Potential of treated wastewater usage for adaptation to climate change: Jordan as a success story

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Abstract

Jordan sustainable development is obstructed by severe water scarcity that induces imbalances and shortages of water supply for various uses especially under high population growth rate, sudden immigrations, and climate change. Reserving water for drinking by treating WWTPs effluent and reusing for non-drinking could be a solution. This paper investigated the capability and contribution of the existing WWTPs' effluent for reuse in agriculture sector as an adaptive measure. The paper provided clear understanding for the current and future climate changes impacts, developed climate change and water policies, current water resources and demands for agriculture sector, and suggested adaptive measures. Further, it emphasized on characterizing the WWTPs and quantification of effluent taking into account the satisfaction to Jordanian standards and guidelines. Major WWTP's effluents are within Jordanian standards; however some WWTP's have concerns to microbial quality that restricts their reuse. Samra WWTP effluent can be used for highly restricted class of cooked vegetables, parks, and playgrounds. The results demonstrated that wastewater reuse can be set as integral part of water resources and the national water budget, can solve environmental problems, and can be a feasible adaptive option when managed properly. Further recommendations for WWTP operations, managements, reuse, and monitoring are included.

Key words: climate change adaptation, treated wastewater reuse, agriculture

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1. Introduction

The Hashemite Kingdom of Jordan, like many countries, is overwhelmed by water stress as a result of low precipitation rates, irrigation demands, industrial pollution, and untreated municipal sewage, consequently, Jordan is ranked among the top four most "water poor" countries in the world (Reference?). Fresh water resources in Jordan are seriously limited and are far under the water poverty line of 1000m^3/capita/year. On a per capita basis, available water from existing renewable sources is projected to fall from 150 m^3/capita/year in year 2003 to 90 m^3/capita/year by the year 2025 (MWI, 2009). The 2009 report of the Arab Forum for Environment and Development (AFED) stated that the "Arab countries (including Jordan) are in many ways among the most vulnerable in the world to the potential impacts of climate change, in a region which already suffers from aridity, recurrent drought and water scarcity" (AFED, 2009).

Jordan is experiencing a high population growth largely due to influxes of refugees and returnees to the country in response to political crises throughout the Middle East, rural to urban migration, and increased modernization and higher standards of living. These factors put increased stress on water availability and require a delicate balance to be struck between household and irrigation demands for water (Ammary, 2007). The Jordanian government is following a sustainability plan to manage the water scarcity. Aspects of sustainability plan of water management is to address vital issues as increasing available water resources from both conventional and non-conventional sources, modeling future water demands according to water use and growth rates, reducing water pollution through management and regulatory plans, and improving technologies for water resources management and waste water treatment.

The pressures on water resources are significantly exacerbated by climate change. The Intergovernmental Panel on Climate Change (IPCC) reports that by the 2020s approximately 0.5 billion people could see increased water resources stress as a result of climate change (IPCC, 2001). In Jordan, climate change will result in reduced rainfall and increased temperatures, further reducing the availability of water for drinking, household use, and agriculture (MoEnv, 2014). It is known that climate change is limiting the ability of Jordan to reach its poverty reduction and sustainable development objectives conceived under the United Nations' Millennium Development Goals (MDGs). The achievement of the MDG targets will depend mainly on effective planning for managing climate risks. This poses serious challenges for water resources management. "Adaptation to climate change is therefore a moral, economic and social imperative: action is needed now and water management should be a central element in the adaptation strategy of any country" (UN, 2009). Adaptation to climate change is, consequently, of urgent importance.

Among the possible water sector adaptations to climate change, several mega projects are either implemented (e.g. Deisi project) or under construction (e.g. the Red Sea–Dead Sea canal). The non-renewable Deisi aquifer water transportation project can supply up to 100 MCM/year upon completion, however this amount is enough only to replenish the anticipated increase in water demand. The Red Sea–Dead Sea canal project faces two main barriers: the very high capital costs, and transboundary political limitations. Non-conventional water resources in Jordan (wastewater reuse and desalinization) offer options for climate change adaptation. Seawater desalination requires high capital investment costs, and while brackish water desalination has a good potential of development, its quantity is not high as estimated in 2013(around 14 MCM/year) (MWI, 2015). Wastewater reuse has a low marginal cost and is proven to be a highly feasible option in Jordan. The objective of this paper is to investigate the potential of using treated wastewater in Jordan as a climate change adaptation measure through economical exchange of freshwater in the agriculture sector.

2. Current and Future Climate Change

Climate Change (CC) has gained widespread recognition only in the last few years despite the fact that the phenomenon has been set in motion by anthropogenic impacts over the past few decades. Since the entry of the UNFCCC into force in 1994, the Government of Jordan (GoJ) started working to fulfill its obligations to the convention by assigning the Ministry of Environment (MoEnv) as a focal point. The fulfillment of the national obligation to UNFCCC implies that Jordan should have the human, organizational, institutional and financial resources for developing the required tasks and functions on a permanent basis (NEEDS, 2010).

According to the Jordanian first, second, and third national communications report submitted to UNFCCC in 1999, 2009, and 2014, respectively, the estimated historical changes in climatic variables were significantly indicative for increase in temperature and reduction in precipitation (MoEnv, 1999; MoEnv, 2009; MoEnv, 2014). The scenario projections suggest warmer and drier climate, warmer summer, drier autumn and winter, with chances of heat waves, more drought and thus a contrasted water balance, and trends of extreme events. In respect to recent studies, the future projections using multi-model ensembles suggest an "extremely likely" rise in mean temperature between 3.1°C to 5.1°C by the end of year 2100, and a "likely" decrease in precipitation from 15 to 21% in the majority of the country (MoEnv, 2014).

2.1 Impacts of Climate Change on Water Resources

All conducted water studies in Jordan identify scarcity of water as one of the major barriers facing sustainable development: a situation that will be magnified by climate change. The impact sensitivity on water sector is high, indicating that the water system can be adversely impacted by climate change. Expected impacts are less recharge and replenishment, groundwater depletion and salinization, surface water contamination, soil erosion, desertification, disappearance of small springs, significant reduction in the discharge of major springs, violations and vandalism, land abundance, social conflicts and economic stresses (Abdulla et al., 2009; Altz-Stamm, 2012; MoEnv, 2014).

Agricultural production is closely tied to climate, making agriculture one of the most climate-sensitive of all economic sectors. Thus, the agriculture production is predicted to reduce significantly. According to Al-Bakri et al. (2010), a 2°C increase in temperature and 20% decrease in precipitation will decrease wheat yield by 21%, 35% for barley, and 10% for tuber and root crops.

