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# Analyzing the trade-offs of wastewater re use in agriculture: An Analytical framework

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# Analyzing the trade-offs of wastewater re use in agriculture: An Analytical framework

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**Abstract**

*Wastewater reuse in agriculture has been identified as a way to alleviate water scarcity, improve crop productivity and improve environmental sustainability. Given that agriculture is the biggest user of freshwater, wastewater irrigation is in line with IWRM as it improves water allocations in other sectors (especially water for domestic uses and also for ecological functions). Even though wastewater reuse in agriculture has high returns and may have ecosystem benefits, there are some costs associated with its use (wastewater treatment, health, environment and ecological costs. This paper developed an integrated systems modeling framework which will contribute to the design of comprehensive wastewater management regimes (which simultaneously consider the environmental, economic and health impacts) that make use of wastewater safer and more sustainable without relying on non-affordable treatment technologies. In addition, the study puts wastewater on the policy agenda by demonstrating the economic and environmental benefits of wastewater reuse in agriculture and also assesses possible tradeoffs which have to be taken into account when planning wastewater reuse in agriculture.*

**Key words**

*Wastewater reuse, tradeoffs, effluent quality, agriculture*

## 1 Introduction and background

Water scarcity is one of the major constraints to socio-economic development in the arid and semi-arid regions. In addition to low rainfall and frequent droughts, increasing demand for water resources of irrigated agriculture, urbanization, population growth and changing consumption patterns and industrialization and supply-side limiting factors such as water pollution exacerbate the scarcity of water resources. Currently, water consumption in most arid and semi-arid areas is higher than the available water and the water demand for industries, domestic and agriculture are being met at the expense of the ecological requirements (Boelee, 2011). With climate change predicted to result in a 10-20% reduction in precipitation and increasing variability in some regions by 2050 (IPCC, 2001) and the demand for water resources expected to increase partly due to expected increases in population growth and urbanization (UNEP, 2003), the problem is likely to worsen. The increasing scarcity of the water resources will lead to intense competition for the resource across sectors (uses) and strategies for efficient allocation of the resource will become paramount. Currently, the agriculture sector consumes 70% of available freshwater resources and 93% of water consumption worldwide (Turner et al, 2004; Tanji and Kielen 2002). Within the sector there is competition for water among enterprises and between upstream and downstream uses in basins. Other sectors which compete with the agriculture sector for water include domestic, industrial and ecological requirements. As agriculture is the major consumer of water, strategies for improving water use efficiency in this sector or identifying alternative uses are paramount for reducing water scarcity and freeing water resources for use in other sectors where it has higher economic value. The use of wastewater in agriculture is a possible strategy for addressing water scarcity and nutrient deficiency in agricultural systems in the face of climate change. Reuse of wastewater in agriculture follows the principles of IWRM because it improves efficiency, equity and environmental sustainability as reuse is considered part of the wastewater treatment process. In many developing countries, only a small proportion of the wastewater is treated due to financial constraints (setup, operation and maintenance , lack of knowledge about low cost treatment and ignorance about the economic benefits of wastewater re use (Mara, 2004). The few countries that treat water depend largely on a primary wastewater treatment system which is rarely followed by a secondary treatment stage to improve the effluent quality within the available cost. Most of the wastewater is often directly disposed into water bodies thereby contaminating the environment and posing health risks to humans. More than half of the global water bodies are seriously polluted by untreated wastewater (UNEP, 2002). The current growing population, increasing urbanization is exacerbating the wastewater management as this often increases the volume of wastewater. Given the high costs of water treatment, sewage treatment processes that can achieve an effluent standard at minimal cost are generally preferred by any country, especially developing countries (Sato, 2006). Treatment of wastewater to reduce pathogens (like the stabilization ponds) can be used for agricultural irrigation. Recent evidence has shown that reuse of partially treated wastewater especially in agriculture and aquaculture could have high economic benefits. Wastewater reuse in agriculture provides farmers with renewable nutrients, reduces pollution of the environment and eases demand for freshwater which could make it possible to lower water tariffs (Menge, undated, Kasan, 2010; McKenzie, 2005). However, there are also negative aspects related to wastewater reuse and these include soil salinity, health of farmers and consumers, public acceptability, marketability of produce, and economic feasibility and sustainability of wastewater irrigation (IWMI, 2006; WHO, 2006; Raschid-Sally and Jayakody, 2008, Husaain et al, 2002).

To date, most wastewater-related research in developing countries has largely focused on issues related to improvements in water quality, environmental and health impacts of wastewater use (Dikinya and Areola, 2009; Mosiuoa et al, 2009). Moreover, most of these studies focused on one aspect in isolation thereby ignoring the environmental-health-economic linkages and trade-offs inherent in waste water use systems. Even among the studies that focused on a single aspect, very little attention has been given to economic and social aspects of wastewater recycling in developing countries.

Against this background, this study contributes to addressing some of the aforementioned knowledge gaps by developing an integrated analytical model for evaluating the economic, environmental and health impacts of wastewater re-use in agriculture. By adopting an integrated systems modeling framework this study will contribute to the design of comprehensive wastewater management regimes (which simultaneously consider the environmental, economic and health impacts) that make use of wastewater safer and more sustainable without relying on non-affordable treatment technologies. In addition, the study puts wastewater on the policy agenda by demonstrating the economic and environmental benefits of wastewater use in agriculture.

## 1.1 Research questions

1. Is it cost effective to plan for water management which involves reuse of wastewater in agriculture; under which settings is it cost effective to plan for water management involving re-use?
2. What are the possible tradeoffs involved in wastewater reuse for agriculture?

## 1.2 Study objectives

The overall objective of this paper is to analyze the environmental, health and economic trade-offs of wastewater reuse in agriculture. Specifically the study seeks to:

- Develop a model for analyzing the environmental (water quality), economic (livelihood) and health trade-offs of wastewater reuse in agriculture
- Understand the synergies and the trade-offs inherent in the environmental-health-economic systems.
- Apply the model to assess the benefits and costs of wastewater reuse in irrigated agriculture in terms of health, economic (livelihood) and environmental impacts

## 1.3 Hypothesis

The economic benefits of wastewater reuse in agriculture outweigh the costs (health and environmental).

