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Challenges, Opportunities and Technologies of Wastewater for Agricultural Irrigation in Developing Countries: A Systematic Review

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Abstract

Water insufficiency and wastewater generation is the major anxiety that impacts the livelihood. Renewable water used for irrigation is long-term experience in developed and developing country. However, in developing country the volume of treating and using wastewater is limited due to the lack of adequate data, knowledge, and improper management. Wastewater is an important source of water and nutrients for irrigation in developing countries. It can be used as reclaimed water and applied directly to crops or indirectly after discharge and dilution with water from rivers or reservoirs. Undesirable constituents in wastewater can harm human health and the environment. For different reasons, developing countries are still unable to implement comprehensive wastewater treatment programs. This paper evaluation of wastewater irrigation in developing countries, endorse strengthening institutional capacity and establishing links between waste generators and sanitation sectors through inter institutional coordination leads to more efficient management of wastewater and risk reduction.

Keywords: Wastewater; Wastewater treatment; Wastewater irrigation; Wastewater management; Challenge; Opportunity

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Introduction

Water quality and quantity problems at the urban-rural interface are increasing throughout the developing world. Growing demands for water to produce food, supply industries, and support human populations have led to competition for scarce freshwater supplies. Climate change, rapid population growth, freshwater pollution, and depletion are among the factors that aggravate the situation. The reuse of wastewater is increasingly seen as an option to meet these growing needs for water and considered as potential mechanisms to mitigate the challenge. The agricultural sector is globally the largest consumer of water and wastewater globally, accounting for approximately 70% of water use on average [1]. By contributing to food and water security, wastewater irrigation can alleviate strain on water resources by providing a reliable year-round source of water with sufficient nutrients for crop growth [2]. This is especially critical in regions where climate change is expected to exacerbate water stress and increase precipitation variability [3]. Irrigated agriculture especially in arid and semi-arid areas, is facing pressures to reduce its water use in order to also cater for other water users like power and water needs for growing urban and industrial areas, and the ample water that is needed to provide in-stream flows to preserve native fish populations in various regions. Therefore, Farmers in many arid and semiarid areas are forced to find solutions to irrigate their crops, so they often must use treated, untreated or undiluted wastewater which is cheaper than other water sources. Increasing water needs (for drinking, food and irrigation) make the use of effluents (treated wastewater) an effective solution to solve the problem of water scarcity, to save significant quantities of drinking water, to reduce the use of chemical fertilizers (nutrients in the wastewater can replace conventional fertilizers), thereby protecting the environment and improving crop yield. Recently, the reuse of wastewater in agriculture has become a widespread practice in regions where water deficits are most pronounced [4]. Wastewater reuse is an integral part of water demand management, promoting the protection of high quality fresh water and reducing both environmental pollution and overall supply costs. Certainly, irrigation with treated wastewater is already implemented, mainly for agriculture and landscape in worldwide due to insufficiency of freshwater resources. It contributes to optimize water use for irrigation in arid and semi-arid regions. Besides the decrease in the use of freshwater, wastewater reuse also may reduce the discharge of effluents into freshwater ecosystems, enriching the soil with organic matter, macro, and micro nutrients. Therefore, the objective of this paper is to review challenges, opportunities and technologies of wastewater agricultural irrigation in developing countries.

Research Methodology

The paper is based on review and use of secondary data published in journals, research centers, annual reports, technical and consultant reports available in the studies conducted by various researchers, institutions and organizations. Only papers that were peer reviewed, written in the English language, and published between the years 2002 and 2019 were included. The review focused primarily on literature search and restricted to articles and report papers published. After searching each database, individual article titles and abstracts were assessed to determine their relevance to the topic of this review. A literature search for this review focused primarily on studies conducted in developing countries. Based on the review objectives and content types, articles and published reports were retrieved from databases mainly focusing on empirical results reported on Irrigation and crop yield. Following a critical review, data and literatures were compiled on existing and detailed waste water irrigation, challenges of using waste water irrigation, importance of waste water uses in agricultural irrigation and technologies of using waste water for irrigation.

Four categories of studies were included in the review: The concepts of waste water irrigation on opportunities, challenges and use waste water technologies for irrigation were identified and recommendations are forwarded for the future endeavor of enhancement in agricultural production system.