2.2 Climate Change Policy and Water

The Hashemite Kingdom of Jordan stands at a critical juncture. The country has accumulated a wealth of knowledge and expertise in the climate domain. Through various initiatives, the government of Jordan has attained a clear assessment of the challenges posed by climate change and has also identified the measures needed to address these challenges. However, implementation has been lagging partly due to lack of financial resources, technical capacity, and weak linkages with national plans (MoEnv, 2007a; MoEnv, 2013a).

Jordan is classified as a Non-Annex I party and thus obligated for few commitments to UNFCC. Some of these commitments are to cooperate in preparing for adaptation to the impacts of climate change, take climate change considerations into account in their relevant social, economic, and environmental policies and actions, and promote and cooperate in exchange of relevant scientific, technological, technical, socio-economic, and legal information related to the climate system and climate change (MoEnv, 2013a).

On the other hand, Jordan has developed policies and strategies, and proposed plans to enhance development, management, and use of environmental resources. These policies included measures related to creating enabling environment, defining institutional roles, and establishing management tools which are the three main pillars required for the successful implementation of Integrated Resources Management (IRM). For example, the Ministry of Water and Irrigation (MWI) has developed a comprehensive water strategy entitled "Water for Life" for the period 2008 to 2022 (MWI, 2009). This strategy was updated in 2012, and mainly focuses on effective water demand management, effective water supply operations, and institutional reform. Climate change is called out in the strategy's vision and as one of its core principles. Jordan government has already identified a list of no-regret measures that are required urgently to address the water sector problems in the short and medium term. Several specific adaptation measures in the water sector have been identified within the main areas mentioned above (MoEnv, 2012; MoEnv, 2013b; MoEnv, 2013c).

3. Water Demand for Agriculture

3.1 Agricultural Land Area

Agriculture in Jordan is one of the most vulnerable sectors to CC because water resources and land are limited as most of the country is arid. Similarly, land use in Jordan is dynamic with obvious changes among the different types of use. The root cause of land use change is the high growth rate of population, which resulted in increased pressure on the limited natural resources of the country, particularly water. In general, availability of water resources is the most important factor controlling land use in Jordan. Land use in Jordan is dominated by non-cultivated areas, classified as rangeland, while agricultural areas only form a small proportion of the country (DOS, 2015).

According to the Department of Statistics (DOS) (2013), the total agricultural lands in Jordan is estimated to be about 2.6 $X10^5$ ha of which rainfed lands contributes about 60.4% of the total agricultural lands (i.e. $1.6X10^5$ ha), while irrigated lands represent about 39.6% of the total agricultural lands (i.e. 1.0 $X10^5$ ha). Most of the water in irrigated lands are used for trees (4.5 $X10^4$ ha) and for vegetables ($4.7X10^4$ ha), while irrigated lands allocated for forage crops are only 1.1 $X10^4$ ha. On the other hand, 74% of rainfed lands are planted with forage crops (1.1 $X10^4$ ha), while trees and vegetables represent only 24.5% and 1.5% of total rainfed lands, respectively.

3.2 Water Resources for Agriculture Sector

Jordan's irrigation water resources include conventional as well as non-conventional resources; the latter includes treated wastewater reuse and desalination. The conventional water resources consist of twelve groundwater basins (renewable and nonrenewable) providing 251 MCM/year and forming 55% of total water used for agriculture, and surface water providing 105 MCM/year making 23% of the agricultural use (Figure 1). According to (MWI, 2012) 53.7% of total water use is directed for irrigation purposes. The major sources for irrigation water for the year 2012 are treated wastewater reuse of 100 MCM/year compromising 22% of agricultural water use, groundwater, and surface water. There is no data available about amount of desalinized water used for agriculture since most of it is at the farm level.

The key project for sea water desalination is the Red Sea/Dead Sea Canal project. MWI is planning to start an initial phase of the Red Sea/Dead Sea (RSDS) Desalination Project at Aqaba, which includes the desalination of about (80-100) MCM/year by extracting (177-222) MCM/year of sea water from the Red Sea at the Northern Intake location. Al-Omari et al., (2013) modeled water demand under Red Sea/Dead Sea canal project until 2050, and they found that the domestic demand in Amman and Zarqa will be satisfied starting from the year 2022 until the year 2050. Furthermore, the deficit in the agricultural demand in the Jordan Valley, the largest and the main agricultural area in Jordan, for the year 2050 will drop to about 85 MCM for the RSDS scenario as a result of the increased treated wastewater flow to the valley.

3.1 Suggested Adaptive Measures for Agricultural Water Shortage

Climate change will affect agricultural yield and accompanied services (i.e. Food production, food security, people employed in agriculture) directly because of variations in temperature and rainfall that affect production, and indirectly through stresses on water resources. Other impacts of CC may include increases in seasonal temperature variability, and frequency of temperature extremes, (e.g., frost and heat waves), decrease in water availability (drought), shorter winters, shifting in growing seasons, short life of wild flowers and thus honey production, frequency distribution and severity of pest and disease outbreaks, incidence of fires, changes in soil quality, and failure to meet chilling requirements (MoE, 2009). Given the broad potential impacts of CC on water and agriculture, there is a need for both general and specific measures to adapt to these impacts. A safe and permanent source of water is just one adaptation that is needed.

Several studies (i.e. Hammouri et al., 2015) were conducted in Jordan to address the major impacts and adaptation measures for the shortages in water especially in agriculture sector. Suggested adaptation measures include anticipatory, autonomous and planned adaptation; water harvesting adaptation measures and land resources adaptation measures (e.g. land-use management, effective water use, reducing need for water, water conservation measures, modification of crop calendar); adopting a “Conservation Agriculture (CA)” approach; crop diversification; improved water management; better strategies on crop selection and planting, modification of policies; and implementation of action plans.