# 2 Conceptual Framework

## 2.1 Wastewater Effluents

Wastewater refers to different qualities which range from raw to diluted wastewater. In this study Wastewater is a combination of domestic effluents, industrial effluent, storm water and water from commercial institutions; that are released into the common sewerage network of a city. The composition of wastewater varies; in addition to water (which is 99%) it also has 1% suspended, colloidal and dissolved solids. Municipal wastewater contains organic matter and nutrients (N, P, K); inorganic matter or dissolved minerals; toxic chemicals; and pathogens. The composition of the non-pathogenic components in wastewater vary over time and sites and regions, so it is necessary to monitor wastewater quality regularly and come up with risk mitigation and reduction strategies. The composition of typical raw wastewater depends on the socioeconomic characteristics of the residential communities and number and types of industrial and commercial units, such that global demographic and economic change also has implications for environmental health protection and wastewater governance approaches (Hanjraa et al, 2012; Husain et al, 2002; Qadir and Scott, undated).

### 2.2 Wastewater Treatment Technology

Municipal wastewater treatment is a well-developed engineering science and various processes and techniques are available to efficiently treat the waste (Hussain et al, 2002). Wastewater treatment objectives and priorities as well as the available investment resources have to be considered in the choice of the treatment alternatives. Although wastewater treatment improves water quality its adoption in developing countries is limited by the high capital investment in this technology, high energy costs and operation and maintenance problems. The major drivers of wastewater treatment and reuse is generally physical water scarcity and studies show in addition to this; the level of water treatment also depends a lot on norms and standards of a society. Findings of studies showed that in India wastewater is indirectly treated by reuse in agriculture whilst in Australia, the treatment done is just enough to meet environmental standards for safe disposal. Also poor institutional frameworks in developing countries limit the wastewater treatments and that there less considerations for the environment. The level of treatment ranges from primary which produces the lowest water quality to tertiary which produces the best water quality (Hussain et al, 2002; Devi, 2009). Primary treatment generally consists of physical processes involving mechanical screening, grit removal and sedimentation which aim at removal of oil and fats, settle able suspended and floating solids; simultaneously at least 30% of biochemical oxygen demand (BOD), 25% of Kjeldahl-N and total P are removed, 50 to 70% of the total suspended solids (SS), and 65% of the oil and grease are removed during primary treatment. Faecal coliform numbers are reduced by one or two orders of magnitude only, whereas five to six orders of magnitude are required to make it fit for agricultural reuse. Secondary treatment mainly converts biodegradable organic matter (thereby reducing BOD) and Kjeldahl-N to carbon dioxide, water and nitrates by means of microbiological processes (Helmer & Hespanhol, 1997; Pescod, 1992). Secondary treatment processes can remove up to 90% of the organic matter in wastewater by using biological treatment processes. The two most common conventional methods used to achieve secondary treatment are attached growth processes and suspended growth processes (Environmental Protection Agency (EPA), 2004) Activated sludge process is a biological treatment process that utilizes a suspended growth of organisms in order to remove BOD and suspended solids. Trickling filters are one of the biological treatment processes that are used to remove organic matter from wastewater by degrading the organic matter and can also be used for nitrification and denitrification. Trickling filters are an attached growth system in which the biological process uses an inert medium to attach microorganisms and remove organic matter from wastewater (Suleaman, 2009).

In some treatment plants, primary and secondary stages may be combined into one basic operation. At many wastewater treatment facilities, influent passes through preliminary treatment units before primary and secondary treatment begins (EPA, 2004). Waste stabilization ponds are the first choice for treating the wastewater in many parts of the world, especially in small rural communities. There are three categorizations of waste stabilization ponds depending on their dissolved oxygen depth profile, namely: aerobic ponds, anaerobic ponds, and facultative ponds. In aerobic ponds, there is a varying concentration of oxygen throughout its depth while in an anaerobic ponds; there is lack of oxygen at any depth except with very few top centimeters at the air liquid interface. In facultative ponds, there is a support of oxygen aerobic condition in its top zone and the pond is anaerobic or lack oxygen at the lower depths or bottom zone (Suleaman, 2009). Waste stabilization ponds are recommended by the WHO for the treatment of wastewater for reuse in agriculture and aquaculture, especially because of its effectiveness in removing nematodes (worms) and helminthes eggs (WHO, 2006). Aerated Lagoons / oxidation ponds are artificial bodies for wastewater treatment that require a proper design, construction and maintenance in order to obtain a satisfactory treatment even for raw wastewater. The aerated lagoons or oxidation ponds are suitable in areas where cost of available large surface of the land is low (Suleaman, 2009). Lagoons remove biodegradable organic material and some of the nitrogen from wastewater (EPA, 2004). Stabilization pods have an advantage that they are efficient and inexpensive (both in terms of capital investment and operation and maintenance). The disadvantages of waste stabilization are that it is land intensive and there are high water losses through evapotranspiration. Also wastewater from pond stabilization can only be used for restricted irrigation and this limits the type of crops which can be irrigated with the water (Hussain et al, 2002).

Tertiary treatment is designed to remove the nutrients, total N (comprising Kjeldahl-N, nitrate and nitrite) and total P (comprising particulate and soluble phosphorus) from the secondary effluents. Additional suspended solids removal and BOD reduction is achieved by these processes. The objective of tertiary treatment is mainly to reduce the potential occurrence of eutrophication in sensitive, surface water bodies. Advanced treatment processes are normally applied to industrial wastewater only, for removal of specific contaminants (Helmer & Hespanhol, 1997). Pollutant characteristics of the wastewater vary depending on the processes used in production and the quality of paper produced. However, in general, high organic material and suspended solid contents are considered as major pollutants of pulp and paper industry effluents. Major pollutant indicators biological oxygen demand (BOD) and suspended solid (SS) were chosen as design parameters (Buyukkamaci & Koke, 2010).

### 2.3 Wastewater Treatment Cost

In developing countries, such treatment systems must fulfill many requirements, such as simple design, use of non-sophisticated equipment, high treatment efficiency, and low operating and capital costs. Anaerobic technologies should be considered for domestic wastewater treatment as an alternative to more conventional aerobic technologies in most developing countries for a variety of reasons. Anaerobic technologies already have been applied successfully for the treatment of a number of waste streams, including low strength wastewaters such as domestic wastewater, particularly under tropical conditions. Anaerobic treatment can be carried out with technically simple setups, at any scale, and at almost any place. It produces a small amount of excess, well stabilized sludge, and energy can be recovered in the form of biogas. The process can be carried out in both centralized and decentralized modes, and the latter application can lead to significant savings in investment costs of sewerage systems (Aiyuk, 2004).

