Review

Sustainable use and management of non-conventional water resources for rehabilitation of marginal lands in arid and semiarid environments

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ABSTRACT

Land and water are the most basic resources for the food production systems. However, the looming water scarcity is threatening the sustainability of food production systems to feed the growing population. Crop production on marginal and degraded lands using the non-conventional water resources may help to achieve the food security for the future generations. Non-conventional water resources (NCW), viz. saline water, wastewater and grey water, can be used for food production systems after proper treatment for the rehabilitation of marginal and degraded lands. In this review, experiences and perspectives of use of NCW in Middle East and North Africa (MENA) region are discussed. The availability of NCW, their quantity and possible utilization in agriculture, landscaping, and forestry have been highlighted. In the MENA region, wastewater treatment facilities are limited with the exception of Saudi Arabia, UAE, Kuwait, Qatar and Jordan but consumption has been increased due to population increase. The changes in soil physical, chemical and biological parameters after using the untreated wastewater are also elaborated. The pragmatic strategies for NCW treatments including desalination, wastewater treatment; reuse of agricultural drainage water, groundwater extraction and rainwater collection have been described. Here we reviewed that, (i) Legislation should be done, to encourage farmers to use NCW and to grow genotypes which accumulate relatively very low amounts of metals in their edible parts, especially in pre-urban areas. (ii) Water treatment technologies should be advocated and implemented for use of NCW. (iii) The NCW reuse should be considered an integral component in every country's national development strategic plan. It was concluded that safe reuse of NCW has great potential that can only be effectively used through resource planning, environmental management and financing arrangements.

EY-WORDS: water-scarcity; non-conventional water; treated wastewater; grey water; land degradation; MENA region.

Table of Contents

1. Introduction

1.1 Greywater, rainfall water and cloud seeding as alternative water resources

2. Wastewater from refuse to resource

2.1. Characteristics of wastewaters

2.2. Municipal wastewater effects on soil physical, chemical and biological properties

2.3. Agricultural wastewater: effects on soil physical, chemical and biological properties

2.4. Indicators of soil quality in wastewater amended soil

2.5. Soil as biotechnological plant: an option for wastewater treatment

3. SUSTAINABLE USE OF WASTEWATER IN MENA MARGINAL ENVIRONMENT

3.1. Tunisia

3.2. Jordan

3.3. Lebanon

3.4. Kuwait

3.5. Syria

3.6. Palestinian Territories

3.7. Saudi Arabia

3.8. Egypt

4. Advantages or disadvantages of using non-conventional water

5. Policy issues and institutional support

5.1. Parameters of health significance

5.2. Elemental analysis of food and safe limits guidelines

6. Conclusion

1. Introduction

Land and water are essential resources for the production of food and constitute two of the most fundamental resources for mankind. Despite the importance of water for agriculture, it is essential for industrial and tourism sectors, for human life and nature conservation. However, global water scarcity is causing serious threats to further undermine important development progress (Rosegrant, 2016). The majority of water (about 80%) is used for irrigation in agriculture while global water demand has tripled together with the substantial decline in fresh water resources since 1950s (Gleick, 2003). Global agriculture is unable to feed world growing population that is projected to increase from 6. 7 billion (2005) to 9.2 billion by 2050, (UN, 2015). The present scenario demands expansion of agriculture towards marginal and degraded lands that could help to increase food supply avoiding the environmental and land degradation (Fargione et al., 2008). However, water scarcity remain the major bottlelink in arid and semi-arid regions especially Middle East and North Africa (MENA) (Alcamo et al., 2007; ABS, 2008; Fedoroff et al., 2010), where continued water demand by user (urban, pre-urban and industry) are threatening the food production, food security, and forestry sector (UNDP, 2007). Most of the Arabian Peninsula are classified as hyper-arid with aridity index <0.03 (UNCCD, 2004) and Oman is the driest country with 62 mm/year rainfall on average (FAO, 2010; 2011; 2017).

The renewable water resources pro capita decreased from 1250 m^3 in 1950 to 100 m^3 in 2007 and 76.2m^3 in 2014 (The World Bank, 2017) appearing the lowest in the world. Since agriculture depends mainly on irrigation and it consumes 80-90% of available water resources, the agricultural water demand is estimated to be 28.2 billion m^3 against the ground water availability of 18030 million m^3 in the Peninsula (The World Bank, 2017). For these reasons, non-conventional water resources could be used as an alternate option to partially counteract water scarcity with positive environmental effects on hydrological cycle, water reserves, green coverage and climate in the region (Haddad, 2011). Appropriate strategies for non-conventional water treatments have been proposed which include desalination, wastewater treatment; reuse of agricultural drainage water, groundwater extraction and rainwater collection (Djurma et al., 2014). Researches combining the socio-economic, physical and chemical impact of non-conventional waters, technical, biophysical, and safe and economical viable methodologies will help to create an integrated water management system that can be useful to rehabilitate marginal lands in arid and semiarid areas. Non-conventional water (saline water, treated wastewater and grey water) was successfully used in agriculture (cereals, oil seed crops, date palm, perennial forage grasses, vegetables, forestry and aquaculture); suggesting that if properly treated, this water has potential and capability to rehabilitate marginal and degraded lands for fulfilling the ever-increasing demand of food, feed and forage in the MENA (Hussain et al., 2016; Al-Dakheel & Hussain 2016; Qureshi et al., 2016). To find a sustainable solution to the increasing water demand, this manuscript reviewed the recent literature related to the availability of non-conventional water resources, quantity and their possible utilization in agriculture, landscaping, forestry and food crop production emphasizing and sharing knowledge's regarding the effects on soil quality and fertility. The aim is to provide a number of examples for countries for implementing water recycling and reuse projects and practices leading to safe and productive use of wastewater in different sectors but in particular way in agriculture.The objective is to develop guidelines that can be adopted by local governments in irrigation program for the rehabilitation of marginal lands in arid and semiarid countries in which the water-scarcity represents a growing real problem.

