-intestinal infections in people. People can become sick when eating polluted food crops and farmers, in direct contact with wastewater and contaminated soil, are also at risk [49].

The concern over reusing treated wastewater not only involves treatment infrastructure and technology but includes the quality of the influents [50].

There is no separation between domestic, industrial, and medical wastes; all are combined and meet in the same treatment plant. Generally, wastewater in the Arab region is increasingly loaded with further potentially harmful substances that must be removed prior to wastewater reuse. These contaminants include heavy metals, trace pollutants including organic and inorganic compounds, and emerging contaminants such as pharmaceutical substances. The discharge of untreated industrial streams into the sewage network causes an additional burden on the quality of treated wastewater (ultimately to be reused in agriculture). This is the case of the fishery industries in several coastal cities, which discharge high loads of salt leading to increased salinity in the wastewater plant effluent.

In terms of environmental safety, unregulated irrigation with wastewater may lead to problems such as deterioration in soil structure, fertility and productivity resulting soil clogging due to high content of suspended solids in treated wastewater resulting in poor infiltration, soil salinization, and phyto-toxicity [51]. Based on high evaporation and water losses, salt levels in soil have tended to increase in some areas that have been irrigated with treated wastewater, which was attributed to the increased salinity of wastewater discharge and ineffective on-farm management [49]. Higher salinity limits the crops which can be irrigated with treated wastewater.

Potential environmental impacts from the reuse of wastewater in agriculture may also include groundwater and surface water contamination as well as degradation to natural habitat and ecosystems. In some countries (e.g. Tunisia), the main environmental quality constraint to the reuse of wastewater is the excess of nitrogen [52].

Table 1: Water withdrawal, untreated and treated wastewater in the different Arab countries.

<table>
<thead>
<tr>
<th>Country</th>
<th>Total water withdrawal (10^9 m³/year)</th>
<th>Total wastewater produced (10^9 m³/year)</th>
<th>Volume of treated wastewater (10^9 m³/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algeria</td>
<td>6.070 (2000)</td>
<td>0.8200 (2002)</td>
<td>-</td>
</tr>
<tr>
<td>Bahrain</td>
<td>0.357 (2003)</td>
<td>0.0449 (1991)</td>
<td>0.0619 (2005)</td>
</tr>
<tr>
<td>Comoros</td>
<td>0.010 (1999)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Djibouti</td>
<td>0.019 (2000)</td>
<td>-</td>
<td>0.000 (2000)</td>
</tr>
<tr>
<td>Iraq</td>
<td>66.000 (2000)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jordan</td>
<td>0.941 (2005)</td>
<td>0.0820 (2000)</td>
<td>0.1074 (2005)</td>
</tr>
<tr>
<td>Kuwait</td>
<td>0.913 (2002)</td>
<td>0.2440 (2003)</td>
<td>0.2500 (2005)</td>
</tr>
<tr>
<td>Lebanon</td>
<td>1.310 (2005)</td>
<td>0.3100 (2001)</td>
<td>0.0040 (2006)</td>
</tr>
<tr>
<td>Mauritania</td>
<td>1.700 (2000)</td>
<td>-</td>
<td>0.0007 (1998)</td>
</tr>
<tr>
<td>Qatar</td>
<td>0.444 (2005)</td>
<td>0.0550 (2005)</td>
<td>0.0580 (2006)</td>
</tr>
<tr>
<td>Sudan</td>
<td>37.320 (2000)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Palestine</td>
<td>0.418 (2005)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Potential environmental impacts from the reuse of wastewater in agriculture may also include groundwater and surface water contamination as well as degradation to natural habitat and ecosystems. In some countries (e.g. Tunisia), the main environmental quality constraint to the reuse of wastewater is the excess of nitrogen [52].

So far, different Arab countries have employed different regulatory approaches and standards to manage the reuse of treated wastewater and sludge. In this context, it is important to comply with the framework criteria given in the WHO guidelines as local comprehensive ones for the safe use of wastewater. To be relevant and responsive, the WHO guidelines need to be adapted to conditions local to each country. In fact, different levels of accepted quality standards will give incentives for improvement in wastewater quality over time. Viable options based on different treatment levels and different end-uses of wastewater (including food and non-food crops, landscaping, or groundwater recharge) should be assessed in order to define the parameters for social acceptance in the region.

Water scarcity, socio-economy, finance, technical issues and political uncertainty in some areas play important roles on the implementation and setup of norms and guidelines of wastewater reuse [53].

Besides mandatory requirements, it is recommended to establish codes of best practice for the use of wastewater in different countries for various applications. The codes of best practice should contain certain provisions for not impairing the quality of groundwater, for the prevention of leaching from storage, and for the selection of application periods in terms of weather conditions. Best practice should also include selection criteria for crops and for appropriate irrigation methods. The choice of wastewater irrigation application method depends on the quality of the effluent, crops to be grown, farmers’ tradition, background, and skills, and finally the potential risk to workers and public health risks.
public health. Localized irrigation techniques (e.g., bubbler, drip, and trickle), offer farm workers the most health protection as they apply wastewater directly to the plants.

Potentially hazardous materials, elements, or compounds are present in wastewater due to daily use of cleaning products, detergents, personal care products and medicines are other contaminants to consider [54].

### Wastewater Reuse: Regional/local guidelines and regulations

All Arab countries have programs for reusing treated wastewater in irrigation. Fodder crops, cereals, alfalfa, olive, and fruit trees are the crops most commonly irrigated with treated wastewater. Despite its common uses, few countries have institutional guidelines for regulating its reuse [50]. Still, the full value of treated wastewater has been recognized in only a few water-stressed Arab countries (Tunisia, Jordan, and the Gulf countries). In these countries, fully-fledged local or state regulations supported by national guidelines set the basic conditions for wastewater treatment and safe reuse. Another layer of the problem is the subsequent reuse options and the quality standards as defined in the national legislation.