Wastewater treatment is expensive both in terms of land required, cost of setting up, and operation and maintenance (energy consumption is high). Most low income countries only treat a portion of the wastewater and most of the untreated wastewater is disposed and pollute water bodies and groundwater. This situation is not limited to low-income countries that have no capacity to collect and treat wastewater comprehensively, but occurs also in fast-growing economies like China, Brazil, and some countries of the Middle East and North Africa region. The cost of a sewage treatment process varies significantly depending on the time frame and location. Moreover, the configuration of any similar type of treatment process may vary according to the size of the local community or climatic conditions of the area, which in turn affects cost. These factors considerably affect the task of standardizing the cost of any process. These costs and land requirements are often expressed by the following equation (Satoa et al, 2007).

The high cost (for construction, maintenance, and operation) of the most conventional treatment processes has brought about economic pressures to societies even in the developed countries, and has forced engineers to search for creative, cost-effective and environmentally sound ways to control water pollution. In addition to the cost of the treatment unit and its ancillary equipment, the capital costs of investment include piping, instrumentation and controls, pumps, installation, engineering, delivery and contingencies. On the other hand the land requirements cost should include the total area needed for the equipment plus peripherals (pumps, controls, access areas, and so on) (UN, 2003). The quantification of the costs associated with the operation of WWTPs is straightforward because these costs are strictly controlled by the operating companies. In general, WWTP operating costs are influenced by the effluent quality. In this sense, one can roughly distinguish three types of treatment: (i) primary treatment which involves screening, grinding and sedimentation to remove the floating and settleable solids found in wastewater, (ii) secondary treatment that is accomplished by a biological process and sedimentation allowing to remove organic material that is either colloidal in size and dissolved, and (iii) tertiary treatment which permits the removal of specific contaminants not normally removed during conventional secondary treatments such as nutrients and pathogens. The average WWTP operating costs ratio between the types of treatment was estimated to be 1, 2, and 3 for primary, secondary and tertiary treatments respectively (Molinos-Senante et al, 2010). The operation cost elements can be identified as the energy cost, staff costs, chemicals cost, waste management cost and maintenance cost.

Table 1 shows the advantages and disadvantages of the various wastewater treatments techniques (Pescod, 1992). The tabulated treatment process shows primary and secondary treatment process with the exception stabilization ponds (because it combines both primary and secondary treatment based on the type of ponds and the total system efficiency). Wastewater treatment tariffs per cubic meter vary with because of the diversity of treatment technology, climate conditions, wastewater characteristics, sewage system, the available financial resources for the capital cost, operation system, pumping system, treatment plant volume, the availability of the fresh water, social acceptance, water allocation system, and purchasing power of the country.

Table 1 the advantages and disadvantages of the various wastewater treatments techniques

| | Criteria | *Preliminary or Primary Treatment | Stabilization ponds | Aerated lagoon | Oxidation ditch | Trickling filter | Activated sludge |
|---|---|---|---|---|---|---|---|
| Plant Performance | BOD removal | Poor | Good | Good | Good | Fair | Fair |
| | SS removal | Poor | Fair | Fair | Good | Good | Good |
| | FC removal | Poor | Good | Good | Fair | Poor | Poor |
| | Helminth removal | Poor | Good | Fair | Fair | Poor | Fair |
| | Virus removal | Poor | Good | Good | Fair | Poor | Fair |
| Economic factors | Simple & cheap construction | Good | Good | Good | Fair | Poor | Poor |
| | Simple operation | Good | Good | Fair | Fair | Fair | Poor |
| | Land requirement | Good | Poor | Fair | Good | Good | Good |
| | Maintenance costs | Good | Good | Poor | Poor | Fair | Poor |
| | Energy demand | Good | Good | Poor | Poor | Fair | Poor |
| | Sludge removal costs | Good | Good | Fair | Poor | Fair | Fair |

BOD: Biological oxygen demand (represent the organic load)
SS: Suspended solid
FC: Faecal Coliforms Bacteria (represent the microorganism present in wastewater)
*: added by the researcher

Figure 1 shows the variation of treatment cost versus the target efficiency of secondary treated wastewater in Jordan (plants with low wastewater volume, 1000-5000m$^3$/day). The lowest efficiency came from stabilization pond technology whereas the highest efficiency came from activated sludge and extended aeration technology. According to table 1 above acceptable effluent quality can be obtain from stabilization pond technique in spite of its disadvantages of land requirement. The exponential relation between efficiency and cost reflects the possibility to get acceptable efficiency within the available budget.

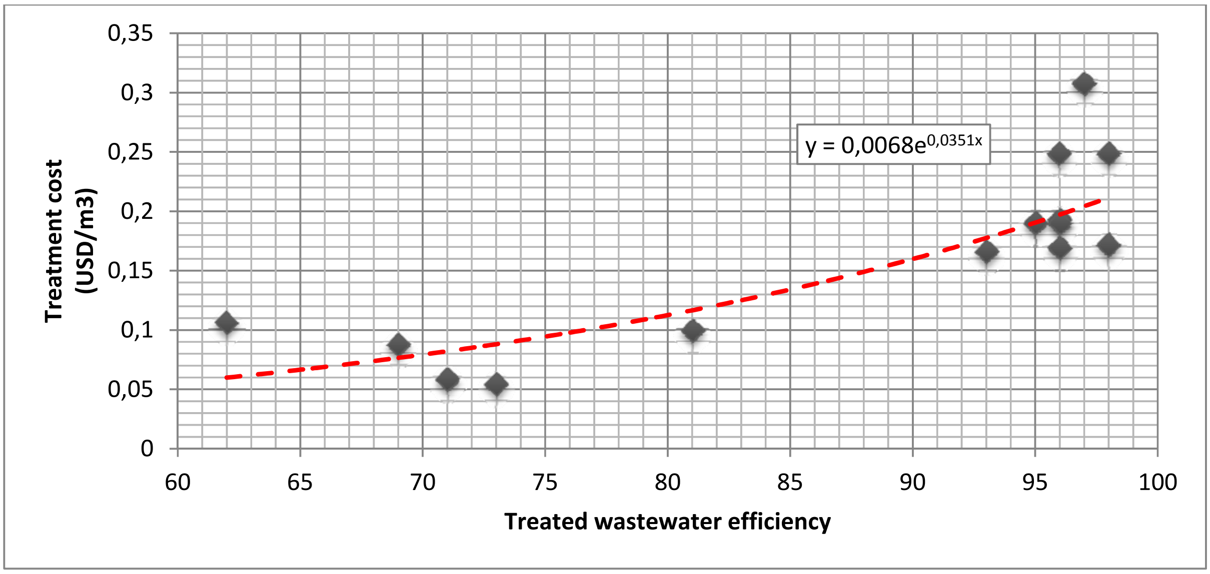


Figure 1 variation of treatment cost versus the target treated wastewater efficiency in Jordan (this figure developed based on secondary data listed in (UN, 2003))