The use and treatment of non-conventional water resources are in turn considered below;

1.1 Greywater, rainfall water and cloud seeding as alternative water resources

Alternate water resources are an important asset in arid and semi-arid Arabian Peninsula that can be used for irrigation of salt and drought tolerant food, forage, oil seed crops and halophytes (Hussain & Al-Dakheel 2015; Hussain et al., 2016). Greywater is a valuable promising alternative resource whose use is increasing worldwide to compensate the lack of freshwater resources. Greywater comes from domestic use like bathing and washing clothes except toilets (Eriksson et al., 2002). In general, the volume of grey water accounts between 50% and 80% of the domestic household water uses (Eriksson et al., 2002; Redwood, 2008; Burnat and Eshtayah, 2010). The amount of greywater generation per capita in Gulf States is different based on several factors including lifestyles, age, and gender and water availability. Greywater account for 82% of fresh water consumption in Oman and originated from sinks, showers, kitchen (Jamrah et al., 2008, while the domestic generated grey water volume in Jordan is approximately estimated about 50 liters per capita per day (L/c/d) (Faruqui, and Al-Jayyousi, 2002), .Saving fresh water and using greywater for agriculture and landscaping has got much attention in North Africa. For example, According to Ghisi and Ferreira (2007) greywater can save up to 35% consumption of fresh water even if necessary precautions should be taken to avoid health risks due to the presence of bacteria and microbes in the greywater (Widiastuti et al., 2008) Greywater from different sources have different chemical compositions. The mixed greywater contains 10-8000 and 90-350 mg/L for COD and BOD, however, it contains low concentrations of contaminants compared to those in raw sewage water and black water (WHO, 2006). However, higher pH was observed in laundry greywater (Eriksson et al., 2002). The contaminants present in greywater are reported in Table 1. Fig. 1 illustrates the stages of greywater treatment useful to reduce the growth of bacteria, other microbes, organic pollutant and chlorine (Winward et al., 2008). In agreement with USEPA regulation (Misra and Sivongxay, 2009; Li et al., 2009); greywater can be used only after filtration, disinfection and biological treatment, to avoid ecosystem contamination. Based on the International Plumbing Code IPC 2000, greywater can be reused for toilet flushing (GWPP, 2005), if no detectable coliforms appear in 100 mL of the effluent, BOD is than 10 mg/L and the residual chlorine is more than 1 mg/L, pH equal to 6-9, and turbidity <2 NTU (Li et al., 2009; Al-Jayyousi, 2003). Grey water use, therefore, is under study and of interest to water management agencies and scientists. Therefore, different treatment techniques have been developed and installed, such as natural zeolites (Widiastuti et al., 2008); mulch tower (mulch, coarse sand, fine and coarse gravel) (Zuma et al., 2009); bio-reactor (Eriksson et al., 2002); aerobic and anaerobic bio-filters; bio-rotors and submerged aerated filters; bio-rolls (Allen et al., 2010; Friedler et al., 2010) chemically treatment through coagulants and ion exchange and artificial wetlands (Pidou et al., 2008 The implementation of grey water system management could help rural community to reuse a portion of their effluents for irrigation.

To augment the water scarcity, rainwater is another important non-conventional water resource that is widely used to alleviate the water scarcity (Cheng and Liao 2009). The methodology involves collection, storage and safe use of this water for agriculture, landscaping and forestry purpose. Several Arab countries with highly variable rainfall and transboundary waters have invested heavily in water storage and conveyance networks. These networks preserve water sustainability, ensure water availability despite erratic rainfall and reduce the risk of water related disasters (Kfouri et al., 2009). Water harvesting techniques can be broadly classified into: (1) macro-collection and floodwater harvesting and diversion methods, and (2) micro-collections methods, where the catchment area and the cropped area are distinct but adjacent to each other. Boers and Ben-Asher (1982) defined micro-collection; the system where the collection area was less than 100 m in length. Conversely, macro-collection techniques capture runoff water from hillsides or small arid watersheds. Rainwater can also be collected from rooftops or from sloping, rocky or crusting lands in cisterns. These types of systems are often used for domestic necessity or irrigation purposes. In Sweden, Brazil, and UK, harvested rainwater is serving as good fraction of potable water (Ghisi et al., 2007). In Jordan, about 15.5 million m^3/year water is collected through roof harvesting (Abdulla and Shareef 2009). In villages and rural environment, mostly harvested rainwater is considered clean and renewable water resource due to negligible air pollution. Rainwater can also be harvested in field by directing the surface runoff toward a rainwater reservoir or to agricultural areas. Furthermore, specifically designed water reservoirs (rainwater collecting ponds) can be used in certain locations depending upon geographic information system and topographical maps. According to Alkouri (2011), large semi-circular bunds may be develop to reduce erosion (16-53%) of annual rainfall (<100 mm). The success of this non-conventional water highly depends upon kind of soil, slope, rainfall, amount of runoff, socioeconomic situation, production methodology and water harvesting techniques.

Cloud seeding is a process of weather modification to change type of precipitation to attain cloud condensation. The latter has the advantage of altering the microphysical processes within the cloud. Cloud seeding also occurs through the procedure of ice nucleate in nature, most of which are bacterial in origin. It necessitates presence of water vapor in the atmosphere (Moseman, 2009). Recently, cloud seeding was carried out in United Arab Emirates (UAE) and stake holders from all the sectors (agriculture, industry, tourism) has welcome it. Cloud seeding involves flying light aircraft into the base of five or six clouds and releasing flares containing potassium chloride, sodium chloride and magnesium. The mixture encourages water vapor in the clouds to form droplets heavy enough to fall as rain. UAE with a growing population (10.4 million by 2020), there is huge pressure to search alternate sources of fresh water instead of relying on the desalinated water. Due to cloud seeding, UAE was successful to receive 287 mm of rain in Dubai that was the highest since 1977, where it had never exceeded the 120 mm. According to the studies conducted by the National Centre for Meteorology and Seismology (NCMS); The UAE, cloud seeding is much more cost-effective than the desalination method.

2. Wastewater from refuse to resource

2.1. Characteristics of wastewaters

Wastewater refers to all effluent from household, commercial establishments and institutions, hospitals, industries and so on. It also includes storm water and urban runoff, water effluents from agriculture, horticulture, aquaculture and livestock breeding. Various pollutants like pathogens, heavy metals, residual drugs, organic compounds, pharmaceuticals and health care products are present in the different types of wastewaters. The indiscriminate use of wastewaters for irrigation is associated with specific health risks (Table 2), and social, cultural, economic and environmental circumstances must be considered to meet quality parameters (WHO 2006, EPA 2012). The reduction of microbes and chemicals and public exposure are key points for decreasing the risks linked to public health, ecosystem and environment (EPA 2012; NRC 2012).

