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Use of Reclaimed Wastewater in Agriculture

A Literature Review

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1. Abstract

Due to the rapid development of urban and rural domestic water supplies, conventional water resources have been seriously depleted and reclaimed wastewater (RWW) use for irrigation, among other non-conventional water sources, has gained an increasing role in the planning and development of additional water supplies. This literature review elaborates the benefits and risks associated with RWW as a non-conventional water resource with an emphasis on research carried out in the Middle East and North Africa (MENA) region. The use of RWW for agricultural irrigation is often viewed as a positive means of recycling water due to the potentially large volumes of water that can be made available. RWW has the advantage of being a constant, reliable water source and reduces the amount of fresh water extracted from the environment. There remain concerns about the quality of the RWW and its potential negative impact on both crops themselves and on the end users of the crops. Water quality issues that can create perceived problems in agriculture include nutrient and sodium concentrations, heavy metals, and the presence of contaminants such as human and animal pathogens, all of which can be safely managed. The risks associated with using RWW are not the same in all countries due to many reasons: different RWW properties and its management, soil profiles, crop diversity and management, and climate, to name a few. The review uses scientific and technical works to show that RWW can be a valuable and safe resource for crop irrigation that poses minimal risk to the soil, groundwater and crops, and is a key factor towards food security. The main conclusions issued from this RWW literature review are the following:

- The use of RWW in agriculture can act as a non-conventional water source and contribute to food security.
- Establishment of appropriate national policy framework, addressing specific or local needs, for the use of RWW is necessary.
- Continuous and sustainable monitoring programs or systems for ensuring public safety and protecting the environment are necessary.
- More long-term impacts research on the using of RWW for growing perennial crops as well as its impacts on the animals' health and production is important.
- Extensive capacity building and training necessary (for National staff and farmers) as well as an increase in public awareness on the safe use of RWW in agriculture.
- Public awareness on the safe use of RWW in agriculture must be raised as social acceptance remains a significant barrier to full practice roll-out.

Key words: Reclaimed wastewater, Benefit, risk, Arabian Peninsula, groundwater, long-term

2. Introduction

The world population is expected to be more than 9 billion by 2050. Most urban cities will expand and require more fresh water resources to meet their basic human and public health needs. Demand for food will grow drastically, requiring even more water as agriculture is the largest consumer of water resources. Furthermore, extreme weather conditions that we have been witnessing in recent years due to the Earth's changing climate will worsen. Droughts, floods, and major storms will increase in severity, all of which will pose additional stresses on already stretched water resources. Experts estimate that by 2080, 43-50% of the global population will be living in water-scarce countries, compared to 28% today (UN, 2013).

Globally, the agricultural sector accounts for more than 70% of total global fresh water withdrawal, 90% of global consumptive water use, and with some developing countries using as much as 95% of their water resources for agriculture (FAO-AQUASTAT, 2012). Concurrently, in most developing countries, agriculture employs the largest share of people and is therefore critical for poverty reduction. It should come as no surprise that the use of RWW to varying degrees for agricultural production has been happening around the globe for years. According to WHO, more than 10% of the world's population consumes food produced with RWW. Worldwide, 20 to 45 million hectares are currently being irrigated with either RWW or untreated WW (Sato et al., 2013).

As sources of both water and nutrients for irrigation, the use of RWW has proven positive effects for farmers by improving yields and thus income. However, the use of RWW has generated concern for having negative environmental, health, and socio-economic impacts, as well as the public perception of the edible products produced with this water. The WHO published "Guidelines for Safe Use of Wastewater, Excreta and Greywater" (2006) which use a *Risk Assessment and Management* approach that looks into the full production circle, from the farmer receiving the RWW through cultivation and harvesting, up until the produce reaches the market. The aim of the guideline is to ensure the safety of the produce consumed by humans and to minimize health and environmental impacts.

As a natural meager resource, water is of paramount importance in human life and achievement of socio-economic progress. The problem of water in the Arab world is considered to be one of the most important challenges today in terms of security of quality and quantity, and it also relates directly to food production. Using RWW for irrigation is viewed as a way to increase water resources and also as a means of improving crop growth due to its nutrient content potential of RWW. In water-scarce contexts as such, considering availability and cost associated with its use, RWW can present as an alternative water supply for agriculture and landscaping.

In the Arab states alone, nearly 11 billion m^3/year of wastewater is produced. Out of that, about 5.6 billion m^3/year is treated to various levels of treatments. About 4.3 billion m^3/year of the wastewater produced is used in agricultural production – nearly 40% (ICBA, 2014). Indeed, it is expected that in the coming 30 years, needed increase in agriculture production will be met mainly from enhancing water productivity, soil management and through alternate water sources. This can be translated into water use efficiency, use of non-conventional waters including RWW, and maintaining soil health for crop production (ICBA, 2014).

Toshio et al. (2013) reviewed global, regional, and country level data on wastewater generation, treatment, and use. They indicated that there is a need for updated national data on wastewater generation, treatment, and use, which would also assist in regional and global wastewater assessments. In a study conducted by ICARDA in collaboration with NARS in Kazakhstan, treated wastewater to irrigate crops (sorghum, Sudan grass, sorghum) has been successfully used. The preliminary soil analysis indicated that there was no indication of salinity or heavy metal accumulation.

This literature review elaborates the benefits and risks associated with RWW as a non-conventional water resource with an emphasis on research carried out in the Middle East and North Africa (MENA) region.

3. Reclamation: Wastewater Management, Treatment and Reuse

The use of wastewater in agriculture has long been of interest to scientists, economists and other professionals; RWW can make an important strategic contribution by progressively substituting for expensive desalinated water and rapidly dwindling fresh groundwater supplies. Recently, a number of studies have been published on the efficient management of wastewater, its treatment and reuse in water scarce countries.

Globally, many countries are now using RWW for irrigation in agriculture; the agricultural area under the application of RWW reaches over 40,000 ha in Egypt, around 22,000 ha in Argentina, 17,000 ha in United Arab Emirates and 15,000 ha in USA (IWMI,). In Tunisia, reclaimed water is used on 8,000 ha to irrigate industrial and fodder crops, cereals, vineyard, citrus and other fruit trees (Qadir et al. 2010). And although agriculture plays a major role for RWW use in Jordan, Egypt and Yemen; in the United Arab Emirates, Tunisia and Morocco, there is more of a focus on green space irrigation in urban centers and tourist facilities.

In order to implement sustainable use of water resources and to contribute to food security for increasing demands, RWW projects need to be incorporated into national integrated water management strategies. RWW projects need be developed safely and effectively, and constructed for the long term.

Countries with notable programs of using RWW for irrigation landscapes, crops, or pastures include Australia, Japan, Jordan, Kuwait, Oman, Saudi Arabia, Spain, Tunisia, Morocco, and the United States. These countries have implemented water quality guidelines to ensure that RWW does not cause harm when used for irrigation. Cyprus, Jordan and Tunisia have explicitly included water reuse into their water resources planning, and have official policies calling for water reuse.

3.1. Management of WW and RWW

Wastewater management needs to be approached in a novel way in order to include agricultural demands, socioeconomic and institutional realities, and the importance of helping nature to close ecological cycles. Taking an integral approach, including modifying some of the more traditional sanitation concepts, in order to achieve a balance between long- and short-term ecological risks and society's [unique] pressing needs is necessary. However, there is no one-size-fits-all approach to doing so and further complicating this is that the notion of improving the quality of life does not necessarily mean the same thing in different regions.