Results and Discussion

Concepts of using wastewater for irrigation

Wastewater is defined differently by different authors (people) with a large number of definitions in use. However, [5] report has taken a broad perspective, and defined wastewater as “a combination of one or more of: domestic effluent consisting of black water (excreta, urine and faecal sludge) and greywater (kitchen and bathing wastewater); water from commercial establishments and institutions, including hospitals; industrial effluent, storm water and other urban run-off; agricultural, horticultural and aquaculture effluent, either dissolved or as suspended matter. Direct use of untreated waste water irrigation vegetable is varies with wastewater dilution in the receiving streams and between seasons, consuming lettuce produced with waste water irrigation **(Figure 1).** Wastewater irrigation has a significant potential to contribute to food supply and reduce farmers dependency on fresh water resources**.**

Use of wastewater irrigation as alternative: Wastewater reuse for irrigation is long-term experience in human history since prehistoric civilizations [6]. In both developed and developing countries, the most prevalent practice is the application of wastewater (both treated and untreated) to land. In developed countries where environmental standards are applied, much of the wastewater is treated prior to use for irrigation for crops. In developing countries, though standards are set, these are not always strictly adhered to. Wastewater, in its untreated form, is widely used for agriculture and aquaculture and has been the practice for centuries in developing countries. Wastewater is an important source of water and nutrients for irrigation in developing countries, particularly but not restricted to those located in arid and semi-arid areas and constitutes high amount of nutrients contributing to significant increases in crop yields [7]. There are no general rules possible, as the amount of nutrients applied via wastewater irrigation can vary considerably if the wastewater is raw, treated or diluted with stream water. The possible nutrient input to the soil with different amounts of treated wastewater is given in **Figure 2**.

Wastewater production and use in irrigated agriculture: Municipal wastewater for irrigation is a very experienced task in many places, but the knowledge and the experience in this field

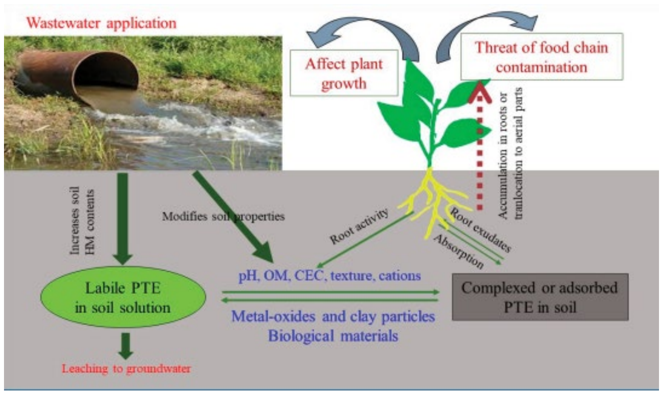

Figure 1 Wastewater crop irrigation.

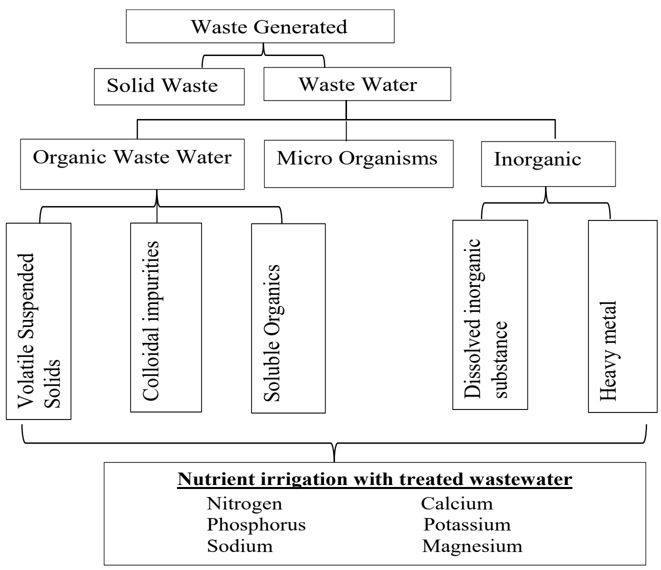

Figure 2 Type and characterizations of wastewater.

are limited [8]. Large volumes of waste water generation are high in city, but use of treated waste water irrigation is low in developing country **(Figure 3)**. The resulting environmental degradation within and downstream of cities has multiple consequences for public health, in particular through the use of untreated wastewater in irrigated agriculture. Despite significant efforts to increase wastewater treatment, options for safeguarding public health via conventional wastewater treatment alone remain limited to smaller inner-urban watersheds. The new WHO guidelines for wastewater irrigation recognize this situation and emphasize the potential of postor non-treatment options. Controlling potential health risks will allow urban water managers in all three cities to build on the benefits from the already existing (but largely informal) wastewater reuse, those being the contribution to food security and reduction of fresh water demands.