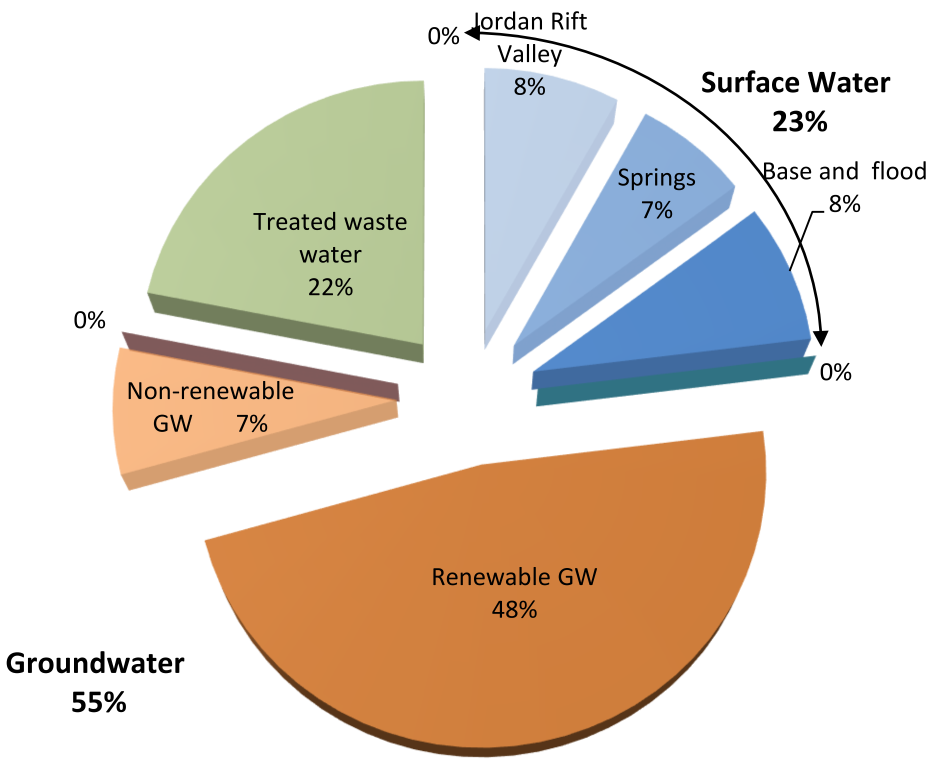

Figure 1: Agricultural water resources in Jordan for 2012

4. Using Treated Wastewater as an Adaptive Measure

Wastewater treatment plants, reuse, and monitoring are each the responsibilities of different governmental bodies. Among which, Water Authority of Jordan (WAJ) is responsible for the operation and maintenance of WWTPs, Jordan Valley Authority (JVA) is responsible for the operation of the water canals and water distribution to farmers (MWI, 1997a). Ministry of Environment (MoEnv) controls water quality of all surface water bodies. Ministry of Agriculture (MoA) is responsible for on-farm advice to farmers. Jordan Food and Drug Administration (JFDA) is responsible for the recently implemented crop monitoring for fresh fruits and vegetables, and the Royal Scientific Society (RSS) is the main actor for implementing monitoring programs of surface and groundwater (Al-Momani, 2011; Seder and Abdel-Jabbar, 2011).

In 2009, a new strategy “Water for Life 2008-2022” was issued based on vision-driven change effort (MWI, 2009). This water strategy outlines a strategic and integrated approach to the sustainable management of existing water resources. It sets out vision and key priorities for water by 2022. It identifies plans for future water and the actions that we will take to ensure that water is available for people, business and nature. The strategy included the goals of the MWI and the actions to manage water in Jordan. Both current status, and future challenges and goals for irrigation water were defined as part of the capability of the farmers to respond to these policies and strategies. The strategy stresses on the need for improved resources management with particular emphasis on sustainability of present and future uses, water protection against pollution, depletion of water resources, achieving the highest practical efficiency in the conveyance, distribution, application and use of water resources.

Adapting to climate change makes the affected communities forge ahead with efforts to find ways to cope with an uncertain future water supply. One solution is to reserve more water for drinking by recycling, treating, and using effluent from wastewater treatment plants for non-drinking uses such as manufacturing or irrigation. Using treated effluent for non-drinking purposes presents a win-win situation that provides ample high-quality, non-potable water to the applications that need it while reserving more drinking water for the residents of rapidly growing communities.

4.1 Existing wastewater treatment plants

As a result of Jordan’s ambitious campaign since the 1980s, 62.4% of the population currently is connected to wastewater collection and treatment systems (MWI, 2015). Currently, there are 31 wastewater treatment plants (WWTPs) (Fig. 2) serving the country with a designed total capacity of 606,305 m^3/day (equivalent to 221.3 MCM/year). The number of WWTPs has almost doubled since 1993 (14 WWTPs with total capacity of 58 MCM/year), indicating government and donors’ efforts to utilize the treated wastewater as a new and additional resource.

