Policy, Laws, and Guidelines of Wastewater Reuse for Agricultural Purposes in Developing Countries

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Abstract In developing countries, an estimated 65% of freshwater withdrawals are currently utilised in agricultural activities that are predominately related to irrigation. As climate change continues to threaten the availability of freshwater, there is a growing need to explore alternative irrigation water sources and treated municipal wastewater reuse has emerged as a viable option. Having been in practice for the past 5,000 years, municipal wastewater reuse continues to be perceived as an innovative water management approach to augment water supplies in water scarce regions.

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Presently several developed countries, confronted with water scarcity, have made significant progress in tapping into this resource. Strong institutional frameworks (policies, regulations, and guidelines) have significantly contributed to the progress. However, in developing countries, particularly Africa, treated municipal wastewater reuse remains an untapped resource, despite climate change projections indicating a decline in rainfall and greater uncertainty of its occurrence, while demand for freshwater is expected to increase in the coming decades. Furthermore, freshwater shortages are exacerbated by flows of untreated municipal wastewater, industrial effluents, and other pollutant sources into natural water bodies. Researchers have alluded to lack of institutional frameworks that comprehensively address and pronounce on the "What", "Where", "When", "Who", and "How" to deploy treated municipal wastewater reuse in agriculture. Through systematic literature review and document analysis of policies, regulations, and guidelines of selected case study countries in Africa, Asia, Latin America, Europe, and North America, this chapter presents a review of the developments in the reuse of treated municipal wastewater in irrigated agriculture. With an objective to unearth impediments in tapping into treated municipal wastewater reuse as an alternative water source for irrigated agriculture in Africa, we present recommendations for improvement of the current landscape. The study established that a well formulated legislative framework is vital for putting in place appropriate policies, regulations, and guidelines to enable successful adoption of projects which use treated wastewater for agricultural activities by farmers. Imbedded in such a framework should be a robust and comprehensive institutional arrangement of relevant departments which work collaboratively, and with skilled human personnel who have capabilities of engaging with relevant stakeholders and addressing technical issues of wastewater collection, transport, treatment, and reclamation, as well as being able to proffer economically viable wastewater reuse projects. Best practices of treated wastewater reuse in agriculture from the State of California and Spain, used as case studies from the USA and EU, should be adapted and refined to local conditions by countries which lag in this practice.

Keywords Developing countries, Guidelines, Irrigated agriculture, Municipal wastewater reuse, Policies, Regulations

1 Introduction

Researchers continue to reverberate how rapid and continuous population growth, coupled with urbanisation, and increased human economic activities, have resulted in freshwater demands surpassing supplies [1]. The United Nations (UN) report of 2015, predicting a global water deficit of 40% by 2030 [2], corroborates the looming freshwater crisis. The ramifications have an adverse effect on green water availability. Researchers estimate an average of 65% of freshwater withdrawals to be channelled towards agriculture globally [3]. Hence, strategies to mitigate water shortage-related risks in agriculture are highly topical. These include investigations into treated municipal wastewater reuse. Presently terrestrial water is the main freshwater source for agricultural production, and the main objective of these investigations is optimisation of water usage to achieve reduction in freshwater withdrawals intended for agricultural activities.

Several developed countries, where water scarcity is a threat to economic activities, have made significant progress in tapping into treated municipal wastewater reuse in irrigated agriculture. This has largely been achieved through putting in place policies, laws, regulations, and guidelines that explicitly articulate treated municipal wastewater reuse procedures and processes in irrigated agriculture. Consequently, stakeholders have been capacitated to efficiently implement the practice [4]. Whereas in developing countries, particularly Africa, treated municipal wastewater reuse in irrigated agriculture continues to be widely unplanned, and untreated wastewater is deployed. Several reasons are documented which include the absence of country specific policies, regulations, and guidelines that explicitly articulate and promote deployment of treated municipal wastewater reuse in irrigated agriculture [5].