Therefore, it is imperative to treat the wastewater before its ultimate use. The different techniques, methodologies and procedures of wastewater treatments for utilization in agriculture, forestry, and landscaping are reported in Table 3. Smart wastewater management is a sustainable way to produce food in a safety way, assuring human health and ecosystem service with economic benefit. Treated wastewater (TWW) has been used in the developed countries worldwide, for agricultural, industrial, urban and recreational purposes (Bixio et al. 2006). Conversely the rate of wastewater treatment is still low in most countries of MENA region for inadequate public budgets dedicated to water reuse treatments or disposal options; inadequate information on the impacts on environment and human health and for having the perception of high cost of developing wastewater treatment systems and low returns without any assessment and feasibility studies (Keraita et al. 2008; 2010; Carr and Potter, 2013).

Because wastewater use in agriculture is a common practice, with approximately 20 million hectares of arable land worldwide irrigated with wastewater (Mateo-Sagasta et al., 2013), it is imperative to highlight and share knowledge about wastewaters impact on soil quality and fertility with the aim of identifying the perspectives of using wastewater in agriculture or degraded soil, and to emphasize the role of soil a means for wastewater treatment.

2.2. Municipal wastewater effects on soil physical, chemical and biological properties

The treatment and reuse of treated municipal water (MW) for rehabilitation of marginal lands, has become popular in arid and semi arid countries (Bixio et al. 2006; Xanthoulis, 2010). This has occurred as result of increasing fresh water scarcity, high cost of chemical fertilizers, availability of MW, rich in nutrients, near agricultural lands and high cost of advanced treatment. A central theme in the planning and practice of wastewater reuse in agriculture has been assessing the associated risks to humans, but less attention has been paid on the impact of MW reuse on soil ecosystem functioning which in turn govern the environmental equilibrium. The soil chemical characteristics are the first to be affected by municipal wastewater application (Singh and Agrawal, 2008), among which pH is the most vulnerable one. It shifts in short time outside the range in which nutrients are available for plant uptake; impair the nutrients available even though they remain in soil. Effluent irrigation changes the electrical conductivity (EC), through adding significant quantities of salts to the soil rhizosphere (sulphates, phosphates, bicarbonates, chlorides of the cations sodium, calcium, potassium and magnesium) and cause consistent increase in soil salinity (unless leaching by rainfall, clean water or excess irrigation occurs), but also an unbalance in nutrient ratio. Nutrient balance within soil is important for growth, biodiversity and smooth activity of soil microorganisms, which are directly responsible for soil quality and soil-ecosystem functioning. Therefore, C-N-S-P (100:10:1:1) balance, Ca/Mg ratios (>4), and the availability of potassium and micronutrients need to be analyzed, maintained and/or corrected before wastewater soil irrigation. The wastewater application results in sodium increment that leads to deterioration of soil structure with serious consequence on soil porosity, water holding capacity and soil microbial biodiversity. The MW possesses organic matter, macro- and micronutrients that may be useful for increasing soil fertility even if their indiscriminate addition can accumulate heavy metals, toxic components and pathogens. However, the effects depend on the period of effluent application (short and long term), concentration of toxic compounds, amount of heavy metals and pathogens but mainly on soil chemical and biochemical characteristics as reported in Table 4. Ines et al. (2016 and 2017) tested the short-term effects of municipal wastewater on carbonate soils (calcic-magnesia soils with course texture) following biological stabilization by pond treatment (TMW). Their results evidenced that total coliforms, fecal coliforms, *Escherichia coli*, and *Salmonella* spp. detected in TMW and soils were under the threshold as recommended by World Health Organization (WHO), and Salmonella was never found in TMW and in soil irrigated with TMW. The absence of pathogens suggested that the pond treatments (anaerobic, aerobic, facultative and mature ponds) were effective low-cost methods to reclaim wastewater lowering BOD, COD and pathogens (EPA, 2011). In a long-term experiment with clay-loam soils, Ganjegunte et al. (2017), reported that TMW improved soil fertility by increasing the concentrations of nitrogen and potassium even if the soil salinity increased with time. No detectable amounts of $PO_4^{---}$and heavy metals (As, Cr, Cd, Hg, Se, Pb) were present in the TMW samples and the pathogen load was within the threshold as recommended by the Environment Quality Standard Commission (EPWU, 2011). Hidri et al. (2013) with long-term experiments (10 years of treated wastewater drip irrigation) on sandy soil concluded that irrigation with treated wastewater (aeration system, mechanical screen, grit removal tanks, and sedimentation tanks) did not have negative effects on the measured soil parameters (pH, organic matter and cation exchange capacity). Transiently, TW increased soil microorganisms with significant resilience of soil ecosystem functioning, micronutrients, potassium and sodium in the soil, increasing the risk of sodification in the irrigated areas. Adhikari et al. (2014) found that physical properties of sandy soils remained unaltered, after irrigation with treated with wastewater, except saturated hydraulic conductivity, which significantly increased, SAR and Na^+ content that were 11-folds higher than control. Qureshi et al. (2016) evaluated the impact of TMW irrigation on the accumulation of heavy metals in sandy soils and vegetables and potential health risks to human associated with them following consumption. They reported a lower uptake of heavy metals by vegetables and health risks for human were insignificant. Meanwhile, they concluded that risk of human exposure to metal contamination can be significantly reduced by selecting appropriate crop species such as *Helianthus annuus* (Ibbini et al. 2009), *Ricinus communis* (Yashmin et al., 2016), *Alyssum species* (Barzanti, 2011), *buttonwood* (Hashemi (2011), *Phragmites cummunis, Typha angustifolia, Cyperus* (Chandra and Yadav 2011).

After conventional treatments, municipal wastewaters can be successfully reused, for agricultural purpose, to irrigate clay more than sandy soils. Considering that in sandy and marginal soils, specifically in arid and semiarid regions, wastewater irrigation increased the percentage of organic matters, total nitrogen K, P, Ca, Mg, Na, but mostly EC and sodium absorption ratio (SAR) with the probability of increase in soil salinity and structure degradation. Consequently, it was suggested to use the fresh and wastewater alternately. The irrigation could be done first with wastewater so that organic matter and nutrients could be used by soil microorganisms and plants and later, by fresh water so that salinity and nitrate accumulation in the soil would be lessened with considerable benefit for soil structure. Benefit and disadvantage of using TMW are illustrated in Fig. 2.