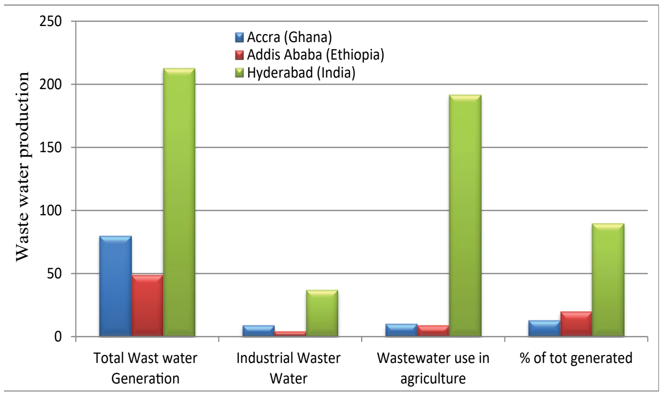

Figure 3 Wastewater generation and treatment.

Wastewater use and treatment in low income country: In many low income countries the absence of technical and financial resources makes it very difficult to efficiently collect and treat waste water **(Figure 4).** The exists limited data in published literature about waste disposal and treatment, as well as its use in agricultural sector of developing countries compared to developed countries. In fact, in developing countries there are no proper university- industry linkages, which is one of the main reasons for the lack of problem-oriented research in this country. The lack of scientific /research data and university-industry research linkages in this country makes it difficult to establish policies, planning and laws for environmentally friend practices, especially in agricultural sector. Moreover, the economic and social factors, as well as the lack of awareness and knowledge of the environmental and health risks among the people of developing countries also hinder the adaptation and implementation of these environmentally friendly practices. The role of research institutes/ universities and funding agencies, as well as government organizations, could play a key role in this regard. Poverty is also considered an important factor behind the use of wastewater for crop irrigation, especially in less-developed countries. Farmers with small agricultural land holdings prefer to use wastewater for irrigation despite the availability of fresh water. This is due to the low-cost of crop production by adopting this irrigation practice. In some developing countries, the limited public awareness, the less commercial development of wastewater recycle/reuse, and the social setup are some of the other key challenges faced in the realm of wastewater use for the agricultural sector. Wastewater recycling/reuse seminars, commercial operation mechanisms, and fiscal support from the government can be highly effective in mitigating the environmental and health issues related to the use of wastewater in the agricultural sector. The above-mentioned facts clearly show an alarming gap of environmentally-friendly practices and environmentally sustainable approaches regarding water treatment among the developed and developing countries, especially in the highly populated areas.

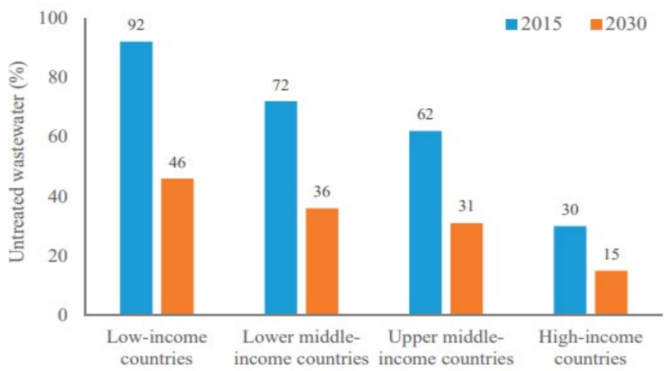

Figure 4 Untreated waste water discharge into the environment in low and high income countries.

Opportunities of wastewater reuse for irrigation

Normally, global agricultural water consumption is about 70% of the total water abstracted; even this figure can be extended to 90% in some local situations **(Figure 5)**. In line with this, the reuse of reclaimed water for agricultural irrigation is good opportunity to reduce severe global water stress [9]. Many driving forces can be identified in practices of wastewater reuse such as water scarcity, environmental and economic consideration as well as technology improvement. Urbanization and consequential water demand drive directly the development of wastewater reuse. The rapid urbanization aggravates water demand and wastewater discharge, resulting in decease of water environment and water supply, and then the decreasing of water resource inhibits the development of urbanization at some extent. Under the above situation, a worse cycle between urbanization and water resource is formed in many cities. Wastewater reuse which can increase water supply and reduce pollutant discharge into surrounding water bodies, provides a chance to unbuckle this cycle. This positive cycle can alleviate water crisis and promote the development of cleaner production and circular economy. In addition, current technologies applied in wastewater reuse such as ultraviolet radiation, maturation ponds, membrane filtration and electrochemical treatment can remove effectively the pollutants including salinity, pathogens, and heavy metals and emerging contaminants. The advanced wastewater treatment technologies greatly reduce the risks associated with wastewater reuse. According to the current policies, regulations and investments on wastewater reuse, wastewater reuse in developing