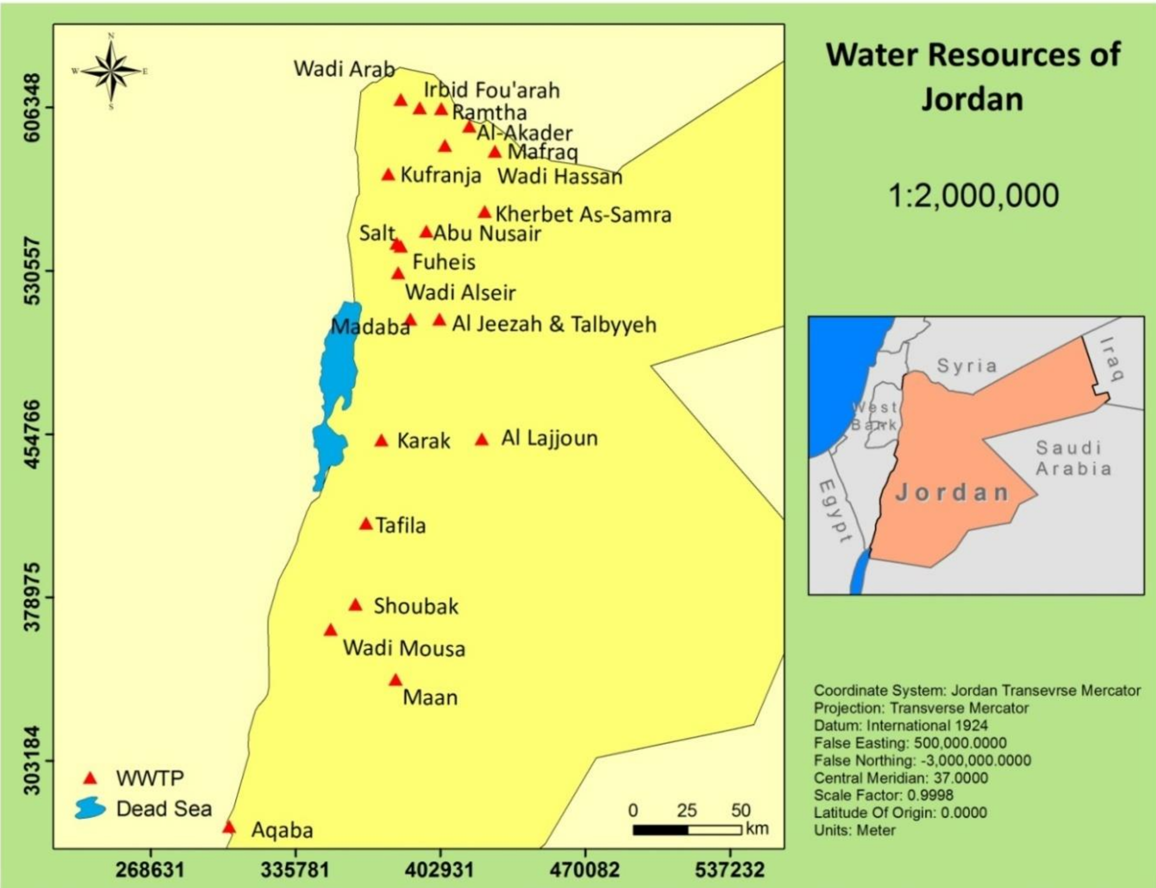

Figure 2: Spatial location of the existing WWTPs in Jordan

4.1.1 Existing WWTPs Characteristics

The major existing WWTPs in terms of capacity, inlet flow (m^3/day), adopted treatment technology, year of commissioning, design BOD, and the produced liquid sludge (m^3/day) are shown in Table (1). In 2013, national capacity of Jordan’s WWTPs was about 323,950 m^3/day (equivalent to 118.2 MCM/year) of raw wastewater. The main adopted treatment technologies are activated sludge, waste stabilization ponds, extended aeration, trickling filters, and oxidation ditches.

The total designed flow for all 31 WWTPs is about 606,305 m^3/year, by which the largest WWTP is the Samra WWTP in Zarqa that is designed to treat 364,000 m^3/day of raw wastewater (60% of the total designed flow of all WWTPs), followed by South Amman WWTP that is designed to hold 52,000 m^3/day (8.6% of the total designed flow of all WWTPs).In terms of actual received raw wastewater flow, the Samara WWTP is receiving 71.2% (i.e. 230,606 m^3/day) of the total flow rate that estimated about 323,950 m^3/day (i.e. 121 MCM/year).

The Samra WWTP treats wastewater released from the Zarqa river basin, which is part of the two populated cities of Greater Amman and Zarqa. The Samra WWTP drains its effluent into the King Talal Dam, which provides irrigation water for the Jordan Valley.

In the term of sufficiency of the designed flow as compared to actual inlet flow, all existing WWTPs have been upgraded to contain almost double the inlet flow. Before upgrading, most of WWTPs suffered from over-capacity flow, especially the Samra WWTP. Samra WWTP was the first plant in Jordan established in 1982 based on stabilization pond technology with a 68,000 m^3 daily inflow capacity and had served only 300,000 citizens at that time. However, due to the sharp population growth rate and sudden migrations (due to unrest situation in neighboring countries), the plant now serves about 2.265 million people living in the Greater Amman and Zarqa areas and thus was over loaded especially in 2002 (before the main upgrade) where it was receiving about 186,000 m^3 daily raw wastewater.

The latest upgrade from 2003 to 2008 was implemented on a Build-Operate-Transfer (BOT) basis. The plant is redesigned and upgraded to accommodate an average daily flow of 420,000 m^3 and a peak daily flow of 840,000 m^3. Currently, the plant consists of primary settling tanks, aeration and secondary settling tanks, anaerobic sludge digesters, biogas power generators and hydro-power generators (using the difference of water levels between Amman and Samra), and an odor control system.

According to MWI (2015), there are some WWTPs that still not functioning yet, namely; South Amman, Mu'tah and Adnaniyyah, Shallaleh, and Shouna Shamaliyyah because they are under construction or commissioning and will be operating soon.

4.1.1 Guidelines for Using Treated Wastewater

The use of treated wastewater for agricultural purposes entails certain restrictions to be developed and applied to ensure public safety and health. Main suggested crops to be grown under treated wastewater include industrial crops and forest trees, parks and playgrounds, cooked vegetables, field crops, or fruit trees. Non-food crops reduce human exposure to the water, which results to less stringent treatment and water quality requirements than other forms of reuse.

Worldwide, there are many organizations that have developed standards and guidelines for using treated wastewater. The most important guidelines are the ones published by the World Health Organization (WHO), and are mainly focused on the needs of developing countries. WHO guidelines specify the microbiological quality and the treatment method required to achieve this quality, which is limited to the use of stabilisation ponds since it is cheaper, simpler, and ensure removal of parasites which is the most infectious agent in the developing world. The aim of the guidelines is to protect exposed populations (consumers, farm workers, populations living near irrigated fields) against excess infection. Other important guidelines, the “Guidelines for Water Reuse,” were developed by US Environmental Protection Agency (EPA, 1992), and were updated in 2004.

Table 1: Wastewater Treatment Plants in Jordan for the year 2013

No.	Plant Name	Service Governorate	Designed flow m^3/day	Inlet flow m^3/day	Treatment Technology	Year of commissioning	Liquid sludge m^3/day	Remarks
1.	Samra	Amman, Zarqa	364,000	230,606	AS	1984 Old 2008 New	3,000	Good
2.	Aqaba- Mechanical	Aqaba	12,000	9,845.5	EA	2005	232	Good
3.	Aqaba-Natural	Aqaba	9,000	6,730.6	WSP	1987	150	Good
4.	Madaba	Madaba	7,600	5,172	AS	2005 New	250	Good
5.	Irbid (Central)	Irbid	11,023	8,132	TF & AS	1987	210	Good (Will be upgraded soon)
6.	Sult	Balqa	7,700	5,290.7	EA	1981Old 1994 Upgrade	130	Good
7.	Jerash	Jerash	9,000	3,680.8	OD	1983	100	Will be upgraded
8.	Mafraq	Mafraq	6,050	2,008.8	WSP	1988	47	Will be upgraded
9.	AinBasha (Baqa)	Amman, Balqa	14,900	10,208.6	TF	1987 Old 2000 Upgrade	250	Good
10.	Karak	Karak	5,500	1,753.4	TF	1988	10	Will be upgraded
11.	Abu-Nuseir	Amman	4,000	2,570.8	AS R,B,C	1986	60	Good
12.	Tafila	Tafila	7,500	1,380	TF	1988	8	Will be upgraded
13.	Ramtha	Ramtha	7,400	3,488.3	AS	(1987) 2004 New	100	Good
14.	Ma'an	Ma'an	5,772	3,170.8	EA	(1989) 2009 New	100	Good
15.	Kufranja	Ajloun	9,000	2,763	TF	1989	60	Will be upgraded
16.	Wadi-Essir	Amman	4,000	3,623.9	Aeration lagoons	1997	86	Good
17.	Wadi Al Arab	Irbid	21,000	10,264	EA	1999	240	Good
18.	WadiMousa	Ma'an	3,400	3,028.9	EA	2000	100	Good