Many management approaches are available and to maximize the benefits and reduce the drawbacks of RWW use for irrigation, they must be put in place in combinations that are appropriate for a given set of local conditions. The use of an integrated management approach has several advantages. Besides being a more reliable multi-barrier system, it permits flexibility and the possibility for the selection of more socially and economically acceptable control measures to protect human health and the environment while fostering food security.

Necessary biophysical management components, aside from overarching policy of RWW use, will vary depending on context, but to be addressed are (Qadir et. al., 2010):

- Water quality improvements
- Human exposure control
- Farm-level wastewater management
- Harvest and post-harvest interventions

Also, better data on current status of RWW use will enhance efforts to improve management strategies and overall opportunities, as well as to better mitigate risks (Qadir et. al., 2010).

3.2. Treatment of Wastewater

For wastewater to be reclaimed for use in agriculture, treatment is needed to reduce pollutants. But specific to treatment of wastewater for agriculture, organic matter and nutrients are not to be targeted for removal, as these are more often than not beneficial for agricultural purposes. It is the pathogens that are to be targeted. This implies that different treatment technologies than those conventionally used for treating wastewater streams to protect receiving water bodies will be necessary. And fortunately, in a number of cases, treatment of wastewater for its reuse can be implemented at a reduced cost – one that is affordable to developing countries (Pescod 1992; Mara 2003; Jiménez and Garduno 2001).

Water quality of treated wastewater depends largely on the quality of the municipal water supply, the nature of the wastes added during use, and the degree of treatment the wastewater receives (Pedrero et. al. 2010). Improvements in wastewater streams' quality will be seen even with primary treatment; however, secondary treatment will help to better achieve standards outlined by WHO.

In a RWW practice review conducted by Pedrero et. al. (2010), the bulk of publications on municipal wastewaters and their treatment relate to the processes and techniques of doing so to optimize quality of effluent. Further, WW quality data routinely measured and reported at the WWTP are mostly for treated effluent disposal or discharge requirements in terms of gross pollution parameters that are of interest in water pollution control; rarely is the effect of these effluents on the environment studied in field conditions, including studying their effects on plant growth and crop production.

In the same review conducted by Pedrero et. al. (2010), overarching findings were that treated wastewater could be used for irrigation given:

- Treatment methods be improved to assure WHO guidelines;
- Treatment methods take into consideration context specificities (eg. soil type, crop types, etc.); and,
- Continuous laboratory control be carried out of treatment output.

The efficiency of wastewater treatment in the MENA region is highly variable and many treatment plants have design limitations to treat a mixture of domestic and industrial wastewater, which is usually the most prevalent form of wastewater reaching the treatment plants. It is important to distinguish between industrial and domestic wastewater streams when possible, as the former is heavier in chemicals and more expensive and complicated to treat, whereas the latter is more laden with pathogens (Qadir et al., 2010). Pollutants such as heavy metals, toxic organic compounds, and salts coming mainly from industrial discharges are difficult to remove from wastewater, and so it is cheaper, easier, and safer to prevent them from being discharged into the sewage system in the first place. It is also important to promote cleaner industrial production processes in order to avoid the use and discharge of toxic compounds, as well as to educate society to reduce the use of toxic compounds at home and their unsafe disposal.

Maximizing storage time is important because storing wastewater improves its quality by reducing the content of pathogens and pollutants associated with suspended solids. Lagoons and dams built for this purpose contribute to improving wastewater quality, at least partially, through sedimentation, biological and physical degradation, photolysis, adsorption, desorption, and competition between species. According to Juanicó and Milstein (2004), lagoons and dams can remove: a) suspended solids; b) organic matter in an extent depending on the retention time; c) heavy metals; d) detergents; e) organic pollutants (e.g. phthalates, alkyl phenols, alkyl benzenes, and hydrocarbons); and, f) most bacteria and helminths. However, most wastewater treatment plants in the MENA region do not have the capacity to accommodate the large volumes of wastewater resulting from increasing urban populations. In some plants, retention times for wastewater treatment have become too short to be effective (Qadir et al., 2010b).

In spite of their advantages, reservoirs have the drawback of evaporating water in arid and semi-arid regions. For instance, the large-scale pond system of Khirbet as Samra near Amman, Jordan, with a surface of 181 ha, evaporates 13–18,000 m^3/day of water in summer, when needs are highest. This volume accounts for 20–25% of the water flow (Duqqah, 2002). With respect to management, storage capacity is also needed to reconcile RWW production with water demand by crops.

Wastewater improves in quality when it is used to irrigate for the same reasons that soils and crops become polluted. This positive effect has been widely documented in literature, and there is even a treatment process known as soil aquifer treatment, or SAT (Bouwer 1987, 1991). Its application to soils and crops reduces the content of microorganisms (6–7 log for bacteria and 100% of helminths and protozoa), organic matter (greater than 90%, including recalcitrant compounds), nutrients (phosphorus, 20–90%; nitrogen, 20–70%), and metals (70–95%), but salinity is increased. There are farm-level RWW management techniques (such as crop selection, irrigation methods, etc.) can be applied when using RWW for agricultural purposes to further reduce risks associated (Qadir et al., 2010).

After application of RWW, most microorganisms are retained in upper soil layers by means of filtration or absorption. Removal is more efficient as the size of the soil grains decreases and there are more active adsorption sites. The distance required to remove microorganisms increases if microorganisms are small in size or if soils are fractured or have macro pores, such in coarse-grain materials, fractured or structured clays, fractured rocks, or limestone caverns (Foster et al. 2004). Microorganisms' adsorption in soils is favored by low pH, high salt concentration in the sewage, and high relative concentrations of calcium and magnesium over monovalent cations such as sodium and potassium on soil.

3.2.1. Application of RWW Conjunctive Use

Use of RWW providesan opportunity for conjunctive use where there is water scarcity and the quality is marginal (highly saline). The conjunctive use calls for using fresh or saline water in combination with RWW, with two options:

1. Mixing (blending), which involves mixing RWW with saline/brackish waters to reduce salinity of irrigating water; and,
2. Cyclic use, which involves the substitution of RWW for saline/brackish water at most sensitive growth stages, and saline water can be used at other stages when plants are strong enough to tolerate salinity and when soil salinity build up can be minimized.

3.2.2. Site and Crop Planning

Crops are enormously varied in nature and behavior; therefore, an appropriate selection can reduce potential risks generated by the use RWW, yet also realize economic gain. Crops that are of major health concerns are those that are eaten raw by humans or animals should be avoided if risk is too great or if the RWW quality is not adequate or dependable. Crops can be selected to overcome salinity and toxicity due to chlorides, sodium, and boron, and reduce health hazards for consumers (FAO and UNESCO 1973). To further minimize risks but meet needs, irrigation of landscape plants, industrial crops, and afforestation for commercial purposes (fruit, timber, fuel, and charcoal) or environmental protection display a much lower risk, mainly due to limited human contact. Crop selection needs to consider both health risks and economic benefits. For instance, when appropriate, flowers can be selected as crops because they carry a low health risk and a high economic value.

Negative impacts associated with RWW irrigation can be controlled by limiting application sites. Areas with restricted access to public, far from potable water sources, or where the aquifer is at a sufficient depth (3 meters deep at a minimum) should be preferred. Also, irrigation areas can be limited to fields where it is possible to have buffer areas around them or where soils have a significant depollution capacity. Wastewater irrigation of pasturing sites should be avoided.