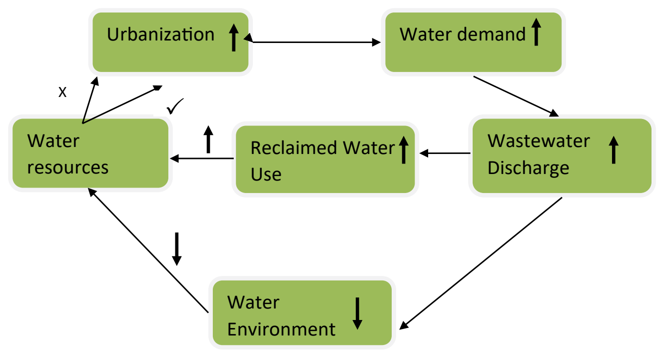

Figure 5 The relationship between urbanization and water resources.

countries is expected to expand greatly in the following decades. Urbanization is a historical process of urban quantity increasing and urban scale expanding due to populations transferring and the secondary and tertiary industries gathering from rural to urban [9]. Rapid urbanization and economic development also forced the cities to search for new water sources. As urban populations in developing countries increase, and residents seek better living standards, larger amounts of freshwater are diverted to domestic, commercial, and industrial sectors, which generate greater volumes of wastewater [10-12]. Globally, wastewater is the potential candidates of water resources to satisfy the world's water demand in the future as the reclamation of wastewater is economically more viable than the desalination of seawater [13].

Technologies of wastewater treatment for irrigation

Wastewater disposal and delivery increases costs and technological needs. Use of new technologies can help reduce costs (e.g., dual distribution and satellite wastewater management systems [14]. Many wastewater treatment technologies were developed, and a lot of efforts were made to reuse the wastewater to satisfy the high demand for water in the world. In developed countries, the reuse of municipal wastewater is normally based on the upgrade of existing wastewater treatment plants (WWTP) with the introduction of tertiary treatments. Several pilot studies and full scale installations have shown that a number of different technologies are suitable for producing reclaimed municipal effluents complying with the standards for reuse [8]. The quality of treated wastewater depends to a great extent on the quality of the municipal water supply, nature of the wastes added during use and the degree of treatment the wastewater has received [15]. Also, high quality effluent requires water treatment shift from less developed methods toward advance methods that imply higher costs. Conventionally, the rational utilization of wastewater in rural areas, together with the protection of the environment, can be made after at least partial purification, ideally complete (primary and secondary treatment). The preliminary stage consists of screening and grit chambers which are applied to remove large size solid matters, whereas the primary treatment is to retain total solids by settling, and the float (scum) like grease and oil by skimming [16]. Basically, the sedimentation of solids and skimming of oil and grease are the major tasks in primary conventional wastewater treatment plants [17]. Secondary treatment is fundamentally a biological method that is mainly intended to remove oxygen demanding organic pollutants, whereas the tertiary treatment is to polish the removal of the organic matter residual, nutrients, inorganic molecules, particulate matters and remaining microorganisms [18]. The most common secondary treatment technologies are activated sludge, biological trickling filter and rotating biological contactor processes which are aimed to degrade the complex organic compounds into non-toxic substances [19]. However, photosynthetic organisms are being used frequently instead of the normally decomposing bacteria recently. One of the advantages of such technology is the generation of a considerable amount of oxygen to degrade organic compounds which reduce the aeration tasks. Additionally, advanced treatment technologies like membrane bioreactors recently adopted and are used instead of the activated sludge reactors and trickling filter processes in some places [20]. Membrane bioreactors work in the principle of the activated sludge of biological filtration which emerged with many advantages. Basically, this technology is designed to remove soluble organic matter, nutrients, and micro pollutants from wastewater to improve its energy efficiency, and reduce the operating and maintenance cost. Also, constructed wetlands showed to be a technology that serves as primary, secondary and tertiary wastewater treatment [21]. Globally, with the improvement of analytical methods, many anthropogenic chemicals including pharmaceuticals, biocides, agrochemicals and industrial chemicals have been detected in many treated effluents and receiving water bodies [22] **(Figure 6)**.