2.3. Agricultural wastewater: effects on soil physical, chemical and biological properties

Among the agricultural wastewaters (winery wastewater, wastewater from livestock feedlots and dairies, olive mill wastewater (OWW), swine wastewater (SW), and slaughter house wastewater (SHW), owing to their high pollution load, pose severe environmental problems, especially in Mediterranean areas where they are generated in huge quantities, and need to be disposed in sustainable ways (Dakhli, 2013a, b). OWW is characterized by large volumes, salinity, low pH, phytotoxic compounds (Chaari et al., 2015), and high organic load (chemical oxygen demand (COD, 40 to 200 g/L) (Mahmoud et al., 2012; Dakhli, 2015). Additionally, a great resistance to biodegradation due to the enormous presence of polyphenol and recalcitrant organic substances (10 to 12 g) was also observed (Mekki et al. 2007; Sidari et al., 2010). On the other hand, OWW is some xenobiotic-free vegetative effluent rich in water, organic substances, and in mineral nutrients, such as nitrogen, phosphorous, potassium, iron and magnesium (Mekki et al., 2006;

Taamallah, 2007). For the concomitant presence of valuable organic compounds and toxic chemical elements, that could affect, positively or negatively, the soil properties in respect of the prevalence of one class of compounds on another, many studies explored the effects of OWW on soil physicochemical properties. Even if numerous studies evidenced that the impact of OWW changed in respect to their composition and soil types, a temporary decrease in pH and hydraulic conductivity with a concomitant increase in salinity and bulk density were observed in soils with distinctive characteristics, leading to a generalization of these statements (Saadi et al., 2007; Sidari et al., 2010; Kapellakis et al., 2015; Rusan et al., 2016). The irrigation of clay soils with OWW induced accumulation of salts which caused disintegration of soil structure (Tamimi et al. 2016); on the contrary, the application of olive wastewaters to sandy soils resulted in a significant improvement of soil fertility due to its richness in organic matter and nutrients (Dakhli, 2016) but also an increase in soil electrical conductivity. Chaari et al. (2015) confirmed these results showing that annual application of three OWW doses (50, 100 and 200 $m^3\ ha^{-1}$) for nine successive years improved the fertility of Tunisian sandy soils, for the excessive amounts of organic matter and macronutrients present. OWW could be considered as an attractive alternative in semi-arid areas to implement the rehabilitation of sandy, sandy-loam, characterized by a scarcity of organic matter and water (Ammar et al., 2005; Mechri et al., 2008). It is suggested that soil fertigation through wastewater could be beneficial, if the simple and complex phenolic are under the threshold generating antimicrobial effects (Hachicha et al., 2009; Karpouzas et al., 2010). Siles et al. (2014) concluded that OWW amendment decreased functional diversity and altered microbial functional structures. Depending on its chemical composition, OWW can develop microflora by adding organic carbon to the soil or inhibit microorganisms and phytopathogenic agents by adding antimicrobial substances to the soil, highlighting the importance of a balance between toxic and beneficial compounds in OWW. In concomitance with the composition of OWW, environmental conditions must be a key factor on the effects of OWW on soils. The application of larger OWW volumes (160 or 320 $m^3\ ha^{-1}$) significantly increased the EC values (Sierra et al. 2007; Mekki et al. 2009), proportionally to the supplied volume. In any case, to improve their effectiveness, the amount of OWW to be added to the soil must consider the type of soil texture. The main beneficial and detrimental effects of OWWs on soils with different chemical characteristics and texture are summarized in Fig. 3. The intensive pig farming worldwide generates a huge amount of SW rich in organic matter and nutrients. However, when used indiscriminately and without agronomic criteria, high pathogens and pollution load may negatively affect soil structure, soil chemical properties; contaminate fruits crops and grazing animals and serious environmental hazards (Bertora et al., 2008). In a study on three acidic soils, soil microbial composition and properties were tested. They found that there was significant increase in Gram-negative bacterial population following wastewater application that also helped to increase the nutrients and organic matter in soil (Ma et al., 2015).

Apart from the importance of dose and composition of raw SW, Moretti et al. (2017) showed the importance of soil texture in the organic matter decomposition after successive applications of swine wastewater. They demonstrated that soil texture affected the availability of the added organic materials for soil microorganisms. Clay in soils formed complex with organic matter when amended with diluted SW effluent, maintaining long-term fertility and microbial stability. Fongaro et al. (2017) evaluated the survival, percolation and leaching of model enteric pathogens in clay and sandy soils after bio-fertilization with swine digestate. They reported that the survival of pathogens was significantly lower in clay than sandy soils, highlighting that OM content, soil texture, and rainfall are the principal factors that affected the survival and leaching of microbial pathogens and should to be considered prior to swine wastewater application in agriculture. In a two year study, Aparecida de olivera et al. (2016) demonstrated that the applications of pig liquid waste changed the nutrients and soil microbiota, contributing to improve the chemical and microbiological properties of sandy soils. Even if the SW contains nutrients and organic materials important for the maintenance and growth of microbial population, the prolonged use of SW, especially in sandy soil and at high doses induced lesser diversity of microorganism groups, consolidated the permanence of certain groups of the bacterial community, reducing soil biodiversity at the expense of soil ecosystem functioning but it also depends on soil pH and texture.

2.4. Indicators of soil quality in wastewater amended soil

Considering the contemporarily presence of valuable and detrimental organic and inorganic compounds in municipal and agricultural wastewaters (Dindar et al., 2015), it is a good practice to monitor the soil quality after the addition of wastewaters with respect to sustainable soil management. Soil enzyme activities are early and sensitive indicators of changes in soil ecosystem functioning in both natural and anthropized environments (Muscolo et al., 2015), and can be used to determine soil alteration caused from pollution in a short and long term. Chen et al. (2008) reported an increase in the activities of the enzymes involved in C, N, P and S cycling after soil irrigation with reclaimed municipal wastewater. The results indicated that enzyme concentration (catalase, alkaline phosphatase, acid phosphatase, dehydrogenase, and urease) were good indices to explore the reclaimed MW impact on soil quality. Armenta et al. (2012) demonstrated that the application of municipal wastewater to soil, increased the soil microbial biomass and enzyme activities, acid and alkaline phosphatases (mostly urease activities). Regarding agricultural wastewaters, Gamba et al. (2005) demonstrated that OWW had no toxic effects on soil microflora, and had stimulated their metabolic activity (Sidari et al., 2010). Balota et al. (2011) demonstrated that pig slurry application decreased the ratio of soil enzyme activities per unit of microbial biomass carbon over time. King et al. (2015) supported the previous findings stressing that pig slurry application enhanced in a short time soil enzyme activities, while repeated additions of swine wastewater (rich in nutrients) to soil contributed to reduce the enzyme activities after a long period of time. Antonious (2016) showed that the addition of swine wastewater to soil increased urease and invertase activities, suggesting their use as markers of soil biological activity after the addition of soil amendments. Accordingly, to the above reported findings, urease is the enzyme whose activity mostly increased after any kind of organic amendments. Therefore, it was observed that enzyme, urease, is very important indicator for measuring changes in wastewater-amended soils.