3.2.3. Irrigation Systems

Irrigation methods affect the use of

wastewater. Depending on their efficiency, they use more or less water and therefore reduce or increase water infiltration from irrigation to subsoil and water discharges to surface water bodies. Also, it has been observed that (depending on the irrigation system) pollution in soils and crops can increase or be reduced. Some irrigation systems promote erosion, favor water logging and soil compaction.

Besides the usual factors to be considered when selecting an irrigation method (i.e., water availability, climate, soil, crops to be grown, cost of irrigation method, and the ability of the farmer to manage the system), other considerations need to be taken into account when using RWW such as possible contamination of plants and harvested product, health threats to farm workers, environmental impacts, salinity, and toxicity hazards.

Basin or flood irrigation involves complete coverage of the soil surface and will contaminate vegetables growing near to the ground as well as root crops. Besides not being an efficient method of irrigation, it also exposes farm workers to the effluent more than any other method. Furrow irrigation does not wet the entire soil surface, thus limiting crop contamination. If the effluent is transported through pipes and delivered into individual furrows by means of gated pipes, then risk to irrigation workers will be reduced. Sprinkler irrigation contaminates ground crops, fruit trees, and farm workers, and it can provoke severe leaf damage if water contains chlorides or bicarbonates, resulting in significant yield losses. Trickle and drip irrigation, particularly when the soil surface is covered with plastic sheeting or other mulch, uses effluent more efficiently and can often produce higher crop yields; it certainly provides the greatest degree of health protection for farm workers and consumers (Pescod 1992) but also at the greatest cost.

4. Benefits of Using RWW in Agriculture

Inherent benefits associated with reclaiming treated wastewater for supplemental applications prior to discharge or disposal include preservation of higher quality water resources, environmental protection, and economic gain. Water recycling has proven to be effective and successful in creating a new and reliable water supply, while not compromising public health.

RWW can increase food production and therefore increase income, thus also increasing nutrition and quality of life, and particularly in poorer areas. Wastewater is an important source of water and nutrients for irrigation in developing countries, particularly but not restricted to those located in arid and semi-arid regions. The use of wastewater is widespread and represents around 10% of the total irrigated surface worldwide, although varying widely at local levels. It is promoted in order to save fresh water for water supply and to protect receiving waters. But also, the reuse of treated domestic wastewater in agricultural purposes has been increasingly considered to be beneficial for crop production due to its significant source of nutrients for the plants (Jimenez-Gisneros, 1995&NRC, 1996), as it can help to reduce the requirements for commercial fertilizers (Candela et al., 2007).

4.1. Macronutrients and Organic Matter

RWW is accepted as a substitute for higher quality irrigation water because nutrients present, principally nitrogen (N), phosphorus (P), and potassium (K), are seen as a partial yet significant substitutes for manufactured fertilizers. Kaddous et al (1986) calculated the use of RWW realized approximately a 35% saving in fertilizers cost because it saved about 60%, 33%, and 40% on inorganic N, P, and K fertilizers respectively. Recycling N, P, K, and organic matter to soil is important because it closes their ecological cycles instead of interrupting them, as is traditionally done when these compounds are removed from wastewater, trapped into sludge, and dumped with it in confinement sites or landfills.

It is important to adjust the amount of nitrogen added with RWW. This amount depends on the soil's original nitrogen content (0.05–2%) and crop demand (from 50 to 350 kg/ha of N) (Girovich, 1996). Nitrates are very soluble in water, and as a consequence they are washed out of the soil by irrigation, polluting aquifers or surface water bodies.

With phosphorus, it is the opposite. Phosphorus is very scarce in soils and must almost always be added. Wastewater normally contains lower amounts of phosphorus than required by crops (6–12 mg/L of P), and does not negatively impact the environment, even if applied for long periods through effluents, because it is stable and can be accumulated in soils (Girovich 1996). The recycling of phosphorus is even more important because its reserves are limited and dwindling; recycling it is even being promoted by the phosphate industry (CEEP 2001).

The third macronutrient, potassium, exists in high concentrations in soils (3%) but is not bio-available to plants. Approximately 185 kg/ha of K are required and sewage can supply part of this demand (Mikkelsen and Camberato 1995).

Nutrients make wastewater an effective fertilizer, while organic matter improves soil texture and enriches the humic content, which increases soil humidity, retains metals (through cationic exchange and the formation of organo-metallic compounds), and enhances microbial activity (Ortega-Larrocea et al. 2002). If organic matter content in wastewater is less than 350–500 mg/L, all these effects enhance soil productivity and soil clogging is avoided.

Mohammad and Mazahareh (2003) noted that reclaimed water irrigation decreased soil pH and increased soil salinity, soil phosphorus, potassium, iron, and manganese levels, but soil organic matter was increased only in the topsoil. Mohammad and Ayadi (2004) noted that the uptake of macro and micronutrients by corn increased with RWW irrigation, implying that secondary RWW could be a source of plant nutrients and can be reused for irrigation to increase forage crop production.

5. Risks in RWW Reuse

5.1. Health-Related Risks

Negative effects of RWW use are generally associated with the presence of pathogens and toxic chemical compounds in the wastewater and its long-term use. Four groups are at risk: agricultural workers and their families; crop handlers; consumers of crops, meat, and milk; and, those living near the areas irrigated with wastewater, particularly children and the elderly. Health risks for farmers and consumers depends on the level of treatment undertaken and there are risks from pathogens, skin irritating chemicals and toxic chemicals like heavy metals and pesticides in the water (Keraita *et al.,* 2008).

Health risks associated with chemicals (e.g. TOCs and metals) found in wastewater need to be given more attention, particularly in developing countries where the pace of industrialization is accelerating without proper treatment and disposal of wastewater streams. In these countries, municipal and industrial wastewater is often not segregated, creating a potentially dangerous mixture of toxic substances that must be handled cautiously. Specific to the use of RWW for food crops, although studies have been conducted across the globe, epidemiologically robust studies do not exist that compare health risks associated with wastewater contact (via farming or consumption of irrigated crops) versus other unsanitary practices or exposures such as unsafe street-food, children playing in landfills, poor sanitation facilities etc. (Qadir et. al., 2010) and wherein the greater risk lies.

5.1.1. Nutrients

The impact from nitrogen is the effect most frequently cited in literature and with it the risk of causing methemoglobinemia in infants. In spite of this, a recent investigation prepared on behalf of the WHO concludes that although in the past it has been accepted that consumption of drinking water high in nitrates causes methemoglobinemia in infants, it now appears that nitrate may be one of a number of co-factors that play a sometimes complex role in causing the disease (Fewtrell, 2004).

5.1.2. Microbiological Content

Wastewater contains a variety of excreted organisms, the types and concentrations of which vary depending upon the background levels of disease in the population. Many pathogens can survive for long enough periods of time in soil or on crop surfaces and thus be transmitted to humans or animals.

The most environmentally resistant pathogens are helminth eggs (parasitic worms) making them the main health risk associated with the use of RWW for irrigation (WHO 1989). In developing countries, helminthiasis levels found in wastewater are seven to 80 times greater than those found in developed countries' wastewater (Jiménez 2003); in regions where poverty and poor sanitary conditions prevail, helminthiasis reaches 90% of the population (Bratton and Nesse 1993). There are several kinds of helminthiasis; ascariasis is the most common and is endemic in Africa, Latin America, and the Far East. There are 1.3 billion infections globally. Andalthough it is a disease with a low mortality rate, most of those affected are children under 15 years with problems of faltering growth and/or impaired fitness. Approximately 1.5 million of these children will probably never catch up, even if treated (Silva et al. 1997). In any case, protozoan and helminth eggs are almost always removed by soils, with the exception of extreme rain events where protozoan transportation has been demonstrated (Scott et al. 2004).