19.	Wadi Hassan	Irbid	1,600	1,131.8	OD	2001	40	Good
20.	Tal- Almantah	Balqa	400	300	TF & AS	2005	7	Good
21.	Al-Ekeder	Mafraq	4,000	3,907.8	WSP	2005	92	Good
22.	Al-Lajjoun	Karak	1,200	853.1	WSP	2005	20	Under upgrading
23.	Fuheis	Amman, Balqa	2,400	2,221	AS	1997	16	Good
24.	Al-Jiza	Amman	4,500	703.9	AS	2008	17	Good
25.	Al-Merad	Jerash	9,000	1,000	AS	2011 (2010)	24	Good
26.	Shoobak	Ma'an	350	100	WSP	(2010)	2	Good
27.	AI-Mansorah	Ma'an	50	15	WSP	(2010)	0.4	Good
28.	South Amman	Amman	52,000			Under construction		
29.	Mu'tah and Adnaniyyah	Karak	7,060			Under construction		
30	Shallaleh	Irbid	13,700			Under construction		
31.	Shouna Shamaliyyah	Irbid	1,200			Under construction		

AS: Activated Sludge, WSP: Waste Stab Ponds, EA: Extended Aeration, TF: Trickling filter, OD: Oxidation Ditch
The data was obtained from MWI (2015)

Jordan developed its own regulations in 1982 that were very restrictive and prohibited the reuse of the treated wastewater for agriculture. Revisions were made due to the increased awareness of the opportunities of using treated wastewater and due to the progress in technology. The first Jordanian standard for wastewater reuse was issued by the Ministry of Water and Irrigation in 1995 and was updated in 2002 and 2006 for various qualities of water resources (Table 2). The Jordanian standard is based on WHO guidelines with some modifications to meet the local requirements and conditions.

Table 2: Criteria for treated wastewater reuse in irrigation and their allowable limits

Parameter	Unit	Jordanian Standards 2006[1]		
		A	B	C
BOD	mg/l	30	200	300
COD	mg/l	100	500	500
DO	mg/l	>2	-	-
TSS	mg/l	50	150	150
TDS	mg/l	1500	1500	1500
pH	Unit	6-9	6-9	6-9
Turbidity	NTU	10	-	-
Nitrate	mg/l	30	45	45
Total Nitrogen	mg/l	45	70	70
Total PO_4^{-2}	mg/	30	30	30
Escherishia Coli	MPN/100 ml	100	1000	Not applicable
Intestinal Nematodes	Egg/l	≤ 1	≤ 1	≤ 1

[1]A represents cooked vegetables, parks, playgrounds and sides of roads within city limits, B represents fruit trees, sides of roads outside city limits, and landscape, and C represents field crops, industrial crops and forest trees.

Table 3 shows the actual tests of main effluent criteria for the year 2013with the values higher than Jordanian standards had been shaded. All the treated wastewater plants have effluent pH lower than the standards (6 – 9 units), with highest value for Ma'an WWTP. The relatively low pH's permits the use of effluent for irrigation. Total suspended solids (TSS) comprise all particles larger than 2 microns, mostly inorganic materials, though bacteria and algae can also contribute to TSS. TSS is a specific measurement of all suspended solids, organic and inorganic, by mass. This means that TSS includes settleable solids, and is the direct measurement of the total solids present in a water body. As such, TSS can be used to calculate sedimentation rates, while turbidity cannot. In terms of water quality, high levels of TSS will increase water temperatures and decrease dissolved oxygen (DO) levels. This is because suspended particles absorb more heat from solar radiation than water molecules will. This heat is then transferred to the surrounding water by conduction. Warmer water cannot hold as much dissolved oxygen as colder water, so DO levels will drop. In addition, the increased surface temperature can cause stratification, or layering, of a body of water. When water stratifies, the upper and lower layers do not mix. As decomposition and respiration often occur in the lower layers, they can become too hypoxic (low dissolved oxygen levels) for organisms to survive. All WWTPs have TSS within limits of B and C categories except for four WWTPs; natural Aqaba (constructed in 1987 with waste stab ponds mechanism), Karak (1988 with trickling filter mechanism; needs upgrade), Al-Ekeder, and Al-Lajjoun (2005 waste stab ponds mechanism and reaches their maximum capacity; need extension and upgrade).

Total dissolved solids (TDS, mg/L) comprise all material dissolved in water including mineral salts and small amounts of organic matter, usually anything less than 2 microns. Values of total dissolved solids for WWTPs are lower than the standards except for Tal- Almantah plant that exceeded the standards for the three main categories. High TDS concentration in wastewater could cause toxicity through increases in salinity, or could lower the efficiency of biological treatment by resulting in low COD removal efficiencies.

The results in Table 3 show that most of the WWTPs have E-coli higher than the Jordanian standards for categories A and B except for Samra, Aqaba – Mechanical, Abu-Nuseir, Ramtha, Ma'an, Wadi-Essir, Wadi Mousa, and Wadi Hassan WWTPs. Thus, the exceeding WWTPs must have higher attention regarding sterilizing and chlorination.

Regarding COD, all WWTPs have values within Jordanian standards for categories B and C except Al-Ekeder, and Al-Lajjoun WWTPs where their COD exceeds the standards for all categories.

4.2 Quantification of Treated Wastewater Reuse

Treated wastewater is an essential element in the Kingdom's water strategy. The government in association with partners as USAID, GIZ, and others had developed several projects (e.g. Water Reuse Implementation Project and Reuse in Industry, Agriculture and Landscaping (RIAL, etc.) to improve the reuse of treated wastewater benefits and reform associated policies and regulations. With the current governance system, wastewater treatment falls within the responsibility of the Water Authority of Jordan (WAJ), whereas retail water utilities are in charge of the wastewater collection networks within their service area. Outside the areas serviced by those utilities, WAJ is the entity responsible for wastewater collection networks. Management of irrigation water for Jordan is centered around effective service delivery to farmers as well as management of surface water resources, particularly in the Jordan Valley, where this freshwater is delivered to water treatment plants for drinking water in exchange for treated wastewater which is used for irrigation.