Although it is generally desirable to have higher wastewater quality and adopt quality for non-restricted irrigation, a high capital cost constrains its adoption. (Fine et al 2005) showed that it might not be economically feasible to upgrade wastewater quality to the sanitary requirements of non-restricted irrigation as this would increase costs by an additional US$69 million dollars in Egypt. Also epidemiology surveys shows that any high standards of wastewater quality above those of the WHO currently adopted in most developing countries might not be necessary. They recommended that use of wastewater for sensitive crops may not be economic given the higher sanitary levels required so use of portable water for such crops would be a better option (Fine et al, 2005). In another study by (Hussain et al 2002) studies show that though marginal costs of higher level treatments are very high; sometimes these costs are justified by the crop value, degree of water scarcity and public concern. Other studies (Devi, 2009) show that although the wastewater treatment is not economic, adding the environmental benefits makes the benefits outweigh the costs.

### 2.4 Wastewater Reuse in Agriculture

Wastewater reuse is not a new practice, though there is no comprehensive global data on wastewater reuse, it is estimated that about 7% (or 20 million hectare) of irrigated land uses wastewater or polluted water (WHO, 2006). Of this 20 million ha only 10% uses treated wastewater.

Agriculture is the main consumer of water (consumes over 70% of fresh water worldwide) and often competes with other uses for the scarce resource. Wastewater reuse in agriculture has many benefits which includes alleviating freshwater scarcity, providing a drought resistant source of water, provides nutrients (cuts on fertilizer costs) increase water productivity and confers environmental benefits. Wastewater is also more reliable than surface water and continual supply of wastewater from treatments plants and community sources enables the farmers to cultivate multiple crops throughout the year, raising cropping intensity and output. Wastewater reuse and recycling of its nutrients in agriculture can contribute towards climate change adaptation and mitigation. Variability in composition of wastewater components causes the imbalance of components of wastewater and pause risk to the soil and ecosystems, plants, animals and human beings. The composition of the nonpathogenic components in wastewater vary over time and sites and regions, so it is necessary to monitor wastewater quality regularly and come up with maximize benefits while minimizing impact of these negative impacts to make wastewater irrigation sustainable (Grant et al, 2012; Hanjraa et al, 2012; Fine et al, 2005). The effluent quality varied based on the wastewater treatment technology type as well as the target level of treatment. In the tertiary treatment process applied on the secondary treatment effluent to improve its characteristics in term of nutrients concentration. When using the wastewater effluent for irrigation, nutrient concentrations represent an added value to the agricultural system. Wastewater can meet 75% of the fertilizer requirements of a typical farm in Jordan (Carr et al, in press). On the other hand, excess nutrients can also reduce crop productivity, so there is need for careful nutrient management is essential to reduce fertilizer costs and prevent a reduction in crop yield due to excess nutrients in wastewater (Hanjraa et al, 2012). From an economic viewpoint, wastewater irrigation of crops under proper agronomic and water management practices may provide the following benefits: (i) higher yields, (ii) additional water for irrigation, and (iii) value of fertilizer saved (Hussain et al, 2002).

### 2.5 Health impact from wastewater irrigation

Wastewater contains pathogenic microorganisms such as viruses, bacteria and parasites which have the potential to cause disease and impact human health. Protozoa and helminth eggs are most virulent and they are most difficult to remove by treatment processes; they are often implicated in a number of infectious and gastrointestinal diseases in developing and even developed countries (Hanjraa, 2012). Improved wastewater irrigation is considered as the most effective factor in reducing the hazard of microbial exposure, especially when using relatively low quality wastewater effluent for irrigation. Improvement process depends on the implementation of suitable farm-level practices and post-harvest interventions, which are classified as non-treatment options and can be divided into the following major categories: (i) crop selection and diversification in terms of market value, irrigation requirements, and tolerance of ambient stresses; (ii) irrigation management based on water quality, and irrigation methods, rates, and scheduling; and (iii) soil-based considerations such as soil characteristics, soil preparation practices, application of fertilizers and amendments if needed, and soil health aspects. Flood irrigation is the lowest cost method, if the topography is favorable or farmers can afford a pump. However, water use efficiency is low, thus successful where water is not a limiting factor. Furrow irrigation provides a higher level of health protection, but requires favorable topography and land leveling. Irrigation with sprinklers and watering cans are not recommended as this spreads the water on the crop surface, although cans are usually the cheapest investment option and favored for fragile vegetable beds. Sprinklers require in addition a pump and hose, have medium to high cost, and medium water use efficiency. Irrigating at night and not irrigating during windy conditions are important considerations when using sprinklers. Drip irrigation, especially with sub-surface drippers, can effectively protect farmers and consumers by minimizing crop and human exposure, but irrigation kits with appropriate planting density and pre-treatment of wastewater is needed to avoid clogging of emitters (Qadir et al, 2010). The WHO recommended a microbial guideline of not more than

1000 fecal coliforms (FCs) per 100 ml for unrestricted irrigation of all crops, with special emphasis on the removal of helminth eggs (Finea et al 2006).

There are many studies not only on farmers' exposure and risk of intestinal nematode infections, but also on actual and possible links between the consumption of crops irrigated with wastewater. Post-harvest contamination in markets can be an important factor affecting public health. Besides pathogens, chemical contaminants can be of concern especially in those countries where industrial development has started and industrial effluent enters domestic wastewater and natural streams (Qadir et al, 2010). This shaded cost of the public health impact can be evaluated based on the degree of risk might be affected the farmers or the consumers. Referring to different studies vulnerability factors are irrigation system, farmer behavior, crop types, wastewater quality, harvesting system, consumer behavior, and public awareness effectiveness. In this case, best cost will be at minimum risk (figure 2). (Finea et al, 2006) argues zero-risk approach through the using of basic pathogen removal at the WWTP, followed by additional on farm protective means (or 'barriers' to pathogen infection) that are aimed to block pathogen transfer to the workers, to the consumers of the crop or to the general public. In some cases of improving the vulnerability in a boundary area, extra cost should be added to the treated wastewater cost such as the cost of improving the irrigation system, the harvesting system or the costs of ensuring the safety of the consumer by providing 'barriers' against contamination of the agricultural product by enteric pathogens. However there are some barriers to microbial contamination incur no additional cost: the air-gap between the drippers and the crop, components of the crop itself (peel or shell), and the manner in which the crop is marketed and processed (such as consumption only after proper cooking); these are natural barriers, which help to reduce the cost of effluent reuse (Qadir et al, 2010; Finea et al, 2006).