Besides helminthiasis, other diseases related to the use of wastewater are as follows: cholera, typhoid, and shigellosis, gastric ulcers caused by Helicobacter pylori, giardiasis, amebiasis, and spoon-shaped nails (Blumenthal and Peasey 2002). Treatment plants for both water and wastewater are not designed to treat high microorganism contents and are inefficient in inactivating microbes' resistant to conventional disinfection methods (i.e. protozoa or viruses).

5.1.3. Organic Compounds

Wastewater contains a wide variety of organic compounds, some of which – depending on compound type, concentration, and route and duration of exposure - have toxic or cancer or embryo/fetal effects. Toxic organic compounds have a large size and high molecular weight that do not allow them to be absorbed by plants (Pahren et al. 1979); however, some present in wastewater can remain in fruits and leaves by direct contact. Pesticides are a great concern, but the main polluting pathway is their direct application to fields rather than their introduction through wastewater.

If wastewater is used to irrigate, Total Organic Compound (TOC) content can rise to 6–9 mg/L, a range higher than what is commonly accepted as saf e for water reuse for human consumption (1–2 mg/L) of TOC (Jiméneza, 2006) is the acceptable limit). Even for low concentrations, the concern would be what kind of compound is present.

Of particular concern is a specific group of organic compounds known as endocrine disruptors that can be found in municipal wastewater. Endocrine disruptors derive from many sources, including pesticides, persistent organic pollutants, nonionic detergents, and human pharmaceutical residues. Many of these substances are resistant to conventional wastewater treatment and may persist in the environment for some time. Human health effects potentially linked to exposure to these chemicals include breast, prostate, and testicular cancer; diminished semen quantity and quality; and impaired behavioral/mental, immune, and thyroid function in children. Although direct evidence of adverse health effects in humans is lacking, reproductive abnormalities, altered immune function, and population disruption potentially linked to exposure to these substances have been observed in amphibians, birds, fish, invertebrates, mammals, and reptiles (WHO 1989). Their effects appear to be long-term. Care must be taken with phthalates isolated from aquifers that have formed with the infiltration of wastewater used to irrigate land (Jiménez 2004).

Some TOCs lead to the formation of organ chlorides if water has been previously used for human consumption and disinfected with chlorine (a common method). Foster et al. (2004) found that in aquifers recharged with wastewaters, the potential of trihalomethane formation fluctuates between 20 and 45 micrograms per milligram of TOC and can produce disinfected water with a concentration up to 100 micrograms per liter.

Furthermore, chlorine residuals in excess of 5mg/L can cause severe damage to plant foliage during sprinkler irrigation (Pedrero et. al., 2010)

5.1.4. Heavy Metals

Of all chemical compounds in wastewater, the major health concern is due to heavy metals. Though many are biologically beneficial in small quantities (i.e. iron, cobalt, copper and zinc), some become harmful at high levels of exposure. For some, a human toxicological threshold has yet to be established for wastewater intended for irrigation (i.e., cobalt and copper) or the thresholds are rather high (i.e. zinc). Chemical pollutants in industrial wastewater, such as heavy metals and pesticide residues, may pose serious health risks when accumulating in soils and crops.

Cobalt, copper, and zinc are not likely to be absorbed by plants in sufficient quantities to prove harmful to humans; they're toxic to plants far before reaching levels toxic to humans (Chang et al. 2002).

Cadmium is the metal that poses the greatest risk. Its uptake can increase with time, depending on soil concentration, and it is toxic to humans and animals in doses much lower than those that visibly affected by plants. Absorbed cadmium is stored in the kidney and liver, but meat and milk products are unaffected (Pescod 1992).

Confirmed by the United States Environmental Protection Agency (USEPA) in 1981, heavy metals have no adverse effect on the growth of crops in different locations of the United States, where water has been treated and used for more than 38 years. In Australia, it was stated that the use of sewage and since 1983 has led to a slight increase in the concentration of heavy metals when used to irrigate crops with treated waste water; these studies confirmed that when irrigating vegetables with treated waste water, the heaviest metals remain in the root zone and there is in part a slight move to the branches and negligible amounts in the fruit. Another study found that the use of treated water to irrigate a bilateral maize crop has helped reduce the acidity of the soil and did not affect the metals rally (S, B, Cu, Fe, Mn) in the plant tissue. The concentration of heavy metals (Cd, Cr, Ni, and Pb) stayed below critical levels in the plant tissue (Al-Lahham et al, 2007).

5.2. Environmental

Concerning environmental impact, crops can be contaminated with microbes, heavy metals, and toxic organic compounds (in that order of frequency and importance). Contamination can happen by direct contact between irrigation water with edible plants or, in the case of metals, through absorption from soils, depending on environmental conditions and the type of plants.

Soil is a complex mixture of mineral and organic substances in concentrations that vary widely in different regions and climates. For this reason alone, it is difficult to say whether wastewater compounds and in what concentrations cause problems or provide benefits. Nonetheless, it is currently known that the most visible effect of using wastewater for irrigation is a productivity increase due to its content of nutrients and organic matter (Mara 2003; U.S. EPA 1992).

Crop pollution depends on water quality, agricultural practice (quantity of water applied and irrigation method), as well as type of crop. Oron et al. (1992) and Najafi et al. (2003) found that microbial pollution is reduced if irrigation is performed by subsurface dripping rather than through sprinklers or furrows. With respect to type of crop, simply put, trees are less likely to produce polluted fruits because they are located far from the irrigating sites and potentially polluted soils.

It should be noted that crop contamination occurs not only as a result of wastewater irrigation but also during washing, packing, transportation, and marketing, which are frequently not addressed by water reuse criteria, giving the impression that irrigation is the only problem.

5.2.1. Metals

The most common negative impact of irrigating with wastewater is an increase in metal content that, depending on the level, may or may not be harmful. Irrigation with domestic RWW results in the accumulation of metals in upper layers of soil with no negative effects on crops, even when applied over long periods of time (several decades) (Jiméneza, 2006).

Metals are fixed to soils with a pH of 6.5–8.5 and/or with high organic matter content. Fortunately, sewage pH is always slightly alkaline (7.2–7.6). This value, combined with an important soil and wastewater alkalinity maintains original soil pH (Jiméneza, 2006). Only a small fraction of metals infiltrates lower layers and a much smaller one still enters crops. For instance, around 80–94% of heavy metals cadmium, copper, nickel, and zinc are removed in the first five to 15 centimeters, 5–15% is lixiviated by runoff, and 1–8% is absorbed by grasses (Pescod, 1992). A similar process occurs with fluorine and boron (Ayres and Wescot, 1985).

According to Leach et al. (1980), the most toxic metals to humans—cadmium, lead, and mercury—were absent in groundwater at five sites in the United States after 30–40 years of applying secondary and primary effluents at rates between 0.8 m/yr and 8.6 m/yr to different crops. The reason given was that the initial metal content is low and a soil pH greater than 6.5 precipitated metals.