2.5. Soil as biotechnological plant: an option for wastewater treatment

The major goals, in any wastewater treatment system, are the removal of pollutants that may cause disease before they contaminate groundwater. The soil's ability to purify wastewater is well recognized (Kadam et al., 2008, 2009; Aguilar et al., 2011) and naturally occurring soils (due to their chemical features), have varying capacity to accomplish the pollutant removal. In an effective wastewater treatment system, the most important soil properties, include unsaturated soils to promote aerobic conditions, soil deep enough to remove all the pollutants; soil permeability to air and water. Filtering is a physical treatment process and soil depth is important in removal of different pollutants present in diverse wastewaters. As water moves through the small soil pores, wastewater particles are removed, thus eliminating the cloudiness. After passing through 30 cm of soil, the wastewater was very clear (Mahmoo et al., 2013), the ammonia, was transformed into nitrate and the bad odor removed only if the wastewater filtered through a 60 cm soil layer (Mahmoo et al., 2013). Most of the pollutants like phosphorus and bacteria generally adhere to soil particles and thus can be removed from wastewater, only if passed through soil layer of 50 -120 cm (Al-Haddad et al. 2015). For the above mentioned reasons, the soil can be considered as the best treatment plant that can help to protect the environment and human health.

3. SUSTAINABLE USE OF WASTEWATER IN MENA MARGINAL ENVIRONMENT

Arid and semi-arid Middle East and North Africa (MENA) regions, where the fresh water resources are extremely scarce and under serious threat, have recently started to use treated municipal wastewater for irrigation. The different countries in MENA region are using different wastewaters that are differently treated on the basis of the kind of wastewater produced (Table 5).

3.1. Tunisia

Tunisia has recently started to use TWW for irrigation purposes. Bahri (2008a) stated that olives and citrus orchards in Tunisia have been irrigated with low quality of brackish water and TWW, since 1965, covering an area of 600 ha. In 2008, TWW plant facility in Tunisia became 61. About 0.24 billion km^3 of wastewater is now collected, and utilized for irrigating forage, industrial, cereal and fruit crops (Chenini 2008). Most farmers are using treated wastewater for cultivation and paying subsidized prices, because there is no availability of other fresh water sources (Bahri 2008a,b). Mahjoub and coauthors (2018) gave an overview on the status of the agricultural use of treated wastewater in Tunisia, highlighting its progress. The main focus was on the social dimension and the perception of end-users. The use of wastewater in flourished, exceptionally well. The success of its use was based firstly on the perception of the financial benefit and secondly on the lack of fresh water resources in the region. the acceptance of farmers was high, the reluctance of consumers was still impeding market share; more relaxed regulation together with good practices is suggested as option to improve the situation. In Tunisia, wastewater is distributed to farmers by the local Agricultural Development Authorities, which are responsible to the Ministry of Agriculture. These Authorities construct and maintain the wastewater distribution system. They distribute the wastewater to the farmers according to an organised delivery schedule and collect revenues from the sale of the wastewaters. The farmers are responsible for on-farm distribution, and the cost to the farmer is \$0.031/m^3 of wastewater supplied. Costs are influenced by the necessity of pumping, provision of infrastructure for pipelines, distance from the source to point of application, and type of application. In any case iIrrigated agriculture benefits from the high nutrient levels present in wastewater, thus reducing the need for fertilizer applications (Mahjoub et al., 2018).

3.2. **Jordan**

In Jordan, there is a rapid development in the agriculture and industrial sector with a consequent increase in the demand of fresh water resources that are, of course, extremely limited. Keeping in mind the water scarcity situation, Jordanian government has given top priority to the use of TWW (Hussein and Abu-Sharar, 2002). The main water resources in Jordan are surface and ground-water. Currently, Jordan has 28 operated wastewater treatment plants all over the country; and As-Samra Wastewater Treatment Plant is modern and representing the core of Jordan water management strategy. In Zarqa and Amman regions, the As-Samra plant was processing 367,000 m^3 per day to fulfill water shortage during 2010. Recently, the plant was expanded and modernized to treat up to 530,000 cubic meters of wastewater per day and provide sanitation services to about two million individuals of Capital Amman and Governorate of Zarqa; whom are considered as the first and third most populated cities in Jordan, respectively. The As-Samra Wastewater Treatment Plant is considered as the largest treatment plant in Jordan that treats about 77% of total reclaimed wastewater. The As-Samra wastewater treatment plant is considered one of the largest plants in the region that uses the modern technology to ensure the highest purifications. The amount of daily dry solid sludge production is about 118 ton from As Samra treatment plant. There are around 3,000 donums of 20-30 farmers adjacent to the As-Samra Plant cultivated forage mainly clover and sorghum irrigated with this TWW.

3.3. Lebanon

The majority of wastewater has been used for irrigation in different parts of Lebanon meanwhile, the remaining part was discharged in the lakes, rivers and small streams and later used in Akkar and Bekaa region. From a study conducted by FAO (FAO AQUASTAT 2009) domestic and industrial sectors in Lebanon produce more or less 310 million m^3 of wastewater and about 4 million m^3 was treated during 2006 and used for irrigation the agriculture fields. It has been observed that the use of raw quality untreated wastewater is a widespread practice still current in Lebanon, out of the control of regional and local authorities, with ignorance of the harmful effects on human health and environment. The harmful consequences are mainly due to pathogens, heavy metals and other undesirable constituents (Qadir et al., 2007; Qadir et al., 2010). For instance, in many agricultural areas in Lebanon, sewage water is used to irrigate vegetables which are normally eaten raw, without any control and any national legislation (Dib and Issa, 2003). The untreated wastewater for agricultural purpose is causing allergies, dermatological, gastrointestinal illness and other serious health consequences for human health. Risk management and precautionary solutions are urgently needed to prevent the adverse environmental and health impacts coming from inappropriate wastewater irrigation practices (WHO, 2006).