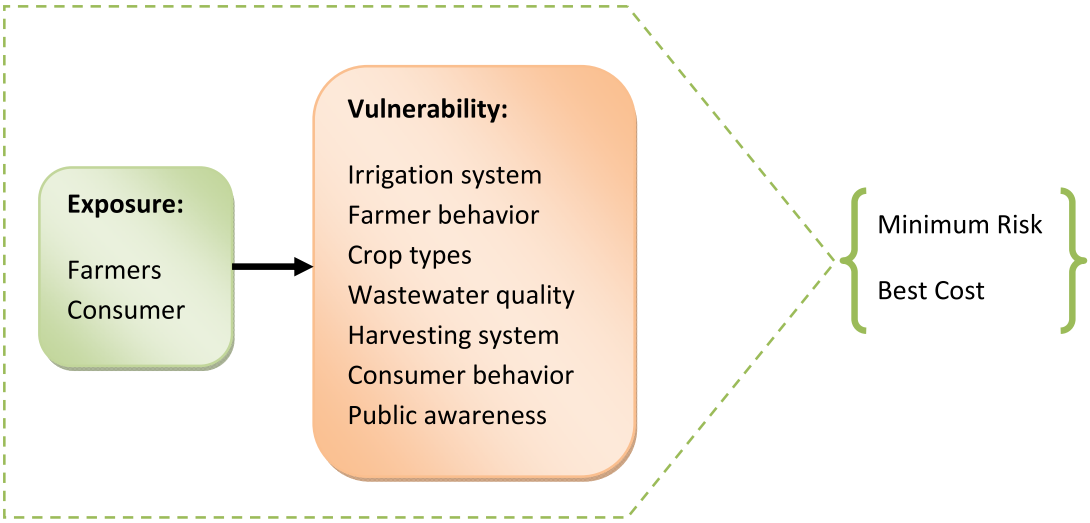


Figure 2 Health impact and wastewater irrigation interaction

## 2.6 Environmental impact from wastewater irrigation

*Soil*

Impact from wastewater on agricultural soil, is mainly due to the presence of high nutrient contents high total dissolved solids and other constituents such as heavy metals, which are added to the soil over time. Wastewater can also contain salts that may accumulate in the root zone with possible harmful impacts on soil health and crop yields. The leaching of these salts below the root zone may cause soil and groundwater pollution (Hussain et al, 2002) Wastewater irrigation may lead to transport of heavy metals to fertile soils, affecting soil flora and fauna and may result in crop contamination. Some of these heavy metals may bio-accumulate in the soil while others such as Cd and Cu may be redistributed by soil fauna such as earthworms (Dikinya & Areola, 2010; Kruse & Barrett, 1985). The impact of wastewater irrigation on soil may depend on a number of factors such as soil properties, plant characteristics and sources of wastewater. The impact of wastewater from industrial, commercial, domestic, and dairy farm sources are likely to differ widely Wastewater irrigation may have long-term economic impacts on the soil, which in turn may affect market prices and land values of saline and waterlogged soils. (Hussain et al, 2002)

*Groundwater*

Wastewater application has the potential to affect the quality of groundwater resources in the long run through excess nutrients and salts found in wastewater leaching below the plant root zone. Groundwater constitutes a major source of potable water for many developing country communities. Hence the potential of groundwater contamination needs to be evaluated before embarking on a major wastewater irrigation program. In addition to the accretion of salts and nitrates, under certain conditions, wastewater irrigation has the potential to translocate pathogenic bacteria and viruses to groundwater. However, the actual impact depends on a host of factors including depth of water table, quality of groundwater, soil drainage, and scale of wastewater irrigation (Hussain et al, 2002).

*Ecological Impacts*

When drainage water from wastewater irrigation schemes drains particularly into small confined lakes and water bodies and surface water, and if phosphates in the orthophosphate form are present, the remains of nutrients may cause Eutrophication (non-point source pollution). This causes imbalances in plant microbiological communities of water bodies. Clearly, the impacts of wastewater irrigation on aquatic systems are largely similar to the impacts of direct disposal of effluent to receiving waters. Water-bodies located near densely built-up areas have a high recreation value. From other side, the likelihood of heavy metals from wastewater affecting the food chain is addressed under soil resources which usually acts as a filter and retains heavy metals in the soil matrix (Hussain et al, 2002; Hamilton et al, 2006). There are various factors may affect the relation between reused treated wastewater and ecosystem. The main factors are: soil properties, land use, geological formation, the distance to the near water body, wastewater quality, irrigation system and scale, and rainfall densities, hydraulic structures in the main watershed.

Property Values

Depreciation of property values may sometimes be solely due to belief that risks persist. Thus both, actual and potential risk to property values due to wastewater irrigation should be evaluated in economic terms. attributes such as size, location, proximity to roads, markets and major population centers, productivity and fertility index, land rent and annual lease revenue, availability of canal/ groundwater, agroforestry, earthwork investments, greenhouse gas emissions and more importantly proximity to wastewater irrigation sites, should be valued in any economical evaluation of wastewater reuse system. Applying the hedonic pricing, the fall of property value due to negative impact caused by wastewater re use can be used as the shadow price of wastewater irrigation impact on the environment (Hussain et al, 2002; Hamilton et al, 2006).

## 3 Analytical Framework

Three main analytical approaches can be used to assess the impact of wastewater use on livelihood, environment, ecology and health and these are economic valuation, multi criteria analysis and integrated models. Economic valuation indicators will be used to identify the value to the direct and indirect services (benefits and costs) provided by wastewater reuse in agriculture in monetary terms. To do this, a conceptual model will be developed to simulate the wastewater pathway in the environmental system and the ecosystem in term of cost benefits indicators.