5.2.2. Nutrients and Organic Matter

There are two types of RWW effects on crops: (1) those that affect yields and (2) those that modify crop quality (appearance, flavor, or pollutant presence). As already mentioned, yield is usually increased by the fertilizing compounds present in wastewater, but it can be diminished if toxic compounds are present.

Nitrogen applied to plants when it is not needed may induce more vegetation than fruit growth and also delay ripening. This has been observed for beets, cane, and rice (Pescod 1992; Morishita 1988). The amount of nitrogen remaining in wastewater after irrigation depends on the nitrogen content and the amount of water applied to crops. Nitrogen removal is enhanced if flooding and drying periods are alternated, which promotes a nitrification/denitrification process on soil that can remove the nitrogen in sewage (Bouwer, 1987). Furthermore, the main impact to surface water bodies is caused by the remaining nitrogen in wastewater that causes eutrophication of lakes, reservoirs, and rivers with low-speed flows. Eutrophication not only affects the water but also wildlife such as birds and fish, having consequent biodiversity, fishing, and recreational loss (Stark et al., 2000). Phosphorus in sewage (5–50 mg/L) is biologically converted to phosphate. In calcareous soils and at an alkaline pH, phosphate precipitates with calcium to form calcium phosphate. In acidic soils, phosphate reacts with iron and aluminum oxides in the soil to form insoluble compounds. Sometimes phosphate is initially immobilized by adsorption to the soil and then slowly reverts to insoluble forms, allowing more adsorption of mobile phosphate. In clean sands with near neutral pH, phosphate can be relatively mobile (Bouwer, 1991). High contents of phosphorus (above those commonly present in municipal wastewater) reduce copper, iron, and zinc availability in alkaline soils (Pescod 1992).

Most organic compounds of human, animal, or plant origin contained in sewage are rapidly transformed in soils to stable, non-toxic organic compounds (humic and fulvic acids). Soils can biodegrade a wider variety and a greater amount of organic compounds than water bodies can. Therefore, water application under controlled conditions (limited irrigation rate and intermittent flooding) permits the biodegradation of hundreds of kilograms of biological oxygen demand per hectare per day (kg BOD/ha/d) with no impact on the environment (Bouwer, 1991). BOD levels are virtually reduced after a few meters of percolation through the soil, where TOC values of 1–5 mg/L can still be measured. Removal of several recalcitrant compounds such as organochlorides or endocrine disrupter compounds by adsorption and biodegradation has been reported in some soils and in several days (WHO 1999; Mansell et al. 2004). Organic matter reaching aquifers from percolating reclaimed water varies between 1–5 mg/L of TOC.

5.2.3. Organic Compounds

Crops' appearance is affected by chlorides (less than 140 mg/L in sensitive ones or greater than 350 mg/L in resistant ones) and carbonates (greater than 500 mg/L of calcium carbonate). Both compounds burn leaves when sprinklers are used to irrigate (Pescod 1992).

5.2.4. Salinity

The main, long-term problem that water reuse causes is soil and groundwater salinization. This occurs even with freshwater (albeit more slowly) if appropriate soil washing and land drainage are not practiced. Salinity effects are of concern particularly in arid and semi-arid regions where accumulated salts are not flushed from the soil profile by natural precipitation and where RWW use is a necessity.

The salinization build-up rate depends on: evaporation, type of soil, its transmissivity as well as organic matter content, the hydraulic loading rate, water quality, land drainage, irrigation rate, and depth to groundwater. To understand why irrigation water is salinized, one must know that during irrigation, an extra amount of water always has to be applied to remove from soils the salts accumulated in the root zone due to water evaporation. This activity is known as leaching, and the water employed for it is called the leaching fraction, which must also be removed from the agricultural site by means of agricultural drainage. Leaching is critical in areas where evaporation is important (arid and semi-arid areas) and where the phreatic level is high and pushes salts to the soil surface.

If clay or organic matter is present in the soil, there will be cation adsorption and ion exchange, which increases salinization (Pescod 1992). If the whole process is not carried out properly, soils tend to become saline and lose their productivity, and also can increase salt content in crops, such as vineyards for wine production (Pescod 1992).

Depending on the type of soils and the washing and drainage conditions, salinity problems can occur with conductivities greater than 3 dS/m in dissolved solids greater than 500 mg/L (being severe if greater than 2,000 mg/L), chlorine less than 140 mg/L, and a sodium absorption ratio (SAR) greater than 3–9. Other problems related to salinity are toxic effects caused by sodium, bicarbonates, and boron.

Normally, wastewaters are not very saline (200–500 mg/L or 0.7–3.0 dS/m). On specific occasions (i.e., saline soils areas, saline discharges to sewers, or sea intrusion to water supplies that generates sewage), salinity concentration can exceed the 2,000 mg/L level, in which case appropriate water management practices need to be followed to prevent soil salinization through leaching and drainage.

5.2.5. Groundwater

The impact on groundwater quality depends on several factors, such as the irrigation rate, the RWW quality, the vulnerability of the aquifer, the method of irrigation used, the rate of artificial compared to natural recharge, the original quality of underground water and its potential use, the time under irrigation, and the type of crops (Foster et al. 2004). An indirect consequence of irrigated agriculture is aquifer recharge, and it occurs in permeable soils whether it is performed with fresh, reclaimed, or reused wastewater (Foster et al. 2004). Recharge happens almost always non-intentionally and has the advantage of increasing the local availability of water. Water infiltration is due to the excess of water applied to irrigate as well as the infiltration of irrigating water during its storage and transportation.

Due to the infiltration of wastewater to aquifers and thus recharge, in the long term, salt content in aquifers will always increase. Based on the original quality, present and future use, as well as interconnections between the aquifer and other water bodies, this effect may or may not be relevant (Farid et al. 1993).

To avoid negative effects stemming from the infiltration of RWW, it is recommended to do the following: (a) recognize its occurrence and quantify the phenomenon; (b) before reusing water, establish cost-effective patterns of rational water use and management; (c) improve agricultural irrigation practices; (d) establish criteria to drill wells used to supply water for human consumption in the surroundings (i.e., distances to irrigation sites, depth of extraction, and appropriate construction); (e) promote water reuse for agriculture, preferably in zones where aquifers are less vulnerable; and (f) undertake constant and efficient monitoring of underground water(Foster et al. 2004).

Some microorganisms, particularly viruses, can reach aquifers if they are present in high concentrations in reused water, if wastewater is applied in very permeable or fractured soils, or the phreatic level is high (Foster et al., 2004).

Groundwater recharge is another option for use of RWW and is particularly considered in countries where seawater intrusion into freshwater aquifers is threatening the already scarce water resources. This practice works as a means by which to treat, and store RWW and to prevent an increase in groundwater Stalinization.

6. RWW use in the MENA Region

The Middle East and North Africa (MENA) region is already facing severe water scarcity with per-capita water availability in several Arab countries dropped below 500 m^3/year. Surface water resources in Arab countries are estimated to be about 224 billion m^3/year of which 77% comes from outside the region. Groundwater sources in the Arab region are quite limited, not exceeding a total of 50 billion m^3/year (ESCWA, 2007). This limited water resources availability poses severe constraints on economic and social development and threaten the livelihood of people. Available surface water is declining and the over-pumping of groundwater has resulted in the declination of water table and increase in groundwater salinity, groundwater depletion, and ecological degradation (World Bank, 2009).