A few Arab countries (e.g. Jordan, Tunis, Morocco) have adopted WHO and FAO effluent reuse guidelines for irrigation [55], which served as the basis for the national Jordanian Standard [56]. Reuse projects also developed agronomic guidelines for the safe use of reclaimed water in the Jordan Valley [57], seeking to reduce the use of commercial fertilizers and associated costs. In addition, the implementation of monitoring activities has contributed to more transparency regarding health and the environmental impacts of irrigation with reclaimed water [58].

The Arab countries can be divided into three categories based on their wastewater disposal practices:

1. In Bahrain, Saudi Arabia, Oman, Qatar, Kuwait and the United Arab Emirates a high percentage of wastewater is treated and reused to irrigate agricultural lands or landscape areas while the remainder is discharged into the sea or open areas after applied advanced treatment. This practice is common due to the availability of well-equipped and advanced treatment plants.

2. Countries such as: Egypt, Morocco, Jordan, Iraq, and Syria follow moderate regulations for the disposal and reuse of treated wastewater which does not meet national or international standards. This may be due to the inability of existing treatment plants to cope with high loads of raw wastewater influent. Consequently, a high percentage of the effluent wastewater is disposed to surface water bodies (if they exist) or to the wadies; while a small portion is used for irrigation.

3. This group includes Palestine, Yemen, and Lebanon, where a large fraction of wastewater effluents are disposed to the sea, wadies and open areas. In most cases no environmental or health control consideration is given to the workers, products, soil, or the possibility of groundwater contamination. In Yemen, raw wastewater is used for irrigation wherever it exists without any treatment necessary to meet standards of wastewater reuse.

### What Can Science Do?

According to [59] the attitude of the scientific world must reflect a world in crisis. Urgent needs should reflect substantial re-orientation of research priorities to better match the pressing needs of populations. Macilwain [59] questioned why so much of the scientific research is driven by the consumer needs of tiny elites. The answer, according to his notes, is: “We’re being naive if we envisage business-as-usual for science in the new century.” Unfortunately, one great danger is that limited funding for valuable multidisciplinary work to be consolidated around single-discipline research. Additionally, new approaches and scientific strategies should extend to conduct an exercise that explores how science as a whole might change shape over the next 20 years [59]. Scientists have always cultivated globalization, and promote solutions with global applications. Engagement is different; a tribal disdain for the social sciences still holds sway in the laboratory, as does a haughty disregard for the views and demands of the general public. Both outlooks need to be jettisoned if science is to contribute and thrive in the world.

Strategies to improve the management of surface and groundwater are proving to be effective vehicles for engaging countries in dialogue and in partnerships that establish the foundation for broad-ranging cooperation on resource use, mutual security, and trade. Scientific research on water demand management and water conservation strategies are clearly the most cost-effective approaches to reduce withdrawals, and, therefore, for reuse to make sense, it must be part of a larger water strategy that manages and regulates demand effectively [60].

Ending hunger does not require a major scientific breakthrough. Preventing the loss of a generation of children due to malnutrition is, on one level, relatively simple: women and children need access to an adequate amount of nutritious food. For the first time in history we have the scientific knowledge, programs, tools and policies to defeat hunger, but we still need global political will. It requires the commitment of national leaders to put in place the right policies and to declare that people will not starve under their leaderships [11].

Considerable research into the global environment is now being undertaken, especially into issues such as climate change, biodiversity and water quality. Development of a new strategic program is needed to help to sustain the earth’s land surface based on a systematic survey of its geochemistry and societal needs [2].

The recommendations below are based on a review of the relevant literature as well as on expert exchanges in the context of several international projects. These recommendations seek to develop a common Arab framework of guidelines for treated wastewater reuse planning, water quality recommendations, and treated wastewater applications. This framework would provide a consistent approach to the management of health and environmental risk. Although not mandatory and having no formal legal status, the proposed framework shares a common objective while allowing flexibility for approach and application suited to national, regional, or local contexts.

### Recommendations

- Besides the need to have integrated water resources management plans, similarities in issues of Arab countries urge and enhance the need to share knowledge, research, and action plans.
- Wastewater in the Arab region should be considered as an important resource of water and the wastewater sector should carry top priorities on research and planning. The reuse of treated wastewater in the Arab region needs fervent political support and the development of appropriate strategies promoting reuse in the context of each country’s overall water resources management plan. Commitment to wastewater reuse should be part of proclaimed water policy and strategy in all countries of the Arab region. The lack of organization in the reuse...
sector should be addressed as a matter of urgency in order to identify the proper institutional structure needed to develop the sector and its regulatory regime. Standards in line with existing or new regulations need to be enforced to preserve the environment and protect consumer health.

- To mitigate health and environmental risks, common norms and standards for the reuse of treated wastewater in these arid to semi-arid regions should be established. Detailed plans are needed for reducing the amount of potentially hazardous materials, elements, or compounds that end up in the sewer and therefore in wastewater or sewage sludge.

- The arid and semi-arid Arab countries should develop a platform for disseminating knowledge gained from existing wastewater treatment facilities. Knowledge-sharing would lead to improved availability of information on the economic and financial benefits, the volumes of treated and reused wastewater, benefits to the water economy, and cost recovery of water reuse systems. Policy-makers should develop national dissemination plans and awareness campaigns for education and advocacy regarding the use of treated wastewater. It is also necessary to communicate up-to-date information on appropriate processing and crop protection technologies to the authorities responsible for wastewater treatment and reuse as well as to other end users.

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