### 3.1 Model Components and Linkages

Wastewater reuse in the agriculture starts from wastewater effluent and end in the environmental arena and the ecosystem. In terms of cost benefit analysis, there are six actors affecting the cost of the wastewater reuse in agricultural system. Agricultural decisions, environmental system, wastewater effluent, health status, and crop productivity are the direct factors in the cost benefit analysis. However, there are other indirect factors that may affect the total cost, namely: the policies and institutions, industrial system and scale, available resources, climate conditions in the target location and socioeconomic status. Figure 3 shows the trade-offs of wastewater re use in agriculture. Policies, institutions, and the available resources can play an important role by giving an incentive or disincentives for wastewater treatment level, agricultural investments, environmental adaptation, public health, and consequently crop production as an output of the process. Wastewater characteristics are related to the climate conditions. Arid and semi-arid regions have high load of organic matters and nutrients, so that the treatment conditions and the efficiency of treatment technology are more diverse than wet regions. Socioeconomic status represents the most hidden and active factors that affect the target process to optimize the direct and indirect cost of wastewater reuse in agriculture. In the agricultural system, fertilizer application is considered as the balance factor between wastewater nutrients load and the needed nutrients for crops to maximize the productivity. Irrigation system, technology, and scale can reduce the target treatment to achieve certain health and environment sustainability outcomes. Also, seeds and crops type as well as the harvesting technology can influence the minimum treatment level to satisfy the available irrigation requirements. The susceptibility of the environmental system, in term of ecosystem and aquifer to the wastewater quality, is the main indicator for the level of sustainability with varied wastewater effluent quality. Soil nutrients, soil drainage, and the distance to surface water bodies are the main drivers to eutrophication. Hydraulic structures may affect on the water and contaminants cycle in environment. Health status is full combined with wastewater pathway in the ecosystem and can make the reuse of a low cost treatment of wastewater more expensive than a higher treatment. Aquifer replenishment can be achieved by wastewater reuse in agriculture; however, nutrient contaminations and heavy metals may reach the aquifer and affect its sustainability. Geological formations, soil drainage, the depth of water table, aquifer quality and aquifer scarcity should be considered carefully in the decision of the wastewater reuse. In terms of cost benefit analysis, there are mutual relations between crop production cost and agricultural decisions as well as environmental system.

Table 2 shows the main cost-benefit indicators of wastewater reuse in agriculture that affect the cost-benefit elements of its pathway in the environment. It shows the variety of wastewater treatment qualities with the cost-benefit elements to achieve acceptable irrigation. Lower wastewater quality (preliminary and primary treatment) shows lower capital and operational cost resulting in higher environmental cost, health costs (including mitigation measures), soil productivity (especially in the long term), and irrigation cost. Higher wastewater quality shows higher capital and operational cost which translates to lower environmental cost, health cost (including mitigation measures), soil productivity, and irrigation cost.

In Table 2, the numbering for the wastewater quality cross tabulation section reflects the degree of effluence on the cost element. For example, number 1 means that this level of treatment has the lowest cost or benefit relative to other levels where positive or negative sign reflects the tendency of the factor or treatment level to be a benefit or a cost respectively. The table reflects unique cross relations of direct and indirect system boundary components and cost elements or cost indicators. In certain cases of low wastewater quality, based on the environmental sustainability, agricultural decisions, climate conditions, and public awareness level, acceptable irrigation may be obtained in term of the total wastewater costs.  The general equation for the total wastewater reuse benefits can be put as the follows:

***Total wastewater reuse benefits*** *= Crop Production - Soil reclamation cost - Aquifer damage cost + Aquifer recharge benefit function - Health cost - Capital and operational cost of wastewater treatment.*

Each element of the total cost has constraints and opportunities to minimize the cost ''as possible'' sharing with other elements and considering indirect or shaded factors.  The shaded factors may affect some terms in this cost equation and can make an unexpected change of the total wastewater cost. The decision makers should optimize returns and costs subject to the available resources and the agricultural, ecological, and environmental system.