In 2012, approximately 98.6% of the total treated wastewater is utilized for irrigation while 1.4% is used for industrial activities, and the treated effluent of major urban areas constituted about 22% of total irrigation water resources. Treated wastewater contributed to about 56% of the total water resources used for irrigation in the North and Middle Jordan Valley and this percentage is increasing on an annual basis due to the increasing amounts of treated wastewater from Samra WWTP and other plants discharging water toward the Jordan Valley, such as Wadi Al Arab WWTP, Wadi Es Sir, Kufranjah, and Sult.

The reuse of treated wastewater occurs both indirectly, after discharge of the effluent to a river and mixing with freshwater, and directly, e.g. without mixing with freshwater. According to MWI (2015), the total amount treated wastewater produced for the year 2013 is about 121 MCM, where direct use is estimated 27.9 MCM representing 23.1% of the total amount produced. Direct treated wastewater reuse was achieved through contracting with about 215 farmers to irrigate an area of about 14,184 dunums (Table 4). For the year 2013, the Samra WWTP accounts for 47% of the total direct treated wastewater reuse (13.12 MCM) irrigating about 3,990 dunums, followed by Aqaba- Mechanical that accounts for 12% (3.347 MCM), then Aqaba-Natural 6.7% (1.867 MCM) irrigating about 1,580 dunums, Madaba 6.5% (1.808 MCM) irrigating about 1,220 dunums, Ramtha 5.7% (1.591 MCM) irrigating about 1,302 dunums, Al-Ekeder 3.8% (1.051MCM) irrigating about 1,069 dunums, and Wadi Mousa 3.6% (0.992MCM) 1,069 dunums.

One of the first pilot projects for direct reuse was implemented in Wadi Musa with support from USAID, where water was used to irrigate a demonstration farm, and then the fields of nearby farmers (Seder and Abdel-Jabbar, 2011).Another pilot project was initiated from the small Wadi Hassan WWTP to irrigate green spaces on the campus of the University of Irbid, and commercial fruit plantations (KfW Development Bank, 2006).The general reuse of treated wastewater is directed for irrigating fodder, olives, fruit trees, palm trees, forest, nursery, wind breaks, turf, and landscape plants. The MWI have created a monitoring utility that is responsible for regular monitoring and testing of the treated wastewater quality, as well as the soil and the plant for environmental precautions.

Taking into account the percent of directly treated wastewater use either inside the WWTP vicinity or through contracts with farmers, some WWTPs are fully committed for direct use as Aqaba- Mechanical, Aqaba-Natural, Madaba, Mafraq, Ramtha, Kufranja, Wadi Mousa, Wadi Hassan, Al-Ekeder, and Al-Jiza (Talbiea). On the other hand, only 15% of the total produced treated wastewater from Samara WWTP is implemented for direct use. Thus indirect reuse of treated wastewater in majority is obtained from Greater Amman. Unfortunately, 77% of the total produced treated wastewater is indirectly used. The treated wastewater from the Samra WWTP flows through the Zarqa River into the King-Talal-Reservoir where it mixes with freshwater and flows thereafter into the King-Abdulla-Canal in the Jordan Valley where it further mixes with freshwater. The diluted treated wastewater is reused on about 4,000 farms covering 100,000 dunums in the Southern part of the valley (i.e. 25 times larger than the area irrigated with direct use), mostly using drip irrigation (Vallentin et al., 2009; Ulaimat, 2012). Similar situations to Samra plant exist at Sult, Jerash, Ain Basha (Baqa), Abu-Nuseir, Ma'an, Wadi-Essir, and Fuheis ranging from 4% to 46.3% direct use. On the other hand, other WWTPs have no direct use such as Wadi Al Arab, Tal- Almantah, and Al-Lajjoun plants where treated wastewater flows through river and valley to be used totally indirectly.

A major water reuse project is being planned to reuse water from three wastewater treatment plants in the area of Irbid in the North of Jordan through a project supported in the framework of Jordanian-German cooperation. As of 2006, only 14% of the wastewater from these plants was being reused. An explanation for this is that farmers in the Jordan Valley are reluctant to use the reclaimed water, which they perceive to be of poor quality, for irrigation. The wastewater thus flows into the Jordan River, unused. In the future, the treated effluent from the three plants will flow through a pipe into the Jordan Valley, generating hydropower from the elevation differential of more than 1,000 m. It will then be mixed with freshwater and delivered to the farmers in a quality that is acceptable to them.

5. Reuse of Treated Wastewater as a Success Story for Climate Change Adaptation

Counter acting increasing water demand due to population growth, rapid urbanization, and threats of climate change by allocating new resources is, on its own, a monumental challenge. In Jordan, this challenge is further exacerbated by the need to satisfy the competing water demands of various sectors. Water is considered the critical constraint for sustainable economic development of Jordan. Jordan is a small, but growing country with limited and fragile water resources and economic situation where water per capita has dropped to 86 M^3/capita/year: thus ranking Jordan as the water poorest country of the world.

Ensuring an adequate, safe, and secure water supply is economic development hurdle for Jordan. Searching for the most affordable adaptation options does not always yield the safest option. There are high risks of water quality deterioration due to rapid growth, and unplanned landuse actions threaten the safety of the remaining unsecured and limited water resources. While treated wastewater reuse has been used for a long time in Jordan, the question remains: Is this option is safe and sustainable? Given the competing demands for fresh water resources between the different water sectors, can this conflict encourage wastewater reuse in agriculture? Looking over the history of water demand and supply in Jordan, treated wastewater reuse can help meet the demand for freshwater with low cost of treatment.

From environmental standpoint, the tremendous amounts of produced wastewater in urban areas are considered a problem by itself. The associated health problems (e.g. pollution, odor, vectors) and the investments needed in wastewater management infrastructure (mostly notable storage) is another problem. Thus, treated wastewater reuse results in environmental, economic, and public health advantages over effluent disposal.