Waste water reuse challenges in developing country

The agricultural irrigation with reclaimed water has both negative and positive outcomes. Some positive effects were observed from farmland irrigated with reclaimed water, but the detailed investigations of the physiological, biochemical, physico-chemical properties of the whole system were limited [23]. The reuse of reclaimed water can incredibly improve the soil composition in terms of Electrical Conductivity (EC), nutrients and trace metal elements. Additionally, it was also reported that the farmland irrigated by treated municipal wastewater increased the soil compositions in terms of nitrogen and phosphorus [24]. Moreover, reclaimed water can significantly increase soil minerals such as ammonium, sodium, and EC [25]. However, commonly wastewater is discharged with little or no treatment in natural water bodies, which can become highly polluted **(Figure 7)**. Farmers in urban and peri urban areas of nearly all developing countries who are in need of water for irrigation often have no other choice than using wastewater. The absence of financial and technical resources in many developing countries makes comprehensive wastewater collection and treatment a long-term future strategy. It is therefore required that in the near term, risk-management and interim solutions are needed to prevent adverse environmental and health impacts from wastewater

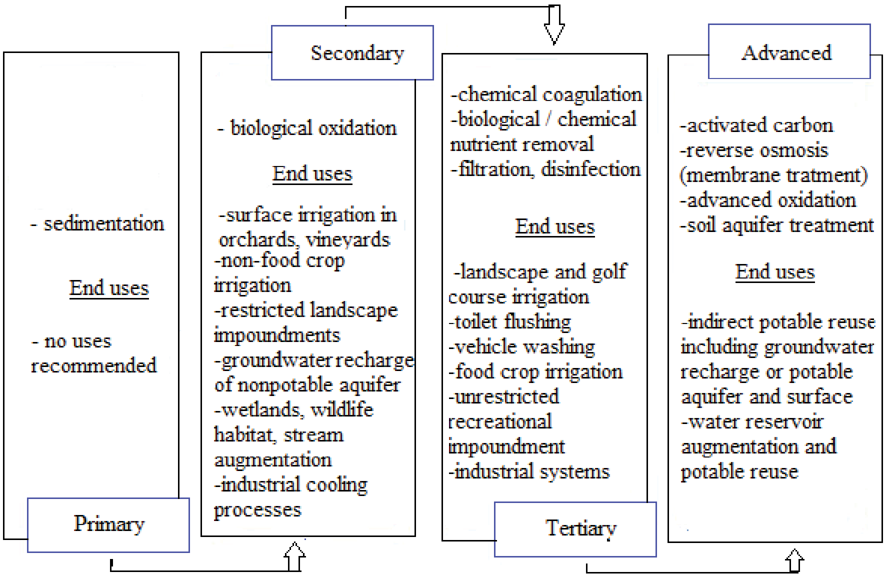

Figure 6 Types and levels of wastewater treatment processes.

Figure 7 Schematic picture of waste water used for irrigation, photo was taken from Harar in Eastern Ethiopia.

irrigation [26,27]. These include user and consumer health protection through interventions at the farm level, post-harvest measures, and public policies to motivate better management of wastewater. In many African cities, population growth has outpaced improvements in sanitation and wastewater infrastructure, making management of urban wastewater a tremendous challenge. In West African cities, usually less than 10% of the generated wastewater is collected in piped sewage systems and receives primary or secondary treatment [2]. In many developing countries, large centralized wastewater collection and treatment systems have proven difficult to sustain. Decentralized systems that are more flexible for long-term operation and financial sustainability and compatible with demands for local effluent use have been promoted in many areas [28-39], although not without challenges.

Conclusion and Recommendations

In the developed country wastewater is an important source of water and nutrients for irrigation in particularly but not restricted to those located in arid and semi-arid areas and constitutes high amount of nutrients contributing to significant increases in crop yields. It is an integral part of water demand management, promoting the protection of high quality fresh water and reducing both environmental pollution and overall supply costs. Many driving forces can be identified in practices of wastewater reuse such as water scarcity, environmental and economic consideration as well as technology improvement. Many wastewater treatment technologies were developed, and a lot of efforts were made to reuse the wastewater to satisfy the high demand for water in the world. Even though, the reuse of reclaimed water can improve the soil texture and supply nutrients for crops, the impact of the emerging pollutants still a large challenge for water reuse. The application of reclaimed water for irrigation can cause chronic toxicity, alter the physico-chemical and microbiological properties of the soil which can result in serious risks to the human and environmental health.

Wastewater, as a substitute for freshwater, contributes considerably to agricultural irrigation to address water scarcity. To a large extent, wastewater irrigation has alleviated water shortage in dry area. Wastewater irrigation has a long history and has operated better in developed countries than in the developing world. Untreated wastewater irrigation can create numerous environmental and health-related problems through soil and crops. The application of suitable treatment and irrigation technologies can present substantial benefits while minimizing risks. Carefully management can ensure such benefits while minimizing risks. Wastewater irrigation still faces many challenges (i.e., increased proposals and other issues). However, through its ongoing development, wastewater irrigation could significantly reduce environmental carrying capacities beneficial utilization in agriculture.

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