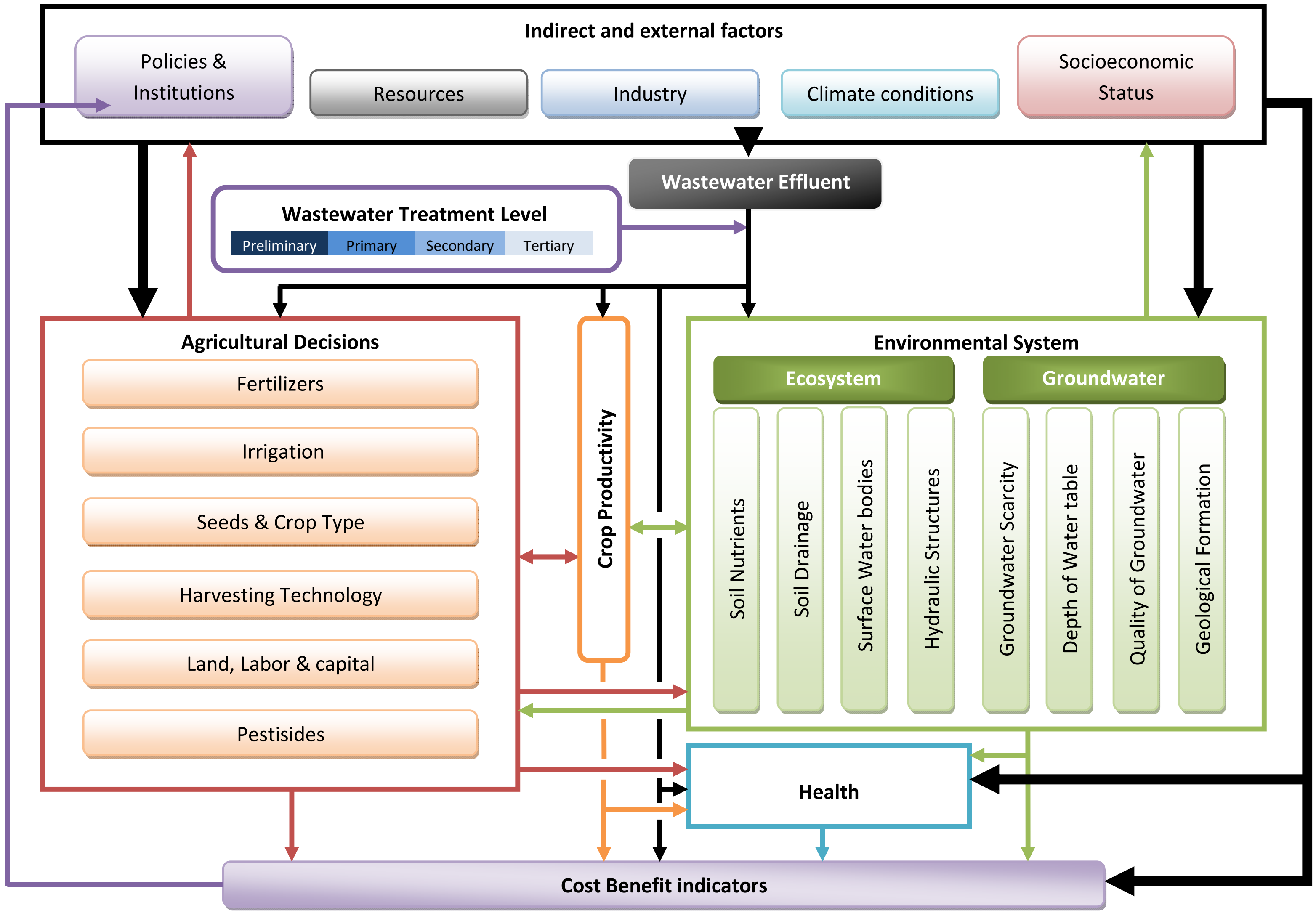


Figure 3 the trade-offs flow chart of wastewater re use in agriculture

Table 2 the cross tabulation between the cost-benefit indicators and the main aspects related to wastewater reuse

- ***** *This factor has a kind of effect on the cost,*
- **0** *This level of WWQ is the baseline relatively to the other levels*
- **+** *This factor has a benefit indicator,*
- **-** *This factor has a cost indicator,*
- **1** *This factor has the lowest cost or benefit indicator relatively to other factors.*

| | | Indirect factors | | | | | WW Quality | | | | Agricultural Decisions | | | | | | | Environmental System | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Institutions** | **Industry** | **Climate conditions** | **Resources** | **Socioeconomic Status** | **No WW treatment** | **Primary Treatment** | **Secondary Treatment** | **Tertiary treatment** | **Irrigation system** | **Fertilizers** | **Harvesting technology** | **Seeds & Crop Type** | **Land, Labor & Capitals** | **Pesticides** | **Crop productivity** | **Soil Status** | **Surface water bodies** | **Hydraulic structures** | **Quality of Groundwater** | **Groundwater Scarcity** | **Depth of water table** | **Geological Formation** | **Health Status** |
| **Cost Benefit indicators** | *Treatment plant capital Cost* | * | * | | * | | 0 | -1 | -2 | -3 | | | | | | | | | | | | | | | |
| | *Treatment Operational Cost* | * | * | | * | | 0 | -1 | -2 | -3 | | | | | | | | | | | | | | | |
| | *Agricultural capital Cost* | * | * | * | * | * | | | | | * | | * | | * | | * | | | | | | | | |
| | *Land Cost* | * | * | * | * | * | | | | | | | | | * | | * | | | | | | | | |
| | *Labor Cost* | * | * | * | * | * | | | | | * | | * | * | * | | * | | | | | | | | * |
| | *Irrigation Cost* | * | * | * | * | * | -4 | -3 | -2 | -1 | * | | | * | * | | * | | | | | | | | |
| | *Fertilizers reduction Benefit* | | | | * | | +3 | +2 | +1 | 0 | | | | | | | | * | | | | | | | |
| | *Medical Cost* | * | | | * | * | -4 | -3 | -2 | -1 | * | | * | | | * | | | * | | * | | * | | * |
| | *Loss of Soil productivity Cost* | | * | * | | | -4 | -3 | -2 | -1 | * | * | * | * | | * | | * | | | | | | * | |
| | *Groundwater replenishment Benefit* | | | * | | | +1 | +1 | +1 | +1 | * | | | | | | | * | | | | * | * | * | |
| | *Ground water protection Cost* | | | * | | * | -4 | -3 | -2 | -1 | * | * | | | | * | | * | | | * | * | * | * | |
| | *Ecosystem protection Cost* | | | * | | * | -4 | -3 | -2 | -1 | * | * | | | | * | | * | * | * | | | | | |
| | *Crop productivity Benefit* | * | | * | * | * | -1 | 0 | +1 | +1 | * | * | * | * | * | * | | * | | | | | | | |
| | *Management & evaluation Cost* | * | | | * | * | -1 | -1 | -1 | -1 | * | | * | | * | | * | * | * | * | * | * | * | * | * |
| | *Wastewater reuse knowledge Cost* | * | | | | * | | | | | | | | | | | | | | | | | | | |
| | *Social impact Cost or Benefit* | * | | | | * | | | | | | | | | | | * | | | | | | | | * |

## 3.2 Model Equations

### 3.2.1 Crop Production Function

To estimate the economic or livelihood effects of wastewater use in agriculture through irrigation we assume that a farmer produces $Q_i$ which is the quantity of crop *i* produced. The production uses a wastewater input which is $WW_i$, $F_i$ is fertilizer, $L_i$ is labour and $S_i$ is seeds and other variable inputs are denoted by $x_{i1 \dots\dots\dots} x_{ij}$ or in the vector form$x_{ij}$. This is expressed as:

$$Q_i = f(F_i, L_i, S_i, WW_i, X_{i1 \dots\dots\dots} X_{ij}) \qquad (1)$$

Following Acharya and Babier (2000) and Hussain et al (2001), we assume that the production function follows a Cobb-Douglas functional form:

$$Q_i = AF_i^{\propto} L_i^{\beta} S_i^{\gamma} WW_i^{\sigma} X_{i1 \dots\dots}^{\theta} X_{ij}^{\mu} \qquad (2)$$

Where α, β, γ, σ, θ and μ are the partial elasticity of inputs with respect to output. From this the Marginal Product of wastewater is derived as:

$$dQ_i/dWW_i = A\sigma(Q_i/WW_i) \qquad (3)$$

This gives a measure of the impact of wastewater on crop production.

The associated costs of producing $Q_i$are given as;

$$C_i = P_f F_i + P_L L_i + P_S S_i + P_{ww} WW_i + P_{x_{ij}} X_{ij} \qquad (4)$$

Where $P_f$, $P_L, P_S, P_{ww}$ *and* $P_{x_{ij}}$ are prices of fertilizer, labour, seeds, wastewater and other variable inputs used in producing crop i respectively.