The reuse of treated wastewater in agriculture supplements available water for irrigation and thus makes available freshwater to be reallocated within the municipal water sector. Also, in comparison with other treatments such as desalinization, wastewater reuse is cheaper. However, in order to ensure environmental and public safety, appropriate water policies, standards, monitoring procedures, qualified regulators, technical expertise, and massive investments in operation and maintenance are required. According to Ghneim (2010), successful wastewater reuse in agriculture is not merely depending on the existence of wastewater networks and wastewater treatment plants. It relies on appropriate policies, legislations, institutional frameworks, and regulations. In addition, it depends on types of policy instruments for the implementation of wastewater policies.

The Jordanian government, with all its entities and divisions, has successfully established an acceptable institutional and legal framework including a wastewater management policy and wastewater standards. The development of these frameworks and standards came as a result of an experimental and flexible approach by adopting different policies related to wastewater reuse such as policies on sanitation, water pricing, standards, and health protection. According to current treated wastewater effluent chemistry as compared to standards, the wastewater reuse implementation has resulted in various positive impacts on the environment and the general human health of the society. Wastewater reuse in agriculture enabled communities to grow more food and make use of this valuable resource and its nutrients. In addition, the safe use of wastewater in agriculture would maximize public health gains and environmental protection (WHO 2006).

As the demands of the municipal sector and the urbanization increases in Jordan, the volume of generated wastewater also grows. With proper treatment, wastewater is currently suitable for different uses (e.g. irrigation, industry, aquifer recharge).Thus, treated wastewater is currently considered an important component of Jordan’s water resources. It forms an integral part of renewable water resources and the national water budget. Although the public acceptance for the reuse of treated wastewater is still low, the growing numbers of successful water reuse projects in Jordan as indicated by the increasing number of contracts with farmers is an indication of a promising future. In addition, wastewater can be a reliable source of water supply even in drought years.

The success of centralized wastewater treatment (e.g. Samra WWTP after being upgraded under BOT management) in either entire or partial use for agriculture production in Jordan Valley, demonstrates the success for treated wastewater to be an adaptive method for climate change to substitute freshwater in irrigated agriculture. On the other hand, effluent quality remains one of the main obstacles for wastewater reuse in agriculture. Historically, some WWTPs in Jordan were operating beyond their design capacity, which resulted in a poor quality treated effluent. Despite this, and according to ACWUA (2010), Jordan can be considered as the most advanced country with regard to quality control and safety schemes for reuse, as it has implemented a safety control system for agricultural produce grown on a mix of treated wastewater and freshwater. For example, Jordan has implemented a Crop Monitoring Program (CMP) for fresh fruits and vegetables produced in the Jordan Valley. However, this scheme is currently limited to the Jordan Valley and requires scale-up to a national level.

Table 3: Treated wastewater quality referred to the Jordanian standards

Plant Name	pH	BOD_5 mg/L	COD mg/L	TSS mg/L	TDS mg/L	E. Coli MPN/100 ml	Within/ not with Jordanian standards
Samra	7.85	9.91	71.09	17	1109.82	18	within
Aqaba - Mechanical	7.89	4.65	26.09	5.45	552.09	6	within
Aqaba - Natural	8.08		340.55 a	221.73 a b c	767.82	51293 a b	COD, TSS, E. Coli
Madaba	8.03	8.64	58.14	13.05	1178	254722 a b	E. Coli
Irbid (Central)	8.13	34.18 a	183.77 a	87.64 a	1064.73	208971 a b	BOD, COD, TSS, E. Coli
Sult	7.95		88.77	55.82 a	827.73	14620 a b	TSS, E. Coli
Jerash	7.86		412.86 a	106.14 a	1408.36	277353 a b	COD, TSS, E. Coli
Mafraq	7.98		364.18 a	125.09 a	1032.36	2628923 a b	COD, TSSE. Coli
AinBasha (Baqa)	8.09	49.5	109.52 a	33	1169.34	1027803 a b	BOD, COD, E. Coli
Karak	7.92		393.95 a	190.55 a b c	963.64	3060615 a b	COD, TSSE. Coli
Abu-Nuseir	7.64	6.98	58.79	8.68	1084.61	5	within
Tafila	8	49.55 a	214.82 a	97.86 a	796.73	2244119 a b	BOD, COD, TSS E. Coli
Ramtha	8.09		56.41	12.5	1393.45	57	within
Ma'an	8.39		46.45	11.64	1054.64	12	within
Kufranja	8.1		331.18 a	96.32 a	1077.27	2150640 a b	COD, TSS, E. Coli
Wadi-Essir	7.87		120.09 a	45.09	864.73	38	COD
Wadi Al Arab	8.05	19.98	88	22.73	984.77	45121 a b	E. Coli
WadiMousa	8.02		47	7.35	835.55	3	within
Wadi Hassan	7.76		56.73	8.14	1107.82	11	within
Tal- Almantah	6.87	35.18 a	179.36 a	97.77 a	1877.18 a b c	4985 a b	BOD, COD, TSS, TDS, E.
Al-Ekeder	8.1		556.09 a b c	283.18 a b c	1241.45	422582 a b	COD, TSS, E. Coli
Al-Lajjoun	8.17		547.73 a b c	284.09 a b c	1491.18	22658 a b	COD, TSS, E. Coli
Fuheis	7.94	4	134.77 a	100 a	980.64	11388 a b	COD, TSS, E. Coli
Al-Jiza	8	7.82	76.82	14.91	1271.45	2130 a b	E. Coli

BOD_5represents the biochemical oxygen demand at 20°C over 5 days and is a measure of the biodegradable organic matter in the wastewater.

(a) represents exceeding Jordanian standards of cooked vegetables, parks, playgrounds and sides of roads within city limits, (b) represents exceeding Jordanian standards of fruit trees, sides of roads outside city limits, and landscape, and (c) represents exceeding Jordanian standards of field crops, industrial crops and forest trees.