Hence, this study reviewed the literature and government documents on developments of policies, laws, regulations, and guidelines that address treated municipal wastewater reuse in irrigated agriculture. In the global North, the State of California in the United States of America (USA) is selected as the case study, taking cognisance of its water scarcity experiences, adverse climate change impacts, uneven spatial distribution of water resources, coupled with its pioneering publication of regulations and standards on treated municipal wastewater reuse in irrigated agriculture in 1918 [6]. This document has shaped global municipal wastewater reuse discourses. Spain is selected in the Europe Union (EU) due to its asymmetrical distribution of water resources and first position ranking in deployment of treated municipal wastewater reuse in irrigated agriculture among EU member states [7]. In the global South, Mexico in Latin America has made significant progress in deploying wastewater reuse in irrigated agriculture, hence its selection as a case study. In Asia, China is selected, considering the complex water management issues arising from pollution of natural water bodies emanating from extensive economic activities. Furthermore, China is ranked first place globally for reported usage of untreated municipal wastewater in irrigated agriculture. In Africa, Egypt in North Africa is among countries that are making progress in the deployment of treated municipal wastewater reuse in irrigated agriculture [8]. While sub-Saharan Africa lags with limited data on municipal wastewater reuse in irrigated agriculture, the only available data depict several hectares of land in South Africa under untreated municipal wastewater irrigation, hence its selection as a case study in the region.

The main objective of this study is to unearth ways to improve and encourage treated municipal wastewater reuse in irrigated agriculture in Sub-Saharan Africa. In carrying this review, the following questions guided the study:

What policies, laws, and guidelines exist in support of municipal wastewater reuse in selected case studies?

What are the challenges in the development and implementation of institutional frameworks (policies, legislation, and guidelines) for municipal wastewater reuse in irrigated agricultural?

2 Methodology

The study employed case study research methodology recommended by [9] for an in-depth exploration of the research questions in the delimited areas. With planned treated municipal wastewater reuse in irrigated agriculture as the unit of analysis, the development of institutional frameworks (policies, laws, and guidelines), pertaining to this unit, is considered the main objective. The study conducted a systematic qualitative analysis of literature and government documents, perceived by [10], to be a suitable technique for policy content analysis.

3 International Guidelines on Municipal Wastewater Reuse in Irrigated Agriculture

Research indicates gaps in the uniformity of policy development and formulation of regulations and guidelines that create an enabling environment for wide deployment of municipal wastewater reuse in several global South regions [11]. Citing absence of universal guidelines and standards, stakeholder confidence in deployment of wastewater reuse globally is significantly eroded [12]. However, there are non-binding guidelines published by international organisations such as World Health Organisation (WHO), Food and Agriculture Organisation (FAO), and International Organisation for Standardization (ISO) that may be of value to global South countries where treated municipal wastewater reuse in irrigated agriculture is in its infancy or non-existent.

The first international organisation to publish guidelines on municipal wastewater reuse for irrigated agriculture was WHO in 1973. The published document was entitled “Reuse of effluents: methods of wastewater treatment and health safeguards”. Its main objectives were to protect public health and to ensure safe application of wastewater reuse and excreta handling in agriculture. However, the document fell short in achieving these objectives as it did not explicitly articulate preventative measures on public health risks associated with wastewater reuse in agriculture and lacked any backing from epidemiological studies. Following extensive epidemiology research, the 1973 WHO guidelines were updated in 1989 and a document entitled “Health guidelines for the use of wastewater in agriculture and aquaculture” was published. This document focused on microbiological threshold levels permissible in irrigated agricultural, and prioritised public health and environmental protection [13]. The current WHO guideline, published in 2006, entitled “Safe use of wastewater, excreta, and greywater” is well informed by extensive research. Issues pertaining to public health are dealt with explicitly through assessment of health risk, health-based targets, and health protection measures. Monitoring and system assessment measures are articulated, and consideration is given to social, cultural, financial, and environmental policy aspects [14]. The WHO guidelines highlight the parasites in humans as the key risk factor and their removal to be paramount.

The FAO followed WHO and published its guidelines in 1987 which were updated in 1999 focusing on effluent quality standards for different uses. The threshold levels of trace elements permissible in irrigation of specific crops is delineated. However, regarding microbial requirements, the guidelines are less restrictive when municipal wastewater reuse is deployed, particularly in unrestricted irrigation category, while proposing stricter water quality levels for fruit trees irrigation, requiring faecal coliforms to be as low as <200/100 mL. Importantly, the physico-chemical parameters of FAO guidelines have informed the set standards, criteria, guidelines, and regulations of several organisations and state agencies [15].

In 2010, upon Israel’s request titled PC 253, the first ISO standard for wastewater reuse in irrigated agriculture was issued. This was followed by Japan’s proposition which was to be established along with Israel’s and China’s, titled TC 282, in 2015. WHO guideline (2006), Australian national water reuse regulations (2006), Israeli regulations for agricultural irrigation (1978,1999, and 2005), and California Code of Regulations (Title 22, division 4, Chapter 3, water recycling criteria (2000)) were the reference materials used in the establishment of the ISO standard. In 2015, the ISO 16075 series on guidelines for deployment of treated municipal wastewater in irrigated agriculture was released.