The needs of an increasing population in the MENA region, estimated at 343.8 million (AOAD, 2009), has put an added pressure on total water withdrawal. The Arab Water Council (AWC, 2006) estimates a further 83 million people need to be supplied with safe water and 96 million are still in need of clean sanitation services in order to meet the Millennium Development Goals (MDGs). This doesn't take into account the increase in water needs required for agriculture to feed the growing population. Exploring new unconventional water resources is becoming increasingly important in the region and RWW needs to be a part of the strategy.

Water limitation is considered as the greatest challenge facing agricultural development in arid and semi-arid regions, particularly during periods of drought, which have necessitated stricter control measures on usage and the need for development of alternative water sources. MENA countries are, by and large, located in a desert region characterized by high temperatures, high evaporation rates and low and erratic rainfall. Furthermore, groundwater is the major source of water for irrigation in these countries, but in countries such as Kuwait, Qatar and Bahrain, groundwater available is mostly brackish.

With increases in population, the amount of wastewater and the number of wastewater treatment plants has increased in most of the MENA countries. The total volume of wastewater generated by the domestic and industrial sectors in the MENA region is 18.4 km^3/yr; of which 8.6 km^3/yr are reported to undergo treatment. The volume of wastewater discharged in an untreated form in the countries is more than50% of the total reported wastewater produced in the region. Of the total treated, about 3.5 km^3/yr are reused as per FAO's AQUASTAT database (Table 1).

The use of RWW as water and nutrient source has been introduced as a viable irrigation water sourcenearing essential in the water scarce MENA region, targeting agriculture predominantly, particularly in Tunisia, Syria, and Jordan. Currently, 41% of RWW is used for irrigation in the region (Table 1).

Irrigation for landscaping and golf courses is also on the rise in member countries of the Gulf Cooperation Council as well as in North Africa (World Bank, 2007), particularly in countries that have yet to carry out comprehensive studies to assess and reduce the risk associated with heavy metals in the RWW to human health. High-income countries in the region use RWW for agricultural and landscape irrigation

RWW is considered as a valuable source in the region's water balance if used safely Municipal wastewater reuse is believed to be one potential intervention strategy for developing nonconventional water resources, which will also help to better manage increasing municipal waste streams. Using RWW can contribute to enhancing the productivity and income of farmers in the region.

Table 1. Total wastewater generated, treated and reused in the MENA region (Source: FAO-AQUASTAT, 2012)

Country	**Generated (km^3/year)**	**Treated (km^3/year)**	**Direct Use (km^3/year)**
Algeria	0.82	0.324	
Egypt	7.078	4.013	1.3
Libya	0.504	0.04	
Morocco	0.7	0.166	0.07
Tunisia	0.287	0.226	0.068
Bahrain	0.151	0.076	0.016
Iran (Islamic Republic of)	3.548	0.885	
Iraq	0.58	0.425	0.005
Jordan	0.18	0.121	0.0649
Kuwait	0.292	0.219	0.078
Lebanon	0.31	0.056	0.002
Oman	0.09	0.009	0.026
Qatar	0.274	0.117	0.047
Saudi Arabia	1.546	1.063	1.003
Syrian Arab Republic	1.37	0.55	0.55
United Arab Emirates	0.5	0.289	0.248
Yemen	0.1315	0.046	0.006
Total (km^3/year)	**18.3615**	**8.625**	**3.4839**

6.1. United Arab Emirates

UAE is one of the top 10 most water scarce countries in the world but its per-capita water use is one of the highest worldwide. The country's population is growing very fast due to employment migration and this has increased the demand of water.

In the UAE, total production of RWW at tertiary level is 600 million m^3, of which 352 million m^3 is used for landscaping, and the remaining 248 million m^3 has the potential for recharge, industry and agriculture (ICBA, 2010). In the UAE, 16,950 ha are irrigated with RWW (Jiménez and Asano, 2008a), of which 15,000 ha are in urban forests, public gardens, trees, shrubs, and grasses along roadways (USEPA, 2004).

However, in the UAE, there is a general reluctance in the agriculture industry to embrace the use of RWW due to concern about its quality. These concerns relate to the chemical, physical and pathological qualities of RWW, which may affect the yield, or quality of the produce and its market acceptance, the soil health, and environmental quality. Trust and confidence in the use of RWW is missing in society because of the lack of proof that its use is vital for the UAE and that it is safe. However, with dwindling water resources, an increase in water demand and progressive water shortages to meet the increasing demands for agriculture and horticultural production, it is anticipated that the RWW will be seen as increasingly viable option for profitable and environmentally sustainable production.

In this context, it is believed that if WW is treated to tertiary level, health risks will be significantly reduced. Shuval et al (1986) pointed out that pathogen contamination is only detected in association with the use of raw or poorly settled wastewater, while inconclusive evidence suggested that the appropriate wastewater treatment could provide a high level of health protection. At this stage, in the UAE, systematic research on the use of RWW in agriculture has not been conducted, which is vital to prove its safe use under UAE environmental conditions.

Mechlem (2013) developed a legal analyses report “UAE Agriculture Strategy”. He stated that at the federal level, reclaimed water falls under the remit of the Ministry of Environment and water (MoEW). The main organizations responsible for reclaimed water management are based at the Emirate level, either with one principal organization or the municipality being involved in collecting, treating and disposing of wastewater. For irrigation purposes, wastewater quality must be assessed for its chemical elements and compounds, nutrient contents and microbiological characteristics. A stringent and well-implemented regulatory regime is required given the health and environmental risks associated with RWW use.

A detailed analysis of the wastewater use sector and its potential, including for agriculture, has been carried out for Abu Dhabi Emirate, including an analysis of legal and institutional issues. Its water reuse standards, derived from international standards, are realistic, affordable and enforceable, and allow unrestricted use in agriculture, forestry and amenities. Abu Dhabi Emirate is currently exploring wider scale use of RWW to recharge aquifers to halt seawater intrusion into ground water basins.

An experimental trial was conducted by Ministry of Climate Change and Enviroment EW in cooperation with APRP-ICARDA scientists in UAE during 2014 (unpublished) growing season to test the impact effect of using RWW in irrigation of three selected forage crops and soil. Primary results showed some accumulation of heavy metals in soil and plant tissues, but lower than the recommended concentration threshold levels. This study will be continued to study the long-term effect of RWW.

6.2. Tunisia

Tunisia is one of the first Arab States to use RWW for agricultural production and have, since 1965, laws that outline best use practice including authorized crops and guidelines for irrigating practice with RWW.As per FAO Aqustat data base approximately 78% of the wastewater generated is treated and 68 Mm3is reused. Reuse of wastewater is an integral part of national water resources strategy. The majority of municipal wastewater undergoes secondary biological treatment, which can then be used on all crops except vegetables. Currently only 20-30% of available TWW is reused. The country made a national target to increase the rate of reuse in agriculture to 50%. There are approximately 110 wastewater treatment plant in operation. Wastewater is mainly reused for agricultural irrigation (8000 ha), landscape irrigation and groundwater recharge.

6.3. Oman

Sultanate of Oman suffer from physical water scarcity because of low rainfall and high temperature. The production of treated wastewater in 2012 was estimated as 90 Mm^3/ year and approximately 42 Mm^3/ year is treated.

There are about 360wastewatertreatment plants distributed in different governorates of the Oman producing more than 42Mm^3/year (http://mrmwr.gov.om/). There are also about 11 sewage treatment plants in the Governorate of Muscat, where the use of RWW started in 1987 at 1,500 m^3/day. At present, almost 22 m^3/ day are used to irrigate parks, green spaces and trees, as it is expected to increase these quantities. Wastewater effluents of existing WWTPs have been used for landscape irrigation and recharging groundwater to resist salt water intrusion in coastal areas (Baawain et al. 2014). Oman is implementing active aquifer recharge with RWW affluent of tertiary standards through injection and infiltration.