3.4. Kuwait

The rapid increase in Kuwaiti population, coupled with fast industrialization and water demand for the agriculture sector, is causing rapid decline in fresh water. The water that the authorities are now supplying to the population is those obtained by desalination and groundwater resources. Ardiya, Jahra, and Riqqa are three wastewater treatment plants in Kuwait. Presently, these three plants produce 76.4 million gallons of treated effluents per day, with Biochemical Oxygen Demand, (BOD) of 10 mg L^{-1}. Sulaibiya is another Wastewater Treatment plant producing

375,000 m³ that contribute to 26% of the country's overall demand. In Kuwait, the amount of treated effluent used for afforesting ration and alfalfa production not exceeded 15% of the total effluent. Kuwait Oil Company (KOC) recognized three Sewage Treatment Plants at Burgan (South Kuwait), Magwa (East Kuwait) and Umm Al-Aish Oasis (North Kuwait) to produce TWW that will be transported through water tankers to Kuwait Oasis, Subaiya Oasis, Spirit of the Desert, Umm Al Aish Oases and used as source for irrigation (Yousef et al. 2015).

3.5. Syria

The Damascus and the Homs wastewater treatment plants account for more than 98% of all TWW with capacities of 177 million m³/year and 49 million m³/ year, respectively. There were also plans for construction of new TWW plants at different spots in the country especially at Latakia and Allepo. According to an estimate, about 9000 hectare areas in Damascus are being irrigation with TWW (177 million cubic meters (WHO 2005). Treated wastewater is available in some Syrian cities including Damascus, Aleppo, Homs, Hama and Salamiyeh, where it is applied for irrigation purposes using improved surface irrigation methods. Through different irrigation projects, a wastewater treatment plant has been established to test the modern irrigation techniques on forage crops and other high-value crops and to evaluate the economic production. Barley and triticale were also cultivated using treated wastewater produced by Salamiyeh Sewerage Treatment Plant during the season 2014-2015. Salinity-tolerant crops such as barley, soybean and oil rape were also cultivated at famers' sites in three villages in cooperation with Directorate of Extension. The field work and demonstration had a significant impact on the farmers' adoption of these new crops using treated wastewater. The success of using treated wastewater in forage production, especially in Salamiyeh has led to wider interest and demands.

3.6. Palestinian Territories

Wastewater management needs significant investment for collection, treatment and disposal of treated effluent. However, collection system of effluent is highly disturbing and lacks management practices due to limited sewage networks. Meanwhile, only few regions have the facility of wastewater treatment. During 2015, the total wastewater generated was estimated at

114.36 MCM, from which 65.82 MCM are generated in the West Bank and 48.54 MCM are generated in the Gaza Strip (ARIJ 2015a, b, c). Meanwhile, the capacity building and financial and technical training is lacking to handle the water scarcity situation and to develop and manage the non-conventional water resources.

The Palestinian Authority has adopted different policies for water resources management, National Water action plan and water law facilitate the use of TWW and to conserve fresh water. There are seven main wastewater treatment facilities in the Palestinian Territories; three are in Gaza strip while the rest in the West Bank. In the Palestine rural areas, several NGO’s also run small scale water treatment plants in the unsewerd rural areas of the West Bank. However, several of these TWW facilities lack the trickling filters and natural treatment plants preceded by septic tanks. In these small treatment units, the organic matter and suspended solids were removed but other matters like nitrogen removal was limited (Mustafa, 1996). The results of a small-scale survey indicated local habitants were ready for purchasing and consuming the crops and vegetables irrigated with TWW, if these are hygienically free of contaminants.

3.7. Saudi Arabia

Previously, the wastewater and effluent were being disposed of in rural areas, wadis and small towns and maximum to the Arabian Sea (Abu-Rizaiza, 1999). However, new established National Water Company has invested $23 billion for sewage collection and treatment infrastructure. This has facilitated the wastewater network coverage and made a partnership between public-private. Now, Saudi Arabia has emerged third largest water reuse market at the global map following USA and China (Abu-Rizaiza, 1999). About 672 million m^3 of wastewater per day was collected in the country while its consumption was less than 20% at the end (Al-Musallam, 2006). There were 30 major wastewater plants for treatment at different levels in 1999 and they were treating approx. 1,426,000 m^3/day wastewater (Jimenez and Asano, 2008). The agriculture sector in Saudi Arabia offers the greatest scope of TWW consumption, while treatment plants had insufficient capacity to handle and treat effectively large quantity of waste water that might cause potential health risks to the public due to the presence of bacteria, virus and microbes in the wastewater, if not treated at the appropriate level (Qadir et al., 2010; Hamoda, 2004).

3.8. Egypt

Egypt is another country in the Arabian Peninsula that is suffering the huge shortage of fresh water resources. About 3.5 billion m^3/year of municipal wastewater has been produced. However, there was only treatment facility for 1.6 billion m^3/year and additional facilities should be planned for treatment of remaining wastewater (Tawfic, 2008).The Cairo and Alexandria, both, generated approx. 2 billion m^3/year that belong to the Delta region while treatment plants in these regions serve 55% of the total population (Tawfic, 2008).

Egypt is starting to use treated wastewater in agriculture to irrigate industrial, oil seed, forage, fuel crops, including recently established agroforestry, and green belts along roads and for landscaping purposes. The methods of irrigation, soil type and specific crops that should be irrigated with TWW are regulated through Egypt Decree 44/2000, that recommend the irrigation of non-edible crops under controlled management that complies with appropriate water quality standards because of the content of pathogens and toxic chemicals that represent the main drawbacks of wastewater reuse in agriculture (Elbana et al., 2014). Monitoring the impact of reusing TWW will reduce health risks and environmental hazards. While Egypt's total water supply for 2015 was 76.4 × 109 m^3, the total refined (drinking/health use) water was 8.9 × 109 m^3, which generated wastewater of around 5 × 109 m^3. The primary, secondary, and tertiary treatments provided total TWW of 3.7 × 109 m^3, with respective percentages of 16.8, 81.4, and 1.8%.

Several organizations in Egypt are tasked with wastewater management and reuse. In addition to the Egyptian laws, legislation, and regulations enacted to protect the environment and water resources from pollution, the Egyptian Code for reusing TWW classifies wastewater into four grades (A, B, C, and D) depending on the level of treatment (Elbana et al., 2017). There are four key challenges to reusing TWW: social (public acceptance of wastewater reuse), management (crop selection, irrigation, and soil-based practices), human health risk, and environmental threats. There are significant opportunities to maximize the benefits of TWW reuse in Egypt as less than 75% of collected wastewater is currently being treated (Elbana et al., 2019). Finally, reusing TWW in agriculture could be the most reliable solution to overcome water scarcity and help to sustain water resources in Egypt (Elbana et al., 2017).