The net benefit from production of crop *i* is given as:

$$NB_i = P_{Q_i} Q_i - C_i \qquad (5)$$

Total net benefits from crop production are

$$NB = \sum_{i=1}^{j} NB_i \qquad (6)$$

### 3.2.2 Soil reclamation cost function

As mentioned in section 2.1.4 wastewater irrigation has negative effects on the soil health (soil fertility, soil structure, salinity, heavy metal accumulation etc.); these lead to reduction soil productivity especially in the long run and lead to depreciation of market value of land or added costs of soil reclamation. The variation in crop productivity can capture these harmful effects caused by wastewater irrigation. However, attributing these negative soil factors to wastewater irrigation could be a problem given that there are many other factors which affect crop productivity.

An alternative way of quantifying wastewater induced land degradation which is more practical is the cost of soil recovery and reclamation costs (like applying lime, gypsum, manure, etc.). This can be applied to small wastewater induced degradation which can be corrected by measures and can be estimated as follows:

$$LDC = \sum_{i=1}^{n} C_i \quad (7)$$

Where LDC is the land degradation costs and $C_i$ is cost of specific reclamation.

### 3.2.3 Aquifer damage cost

Aquifer damage is represented by seepage of nitrates below the root-zone contaminating drinking water. Levels of nitrate exceeding 50 mg/l, according to WHO recommendation, in the potable water supply are considered hazardous. This case can be applied to different harmful elements which reach the aquifer from the irrigation with treated wastewater.

$$C_{aquifer\ damage} = \sum_{i=1}^{n} C_{ERi} \quad (8)$$

*$C_{ER}$ is cost for element i reclamation (like Nitrogen)*

### 3.2.4 Aquifer recharge benefit function

Benefit to aquifer recharge is the relevant value of water from contribution of irrigation to aquifer recharge. The price of the freshwater unit should be used in calculating the total benefit of groundwater recharge by irrigated wastewater.

$$B_{recharge} = P_{FW} \times WW_{net} \quad (9)$$

$B_{recharge}$ is the aquifer recharge benefit

$P_{FW}$ is the price of the freshwater unit

$WW_{net}$ is the new wastewater value reaching the aquifer

### 3.2.5 Health cost

Wastewater has negative impacts on the health of the farmers, the consumers and the whole society exposed to wastewater irrigation impacts. Following (Weldesilassie et al, 2008), the incidence of wastewater related illness can be given as follows;

$$I = \beta Z + \alpha T + \varepsilon \quad (10)$$

Where $I$ is the incidence of wastewater related illness, $Z$ is a vector of exogenous variables that are affected to affect the health of an individual, $\beta$ signifies the parameters of$Z$, T is treatment variable and $\varepsilon$ is an error term.

Quantification of health costs can be done using the following equation modified from (Guang, 2000) is shown below:

$$L = \{PT_i(L_i - L_{Oi}) + Y_i(L_i - L_{Oi}) + PH_i(L_i - L_{Oi})\}M + A \quad (11)$$

Where

| | |
|---|---|
| *L* | *= Value of lost human health resulting from wastewater irrigation per year* |
| *P* | *= Human capital (per capita value), US$/year/person.* |
| *M* | *= Population in the area exposed to wastewater reuse and consumers of crops produced using wastewater (number of persons).* |
| $T_i$ | *= Average annual loss of labor by patients suffering from any one wastewater related diseases (US$/ year).* |
| $Y_i$ | *= Average medical and nursing expenses for patients sick with a wastewater related disease* |
| $H_i$ | *= Average annual work time lost by relatives accompanying family members' sick with one.* |
| $L_i$ ,$L_O$ | *= Respectively, the incidences of wastewater related diseases among population exposed to wastewater reuse and consumption of crops; and clean areas (person/100,000 persons/year).* |
| *A* | *= Costs of averting measures to reduce risk of wastewater related illnesses.* |

### 3.2.6 Capital and operational cost of wastewater treatment

Basically, the capital and operational cost depend on the daily wastewater flow and the target level of treatment as well as the technology of treatment. Following Tsagarakis (2003) the wastewater treatment cost function follows the functional form:

$$TC = aWW^b \tag{12}$$

$WW$ is the treatment volume which depends on the population where *a* and *b* are coefficients which have been used to express land requirements, construction and operational costs.
This equation can be modified to be more general as the following:

$$TC = aWW^b + c$$

Where *c* is constant based on the technology type.

## 4 Conclusion

Water scarcity is one of the arid and semi-arid regions, currently, water consumption in most is higher than the available water and the water demand for industries, domestic and agriculture are being met at the expense of the ecological requirements. As agriculture is the major consumer of water, strategies for improving its water use efficiency and identifying alternative uses are paramount for reducing water scarcity and freeing water resources for use in other sectors where it has higher economic value. Wastewater reuse in agriculture will not only reduce scarcity but also improve crop productivity, reduce the need for fertilizers and be used as part of the wastewater treatment which removes nitrates and other macronutrients from wastewater. However, there are also negative aspects related to wastewater reuse and these include soil salinity, health of farmers and consumers, public acceptability, marketability of produce, and economic feasibility and sustainability of wastewater irrigation. This study adopts an integrated systems modeling framework which allows assessment of possible tradeoffs that make use of wastewater safer and have higher returns whilst minimizing the negative impacts. The study shows the variety of wastewater treatment qualities with the cost-benefit elements to achieve acceptable irrigation, although lower levels of wastewater treatment might result in lower capital and operational cost but results in higher environmental cost, health costs , soil productivity (especially in the long term), and irrigation cost. While on the other hand higher wastewater treatment shows higher capital and operational cost which translates to lower environmental cost, health cost, soil productivity, and irrigation cost. The shaded or indirect factors as well as the susceptibility of the environmental system may affect some terms in this cost equation and can make an unexpected change of the total wastewater cost. In addition, the study puts wastewater on the policy agenda by demonstrating the economic and environmental benefits of wastewater use in agriculture. This study's main hypothesis is that the economic benefits of wastewater reuse in agriculture outweigh the costs (health and environmental), however due to data limitations it was not possible develop an empirical framework which actually quantify benefits and tradeoffs needed to test this hypothesis. As a follow up to this study, we would recommend applying the developed analytical framework to empirical data.

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