Al Khamisi et al. (2013) explored how RWW can be used directly, without aquifer storage and recovery, as a source of irrigation water in conjunction with groundwater for agriculture. They indicated that by blending the streams, cropping areas of wheat, cowpea and maize can be increased by 323, 250, and 318% respectively versus utilization of RWW only.

Several experiments using RWW have been conducted in Oman for annual crops production like sorghum, barley, maize, pearl millet and triticale. The results indicated that the forage yield of sorghum and maize was increased by 30% under RWW irrigation in comparison with that using fresh water whereas this increase was 43% in barley and 56% in triticale crop. Samples from soil and plants were collected to monitor the impact of irrigation with RWW on the chemical contents of soil and plants. The analysis of the major elements of N, P and K, as well as trace elements and heavy metals indicated that all trace elements and heavy metals were at low concentrations in plant tissues and soils compared to Omani standards (Agriculture & Livestock Research, Annual report 2011-2013).

Alkhamisi et al.(2011) conducted a field experiments to determine the effect of water quality (reclaimed and fresh water), water quantity, and their interactions on the growth, yield, and water use efficiency of forage maize during two winter seasons in the Arabian Gulf. The study concluded that RWW irrigation increased yields of forage crops and their water use efficiency.

6.4. Saudi Arabia

Saudi Arabia is one of the driest country in the region which occupies approximately 70% of Arabian Peninsula.The country has limited renewable water resources, but its per capita water use is very high with approx. 250 liters per person per day (Drewes et al. 2012). The total groundwater resources of the country are estimated to beapproximately 2100 km^3 of which 10 percent can be used economically extractable. There is an increasing effort to treat wastewater for reuse to irrigate crops in the Kingdom of Saudi Arabia, as most of the freshwater used in country (89%) is for agriculture (Gleick, 2006, cited by Al-Zawad, 2008). Saudi Arabia currently use 40% of wastewater produced.Saudi Arabia aims to reuse over 65 percent of its water by 2020 and over 90 percent by 2040 (http://english.alarabiya.net/).Urban effluent waste is being treated and used for agricultural, industrial and landscape uses in Saudi Arabia (Al-Wabel et al., 2011, and Al-Garni and Al-Omran, 2009).

RWW used in agriculture is concentrated in Al-Hassa oasis where groundwater depletion has threatened the unique agro-ecosystem of this eastern region. An extensive system of collection, treatment, and transport of RWW from neighboring cities was designed, together with an extensive irrigation system that currently services about 16,000 hectares. 24% of irrigation water in Al-Ahssa is RWW with average salinity between 1.64 and 4.07 dSm-1 (Almehini, 2012). However, the long-term use of RWW in Al-Ahssa oasis has led to increase Pb, Zn, Cu, CO, Cr, As, Cd, Fe, Mn, Ni concentrations in the soil (Al-Omran et al., 2011).

6.5. Egypt

Egypt produces about 7.1km3/year of municipal wastewater, while current treatment capacity is in the range of 4.0km3/year. An additional 1.7 billion m3/yearof treatment capacity is targeted by 2017 (Tawfic, 2008). Although the capacity increase is significant, it will not be sufficient to cope with the future increase in wastewater production from municipal sources and therefore, the untreated loads that will reach water bodies are not expected to decline in the coming years.From this 7.1 km3, 1.3 km3/year is used directly for irrigation (AQUASTAT). The Ministry of Water Resources and Irrigation of Egypt plans to use 2.4 km3/year of TWW to cultivate about 100,000 hectares of agricultural land by 2017 (Misheloff 2010). According to FAO (2005), an estimated 200,000 ha in Egypt are irrigated with treated wastewater. In the north delta region, intensive farming of rice and aquaculture using RWW is carried out as a mean to recharge the underground aquifer and stop seawater intrusion.

6.6. Morocco

The annual volume of wastewater produced in the country is 700 Mm^3 of which 166 Mm^3 is treated and 70 Mm^3 is reused (FAO AQUASTAT, 2013).

Extensive RWW use has been ongoing in the government where, via a partnership with the private sector, a tertiary treatment plant has been built and operates to produce over 90,720 m^3/day leading to the conservation of Marrakesh's Palm grove. This alone saves 33 million m^3/year of fresh water, plus has helped in developing extensive golf courses that support tourism and the economy of the region.

However, for the country at large, data describing the use of RWW for irrigation is not available, although irrigation with RWW has been reported in literature (Jiménez and Asano, 2008a).It has been reported that about 8,000 ha are irrigated with untreated or insufficiently reclaimed wastewater (USEPA, 2004).

6.7. Yemen

Yemen uses 93% of the available water resources for agriculture and per capita water availability in the coutry is approx. 150 m^3/year. The country generates 131 Mm^3 of wastewater every year and 35% is treated and Currently, Yemen currently uses 6 million $m^3$of treated wastewater. In the coastal areas, RWW is used to establish green belts to stabilize active sand dunes (ICBA, 2014). A further 20,000 ha are irrigated with RWW, mainly in the highlands where it is used for forage and cereal crop production. Ameen Rageh (2014) conducted a study for assessing the impact of RWW use in agriculture irrigation in the Amran area. Chemical and biological wastewater and soil samples, carried out in accordance with local and international standards, were analyzed and evaluated. Analysis of the effluent in the facultative pond found fecal coliforms (>2,400 cfu/100ml) and pathogenic protozoa. TheRWW in the study area was moderately saline (2.4 ds/m) and soil analysis indicated that the salinity is high.

6.8. Qatar

TWW is considered as an important resource to meet the growing demands of the country. Agriculture uses approximately 47 Mm^3 of the total waste water produced which is approximately 35% of the total water treated. Total wastewater generated in 2012 was 273 Mm^3/year of which 117 Mm^3 was treated (Table 1). The country is planning to use 73 $Mm^3$of TWW for firefighting by 2020 (Jasim, 2016)

The current treated effluent reuse applications in Qatar are: GW injection (25%), animal fodder irrigation (27%), end user and highway irrigation (37%), and disposed to lagoon (11%) (El Emadi et al., 2014).

Darwish et al. (2015) conducted a review study in Qatar using scientific, economic and technical evidence to show that RWW is a valuable and safe resource for crop irrigation, posing minimal risk to the soil, groundwater, and crops, and is a key factor towards Qatar's food security. Highlighted was the real challenge of using RWW in Qatar for crop production as being social, butthat highly treated domestic wastewater could be a real water resource for irrigation. Technical and economic calculations show minimum risks associated with reuse.

6.9. Kuwait

Kuwait generates about 292 Mm^3 of wastewater in a year, about 75% (219 Mm^3) of which is treated.

The primary use of RWW is agricultural irrigation (4,470 ha), representing 25% of the irrigated area in the country (USEPA, 2004). Only vegetables that are eaten after cooking (potatoes and cauliflower), industrial and forage crops (alfalfa and barely), and highway landscapes may be irrigated with RWW in Kuwait. The use of RWW for landscape irrigation is increasing in urban areas of Kuwait.