4. Advantages or disadvantages of using non-conventional water

The advantages of using non-conventional water are enclosed in the prospective of narrowing the gap between fresh-water availability and demand, moreover in water-scarce countries.

The local use of non-conventional water resources can meet the localized rural water need with minimum costs. The safe use of low quality saline water and treated wastewater for irrigation of non-food crops, landscape and gardening, agroforestry, vegetable production, and oil seed crop as well as food crops could contribute considerably to the reduction of 'water stress' and 'water scarcity' in marginal environments (Qadir et al., 2004, 2007; Al-Dakheel et al., 2015; Hussain and Al-Dakheel 2015; Qureshi et al., 2016), pushing its use and management strategy mainly in MENA. The advantages of using wastewater use had a higher benefit-cost ratio irrespective of the negative externalities associated with it. The net benefit from the crop production per US$ invested for waste-water irrigation returned US$ 5.56 on an average (Baig et al., 2011) depicting maximum net benefit of $ 12.97 in wheat crop. The economic impacts of reusing wastewater depend on the degree of treatment and the nature of the reuse. The costs and benefits should be considered in the context of the specific reuse approach. In Kuwait, central and western regions possess brackish ground water. Mostly, agriculture and farming areas are located in Abdally and Wafra areas, where farmers need significant amount of water for irrigation. These regions are totally dependent on desalinated sea or brackish water that use independently of treatment costs.

Among the disadvantages there are exactly the treatment costs, desalination cost is (about $1.5-$3 per m^3) that is quite high and not practicable forever (Al-Rashed et al. 1998). Therefore, the government agencies mainly in poor area should have to look into alternate water resources as NCW to meet irrigation demands. The disadvantages of using not treated brackish water, are mainly related to the impacts on agricultural production system in terms of decelerated yield, decrease in soil fertility soil dispersion and compaction for high SAR and RSC (Qadir et al., 2007; Murtaza et al., 2010; Murtaza and Zia 2011). The disadvantages of using non-conventional water can be summarized as follow: expensive water treatments; construction of expensive and environmentally damaging dams; flooding of land for reservoirs, requirement of sufficient rainfall and large river catchment; insufficient knowledge about the technical and management options available for reducing the environmental and health risks associated with wastewater use; continued and uncontrolled use of untreated wastewater as an irrigation source.

5. Policy issues and institutional support

The countries in MENA region have limited knowledge shared from regional and international experiences for the future of waste-water reuse. Until now, policy-makers remained helpless in adapting the waste-water management agenda to their respective country's economic context. Multiple constraints have been highlighted to promote more widespread reuse. However, insufficient economic analysis of reuse and treatment options is reflected from the literature/studies undertaken in the MENA. Numerous studies underpin high costs and negative or low rates of return associated with waste-water treatment and in promoting its widespread use. Almost in all countries, relatively more preference for the use of freshwater is found. In addition, lack of effective price signals, difficulties in structuring financial deals, and inherent limitations are the most common findings (Chesrown, 2004; Agannathan et al., 2009). In UAE, and other Gulf countries as well, usually desalinated water is being used. The relative cost of future water delivery will increase due to urbanization processes, governance and political changes. The commitment from the allied departments in vital to formulate policy and implement.

5.1. Parameters of health significance

Many negative externalities are concomitant with the use of waste-water. These include salt-loads, various toxic elements (heavy metals and organic pollutants) and pathogens (virus, helminthes, protozoa, and bacteria). Due to the contaminations and hazardous materials, waste-water affects the soil environment and has bad impacts on human health. In contrast, total health benefits of US$5,500 per year were noticed from a waste-water treatment system for 1,500-people agglomeration elsewhere (UNEP, 2015). Water contamination-induced infections account for 70% of all common diseases and directly affect human health. Thus, the effects of untreated or poorly treated waste-water can potentially have deleterious effects on public health, environment, and economy. The poorly treated waste-water could be harmful to living beings and irrigated soils when implemented under uncontrolled or unregulated circumstances (Adewumi et al., 2010). Edokpayi et al. (2017) showed that wastewater effluents are major contributors to a variety of water pollution problems. The poor quality of wastewater effluents is responsible for the degradation of the receiving surface water body, lands and human health. Wastewater effluent should be treated efficiently to avoid the negative effects on the basis of enforcement of water and environmental laws to protect the health of inhabitants of both rural and urban communities.

5.2. Elemental analysis of food and safe limits guidelines

Guidelines for safe limits in different commodities are available especially those developed by UNEP, WHO, FDA, etc. The main source of accumulation of some metals into the food chain is water and further regulated by the soil characteristics. There is a growing body of evidence to show that the levels of arsenic (As) in rice could pose a threat for rice-loving people. However, As toxic levels could be found under special soil conditions. An action level of 100 parts per billion (ppb) has recently been proposed for inorganic As in infant rice cereal (FDA, 2016). For infants and pregnant women, FDA's has provided certain health care precautions and advices, to avoid the As toxicity. The framework consisting of 9 indicators for ensuring environmental, social and economic sustainability may be implemented for measuring performance of reliability, resilience and vulnerability.

6. Conclusion

In short, the present review indicates that the use of wastewater, grey water, rainwater and sowing of clouds as alternative to fresh water represents a valid strategy in the Middle East and North Africa (MENA) for the recovery of marginal and saline degraded lands. The use of wastewater could also represent a good opportunity for agriculture only if their treatment and use are regulated by laws universally established on the basis of scientific data that must be transversally adopted within all MENA countries. In several countries of MENA region, the wastewater treatment plants are limited, with the exception of Saudi Arabia, the United Arab

Emirates, Kuwait, Qatar and Jordan; while their agricultural production increased due to the use of NCW. However, water reuse has still to overcome several challenges, such as a better planning and management of reusing operations based on a real water demand. This means a better institutional, regulatory, and organizational setting. Additionally, economic and financial practicability of water reuse need to be better considered. Training of farmers of economically poor countries of MENA that use untreated wastewater for irrigation with substantial documented risks to the soil ecosystem, environment and public health is necessary. From this emerges the need not only to implement the treatment technologies, but also to make them mandatory considering the reuse of wastewater as an integral component in the strategic national development plans.