Table 4: Treated wastewater reuse attributes

No.	WWTP name	Amount of outlet MCM/year	No. of agreements	Area irrigated (dunum)	Direct Amount of water used (MCM/year)	Crops	Excess Water Destination	Direct used water (%)
1.	Samra	87.527	34	3990	13.12	Fodder, olives	King Talal dam	%15
2.	Aqaba - Mechanical	3.347	1	-	3.347	Industry, turf	-	%100
3.	Aqaba - Natural	1.867	4	1580	1.867	Palm, wind breaks, turf	-	%100
4.	Madaba	1.808	27	1220.3	1.808	Fodder, olives, nursery	-	%100
5.	Irbid (Central)	2.877	none	-	-	-	Jordan river	0.0 %
6.	Sult	2.464	5	99.54	0.109	Olives, fruit trees	Wadi Shoaib valley	4.4 %
7.	Jerash (Al-Merad)	0.416	1	27.5	0.03	-	King Talal dam	7.2 %
8.	Mafraq	0.572	18	660.20	0.572	Fodder	-	%100
9.	Ain Basha (Baqa)	4.701	15	436.589	0.638	Nursery, polo playground	King Talal dam	%13.6
10.	Karak	0.548	8	608.93	0.548	Fodder, forest, olives	-	%100
11.	Abu-Nuseir	0.983	1	75	0.18	Al Ordon street (landscape)	Berain valley	18.5 %
12.	Tafila	0.327	none	-	-	-	Ghour Fifa	0.0 %
13.	Ramtha	1.591	22	1302.0	1.591	Fodder	-	100 %
14.	Ma'an	0.902	9	382	0.418	Fodder	The valley	46.3 %

15.	Kufranja	0.916	10	811.62	0.916	Fodder, forest trees	-	100 %
16.	Wadi-Essir	1.582	1	61.82	0.068	Olives	Kafrain dam	%4.3
17.	Wadi Al Arab	4.006	none	-	-	-	Jordan river	0.0 %
18.	Wadi Mousa	0.992	38	1069	0.992	Fodder, olives	-	%100
19.	Wadi Hassan	0.435	1	721	0.435	Olives, fruit trees	-	%100
20.	Tal- Almantah	0.129	none	-	-	-	-	0 %
21.	Al-Ekeder	1.051	17	1068.65	1.051	Olives, fruit trees	-	%100
22.	Al-Lajjoun	0.257	none	-	-	-	Lajjoun valley	0.0 %
23.	Fuheis	0.829	1	30	0.033	Fodder	Wadi Shoaib valley	4.0 %
24.	Al-Jiza (Talbiea)	0.146	none	-	0.146	Forest trees, landscape plants	-	100 %
25.	Al-Merad		2	40	0.044	-	King Talal dam	%10.58
26	Shallaleh	0.772	none				Jordan valley	0 %

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Limitations of the treated wastewater standards restrict agricultural use to certain crops and thus will shift the landuse towards applicable classes. Illegal actions from farms might be another serious concern, however the governmental agencies and periodically monitoring the use per flow from the source till the final destination to allocate these lands and take the necessary actions.

According to above, the story of wastewater treatment and reuse in the Jordanian agricultural sector is a feasible option and already in use. In fact, Jordan is considered the most advanced country in MENA region in the field of wastewater reuse in agriculture (other countries in the region had adapted wastewater reuse in their water budget mainly for landscape irrigation and ground water recharge i.e. UAE and Qatar). Wastewater has been considered as a valuable resource rather than a source of pollution and for that reason wastewater has been included as part of the national water budget. In Jordan, the reuse of wastewater in agriculture has been adopted as a tool for water demand management. This process has replaced freshwater resources, which were previously used for irrigation, and allowed freshwater to be reallocated to the municipal sector where higher quality water is needed for potable use.

6. Conclusions

In Jordan, it is predicted that climate change will result in reduced rainfall, increased temperatures, increased chances of heat waves, more frequent droughts, and more extreme weather events. These changes will adversely affect the all sectors, especially the existing fragile water systems (e.g. less recharge and replenishment of surface water and groundwater reserves, groundwater depletion and salinization, desertification) and the agricultural sector, which the country is heavily dependent upon.

The government of Jordan has taken various initiatives (e.g. policies, strategies, action plans) to address these challenges; however, implementation has been lagging partly due to lack of financial resources, technical capacity, and weak internal linkages with national plans. Among the adaptive action being made, reserving more water for drinking by recycling, treating, and using effluent from WWTPs for non-drinking uses (e.g. industrial or irrigation) could be a solution. By questioning the capability and trust worthiness of Jordanian wastewater production for reuse as an adaptive measure to climate change, this paper was able to demonstrate that treatment of wastewater can be set as integral part of renewable water resources and the national water budget, and can solve environmental problems and be considered a feasible adaption option.

Through intensive government and donors efforts, thirty one WWTPs were established with total designed capacity of 221.3 MCM/year. These plants have contributed to satisfy about 22% of total irrigation water demands and thus reserving more drinking water to be reallocated within the municipal water sector. Approximately 98.6% of the total treated wastewater is utilized for irrigation while 1.4% is used for industrial activities.

The treated wastewater production for the year 2013 is estimated about 221.3 MCM/year, from which direct treated wastewater reuse represent only 23.1% of the total amount produced. Direct treated wastewater reuse was achieved through contracting with about 215 farmers to irrigate an area of about 14,184 dunums. The government has managed to institutionally arrange the existing WWTPs operation, reuse, monitoring and quality control under the responsibilities of different bodies (e.g. MWI, WAJ, JVA, MoEnv, MoA, JFDA, and RSS).

Most wastewater treatment plants have been upgraded to accommodate twice the current inlet flow and thus are operating at full efficiency. In comparison with Jordanian standards for treated wastewater reuse, the main WWTP (Samra) and other plants are found to be within the standards and thus can be used for A-class (e.g. cooked vegetables, parks, playgrounds and sides of roads within city limits) or B-class (e.g. fruit trees, sides of roads outside city limits, and landscape). On the other hand, the majority of WWTPs' wastewater quality has exceeded the allowable thresholds especially concerning microbial quality and thus restricting the reuse to only C-class (e.g. field crops, industrial crops and forest trees) which puts a pressure on the WWTPs operators in disinfecting the water before use.

The public acceptance for the reuse is still low, but the farmers have no other alternative for water supply. Samra WWTP success story represents a strong example of best quality control and safety schemes for reuse. The Samra; largest WWTP, is a clear indicative of trustable sustainable and adaptation success of WWTP reuse.

To ensure the wastewater reuse environmental and health sound sustainability, appropriate water policies, standards and monitor, enabling institutional setting, qualified regulators, technical expertise and massive operation and maintenance costs are required. Effluent quality remains the main obstacles for wastewater reuse in agriculture. Limitations of the treated wastewater standards restrict the agriculture use to certain crops and thus shift the landuse. Thus, the WWTPs should be upgraded based on quality monitoring results. The national standards and regulations should periodically modify to fulfill the requirements of WHO, FAO, and EPA guidelines. Finally, farmers in handle with the reuse of treated wastewater should be environmentally trained while their farm lands should be intensively monitored for any possible soil-water-plant systems contaminations.

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