Kuwait's Sulaibiya Wastewater Treatment Plant is the largest membrane-based water reclamation facility in the world to use reverse osmosis (RO) and ultra filtration (UF) membrane-based water purification systems. The facility converts 380,000 m^3/day of municipal effluent to 320,000 m^3/day of high-quality RWW that is used for agriculture. The plant's daily capacity is expandable to 610,000m^3/day.Al-Shammiri et al (2005) indicated that the quality of the wastewater treated by Micro infiltration (MF) unit was suitable for irrigation with low potential for problems.

A case study in Kuwait and Qatar was conducted using this advanced wastewater treatment process comprising UF and RO systems, followed by the artificial recharge of the treated water into a groundwater lens. A simulation model was developed based on hydrogeological studies in which the augmentation of groundwater resources would provide water storage, and prevent depletion and deterioration of the groundwater (Hamoda et al, 2012)).

6.10. Syria

According to the WHO (2005), the Damascus and the Homs wastewater treatment plants in Syria account for more than 98% of all RWW with capacities of 177 million m^3/year and 49 million m^3/year, respectively. According to the WHO (2005), About 177 million m3/day of RWW is reused for irrigating 9,000 hectares in Damascus. A further 9,000 ha are irrigated with RWW in Syria, while 40,000 ha are irrigated with untreated wastewater (Jiménez and Asano, 2008a).

Less than 7% of crops irrigated with RWW in the Allepo region are vegetables as authorities' rules and regulations have them uprooted based on their human risk reduction policy (Qadir et. al. 2010).

6.11. Lebanon

In Lebanon, 310 million m^3 of wastewater were produced in Lebanon by the domestic and industrial sectors (FAO AQUASTAT). Of which, 56 million m^3 of wastewater were treated and 2 million m^3 were used for informal irrigation (FAO AQUASTAT

6.12. Jordan

Jordan is one of the driest countries in the world with per capita of water supply in the country amounts to 148 cubic meters onl (http://www.dos.gov.jo/). Agriculture is the major water user which accounts for 60% of total water resources withdrawn. Both surface and groundwater resources are under significant pressure.

Wastewater has been used for irrigation in Jordan for several decades. In the Jordan Valley, RWW is mixed with freshwater and then used for unrestricted irrigation. Wastewater represents 10% of Jordan's total water supply (WaDImena, 2008) and up to 85% of its RWW is being reused (MED WWR WG, 2007). The inclusion of wastewater reuse in the country's National Water Strategy since 1998 was a signal of placing a high priority on the value of reclaimed water. There are about 27 wastewater treatment plants in operation which is producing 121 Mm^3/year of TWW (approx. 67% of total wastewater produced).

6.13. Bahrain

Bahrain is treating almost 50% of the total wastewater generated (151 Mm^3) and 16 Mm^3 is reused (FAO-AQUASTAT).

Several field trials have been conducted in Bahrain relating to heavy metals and RWW. Safi et al (2012) studied the effects of irrigation with RWW on date palm fruit, leaf and soil for heavy metal content. The results indicated that by irrigation with tertiary RWW for 15-20 years, there was no significant increase of Pd and Cd concentrations in the soil, no significant increase of Pd and Ni concentrations in leaf tissues and no significant increase in Ni, Cd and Cr in the Date Palm fruits.

From July 2010 to June 2011, Ahmed (2013) conducted a study across six farms irrigated with RWW aimed at studying the effect of irrigation with RWW on the concentration of heavy metals in soil and alfalfa crop. The results indicated that the concentration of heavy metals in RWW did not exceed the international standards, except for cadmium, which was double the allowable limit. Ahmed (2013) concluded that RWW can be used safely for irrigating fodder crops with continuous monitoring of heavy metal content in the soil and the crops irrigated with it.

7. Institutions & Policies

Challenges faced in the RWW use realm result largely from lack of political will, inadequate investment and insufficient institutional capacity or coordination despite blame being put largely on lack of funds, lack of technical information or inadequate knowledge of impact. There lies fear of economic repercussions in (international) agricultural trade, where governments are hesitant to acknowledge use of wastewater for irrigation, and therefore they cannot implement food safety and other phytosanitary measures (Qadir et. al., 2010).

When the concept of using RWW is embraced, authorities struggle to obtain sufficient concrete data/evidence, and often do not have enough technical and management options available to develop legislation and policy for reducing risks, or the capacity to enforce them. And where they have been, they often involve unrealistic criteria that are not context-appropriate, and so implementation is rarely possible (Qadir et. al., 2010).

In order to develop strong policies relating to the use of RWW, Governments must be prepared to control the whole process within a broader framework of a national effluent-use policy that forms part of the national water resources plan. There needs to be links between national and regional/municipal levels and rural-urban lines so as to maintain links between the needs of different parties to ensure all objectives are being adequately achieved (Qadir et. al., 2010).

To be successful, a multiple-barrier approach is required to strengthen policy and regulations, including robust stakeholder collaboration between: different ministries (eg. agriculture, economic development, water resources, environment, public health, etc.) and their respective departments, the municipalities, institutions, and user representatives (including independent/livelihood farmers).

Laws and norms need to clearly define water rights, water quality, and agricultural restrictions (e.g., on crops, sites, soils, farming practices). Economic tools may also be useful, but they need to take into account that, in most developing countries, the agricultural sector experiences economic difficulties and that food security is essential. Therefore, social and political considerations should be taken into account when economic tools are applied. Also, in this regard, it must be considered that even though farmers wish to take advantage of the effluent, very often they are neither able nor willing to pay to subsidize the disposal cost of wastewater that is the responsibility of polluters.

Past research has culminated in the development of state, national and international guidelines for the use of RWW in agriculture in the USA and Australia. These guidelines have led to the successful development and continued operation of hundreds, if not thousands, of agriculturally based RWW schemes around the world. With historical proof for the successful use of RWW in horticulture established (Stevens 2006), where appropriate, the use of RWW should be embraced by society as an environmentally responsible method for recycling water and nutrients from society’s waste.

8. Conclusions and recommendations

The use of RWW for agricultural irrigation is often viewed as a positive means of recycling water due to the potential large volumes of water that can be used. RWW can have the advantage of being a constant, reliable water source and reduces the amount of water extracted from the environment. This literature review elaborates the benefits and risks associated with non-conventional water resources with more emphasis on research trials in the world but specific to the MENA region by using scientific and technical evidence to show that RWW can be a valuable and safe resource for crop irrigation that poses minimal risk to the soil, groundwater, and crops and is a key factor towards ensuring food security.

Water quality issues that can create perceived problems in agriculture, both on the crop itself and on the end user of the crops, include nutrient and sodium concentrations, heavy metals, and the presence of contaminants such as human and animal pathogens. Furthermore, risks from using RWW were not the same in all countries due to differences in RWW properties, soil, crop, climate and overall management of RWW as a water resource in agriculture.

In order to implement sustainable use of RWW and to contribute to food security, RWW use projects need to be planned and constructed for the long term and be based on local needs. It is essential to ensure continuous and sustainable monitoring programs/systems. For monitoring and enforcement of the standards and regulations are critical for ensuring public safety and protecting the environment. Moving forward:

- More research to study the long-term impacts of using RWW on the perennial crops as well as humans and animal health are needed.
- Standards and Regulations need to be revised and updated at the country-level, but also meet WHO standards.
- Extensive capacity building and training to support appropriate and safe RWW reuse are needed at many levels
- Public awareness on the safe use of RWW in agriculture must be raised as social acceptance remains a significant barrier to full practice roll-out.

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