It is thus important to invest in decontamination and treatment plants to allow their sustainable use. Planning and the sustainable use of different sources of NCW can be an economical and environmental investment for the agricultural development of respective countries.

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Table 1. The different contaminants in Grey and Wastewater.

Contaminant	Measured parameter	Significance
Suspended solids	T.S, Fixed solids, Volatile solids	Sludge deposits and anaerobic conditions
Biodegradable organics	BOD, COD	Depletion of oxygen and septic conditions.
Nutrients	N, P, K	Growth of undesirable aquatic life.
Stable organics	Chlorinated hydrocarbons	Toxic to environment
Dissolved inorganics	TDS, Ca, Mg, Na,	Excessive salinity and specific ion toxicity.
Heavy metals	Cd, Zn, Ni, Hg, Etc	Toxic
Pathogens	Bacteria, Protozoa, viruses	Can cause diseases

Table 2. The main human health risks from wastewater irrigation. (Source: Abaidoo et al., 2010)

Type of risk	Health risk	Who is at risk	Exposure pathway
Occupational risks (contact)	Parasitic worms such as *A. lumbricoides* and hookworm infections, bacterial and viral infections, skin irritations caused by infectious and non-infectious agents—itching and blister on the hands and feet. Nail problems such as koilonychias (spoon-formed nails)	Farmers/field workers Marketers of wastewater grown produce	Contact with irrigation water and contaminated soils. Contact with irrigation water and contaminated soils Contact with contaminated soils during harvesting Exposure through washing vegetables in wastewater
Consumption related risks (eating)	Mainly bacterial and viral infections such as cholera, typhoid, ETEC, Hepatitis A, viral enteritis which mainly cause diarrhea. Parasitic worms such as *Ascaris lumbricoides*	Vegetable consumers	Eating contaminated vegetables, especially those eaten raw
Environmental risks	Similar risks as those exposed to occupational and consumption risks, but decreasing with distance from farm	Children playing in wastewater-irrigated fields People walking on or nearby fields	Soil particle intake Aerosols

Table 3. Wastewater uses and appropriate treatment level (Source: EPA, 2012).

Increasing Levels of Treatment →				
Treatment Level	**Primary**	**Secondary**	**Tertiary - Filteration and Disinfection**	**Advanced**
Process	Sedimentation	Biological oxidation and disinfection	Chemical coagulation, biological or chemical nutrient removal, media filtration and disinfection	Activated carbon, reverse osmosis, advanced oxidation process, soil aquifer treatments, etc.
End User	No uses recommended	Surface irrigation of orchards	Landscape and golf course irrigation	Indirect potable use, including groundwater recharge and surface water reservoir augmentation
		Non-food crop irrigation	Food crop irrigation	
		Restricted landscape impoundments	Vehicle flushing	
		Groundwater recharge (for non-potable uses)	Toilet flushing	
		Wetlands, wildlife, habitat, stream augmentation	Unrestricted recreational impoundment	
		Industrial cooling processes	Industrial systems	
Acceptance	**Increasing acceptance level for human exposure →**			
Cost	Increasing cost levels →			

Table 4. Summary of the effects of treated and untreated municipal wastewater in short and long term irrigation on selected soil chemical and biochemical properties

	Untreated municipal wastewater				**Treated municipal wastewater**			
Parameters	Short term		Long term		Short term		Long term	
	clay	sandy	clay	sandy	clay	sandy	clay	sandy
Pathogens	-	-	-	+	-	-	-	+
Nutrients	+	+	+	+	+	+	+	+
EC	-	+	-	+	-	+	-	+
SAR	-	+	-	+	-	-	-	+
Heavy Metals	-	-	-	+	-	-	-	+
pH	+	+	+	+	+	+	+	+
Texture	-	-	+	+	+	+	+	-
Soil biodiversity	+	-	+	-	+	+	+	-
Porosity	+	-	+	-	+	+	+	-
Salinization	-	+	-	+	-	+	-	+
Organic matter	+	+	+	+	+	+	+	+

Table 5. Total water withdrawal, raw wastewater generated, and treated wastewater in the different Arab countries.
(Source: FAO AQUASTAT, accessed May 2018).http://www.fao.org/nr/water/aquastat/data/query/results.html

Country	Total internal renewable water resources (IRWR) (10^9m^3/year)	Produced municipal wastewater (10^9m^3/year)	Treated municipal wastewater (10^9m^3/year)	Not treated municipal wastewater (10^9m^3/year)	Treated municipal wastewater discharged (secondary water) (10^9m^3/year)
Algeria	11.25 (2012)	0.820 (2012)	0.324 (2012)	0.496 (2012)	
Egypt	1.800 (2012)	7.078 (2012)	4.013 (2012)	3.065 (2012)	3.011 (2012)
Libya	0.7I0 (2012)	0.504 (2012)	0.04 (2008)		
Morocco	29.00 (2012)	0.700 (2012)	0.166 (2011)	0.501 (2011)	
Tunisia	4.195 (2012)	0.287 (2009)	0.226 (2010)	0.063 (2009)	0.158 (2010)
Bahrain	0.004 (2012)	0.151 (2011)	0.076 (2012)	0.072 (2011)	0.060 (2012)
Kuwait	0.000 (2012)	0.292 (2010)	0.219 (2012)		
Oman	1.400 (2012)		0.009 (2010)		
Qatar	0.056 (2012)	0.274 (2008)	0.117 (2012)		0.013 (2012)
Saudi Arabia	2.400 (2012)	1.546 (2010)	1.063 (2010)	0.483 (2010)	0.060 (2010)
United Arab Emirates	0.15 (2012)				0.047 (2012)
Yemen	2.10 (2012)	0.1315 (2010)			
Iran	1289(2012)	3.5480 (2010)	0.885 (2012)	2.727 (2010)	
Iraq	35.2 (2012)	0.5800 (2012)			
Israel	0.75 (2012)	0.5000 (2010)			
Jordan	0.68 (2012)		0.113 (2012)		
Lebanon	4.80 (2012)	0.3100 (2011)			

Palestinian Territory	0.812 (2012)				
Syrian Arab Republic	7.13 (2012)	1.370 (2012)	0.550 (2012)	0.82I (2012)	0 (2012)
Turkey	227 (2012)	4.073 (2012)	3.257 (2012)	0.816 (2012)	