4 Development of Policies, Regulations, and Guidelines in Municipal Wastewater Reuse in Irrigated Agriculture

Despite treated municipal wastewater reuse gaining momentum globally, the absence of binding universal policies, regulations, and guidelines curtails its wide application. Consequently, several countries have developed theirs that are country specific, prioritising public health and environmental protection. The geographic, economic, and social landscapes actuate the development of these policies, regulations, and guidelines. Accordingly, there are disparities in permissible threshold levels of microbial and physio-chemical parameters [16]. In this regard, developed countries have had several years of experience in developing their regulations and guidelines.

Albeit development of regulations and standards for water reuse in the USA being the responsibility of the states, the Environmental Protection Agency (EPA) has also developed comprehensive water reuse guidelines that work in tandem with those formulated by states and any agencies involved in water reuse projects, to mitigate any incoherence between the federal government and the states [17].

4.1 State of California

The State of California is acknowledged globally for pioneering publication of treated municipal wastewater reuse regulations and guidelines in 1918. These regulations are explicit and comprehensive, delineating stringent restrictions on wastewater reuse parametric threshold levels permissible in irrigation for specific crops, and specifying the irrigation technique to be deployed. While many states in the USA sought what to do with the effluents from their wastewater treatment plants due to the enactment of the Clean Water Act (CWA) by Congress in 1972, that requires the Environmental Protection Agency (EPA) to set minimum standards on effluents from those plants, the State of California was well ahead with water recycling projects. To institutionalise and strengthen treated municipal wastewater reuse practices, the State of California Legislature enacted the Wastewater Reuse Law (WWRL) of 1974 [18]. From the published 1918 guidelines to the water quality standards and treatment reliability criteria that are contained in the California Department of Public Health (CDPH) Water Recycling Criteria (Title 22, Division 4, Chapter 3 of the California Code of Regulations), California has had over a century of safe use of treated municipal water for the irrigation of food crops. These standards and guidelines have been dynamic over time with improved wastewater treatment technologies, increased knowledge of the behaviour of pathogens and their impacts on human health, and changes in agricultural and irrigation practices. A recent review of these CDPH water recycling criteria by the National Water Research Institute [19] provided the data of the annual wastewater being recycled from 1989 that are presented in Fig. 1, while the three highest users of recycled water are agriculture (37%), landscape irrigation (17%), and groundwater recharge and seawater intrusion barrier (19%). With the CWA at the federal level and the WWRL in the state, coupled with the Title 22 of the California Code of Regulations, extensive wastewater reclamation projects were implemented [20]. These projects attracted huge funding from state and federal grants and included farms with large acres of land irrigated with treated wastewater.

The role of institutions in the successful deployment of wastewater reuse in irrigation in the case of California cannot be underestimated. The CDPH, State Water Resources Control Board (SWRCB) and the nine Regional Water Quality Control Boards (RWQCBs) are involved in the recycling of treated wastewater.

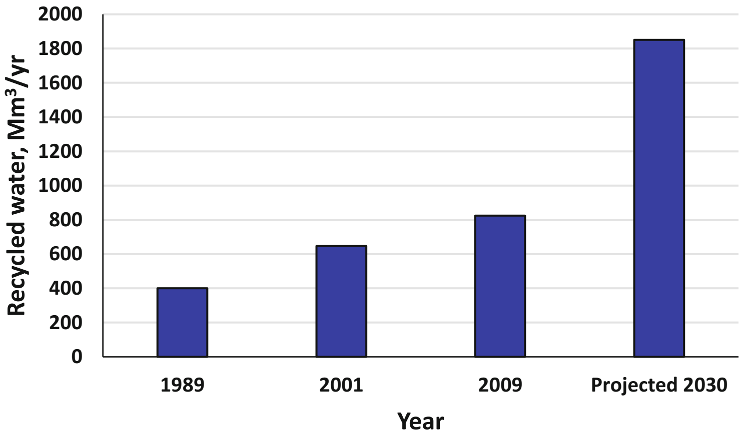


Fig. 1 Treated wastewater in the State of California. Source: [19]

While the State and Regional Water Boards oversee the environmental health of the waters of the State, the SWRCB administers water rights. The CDPH plays the role of establishing public health criteria for wastewater reclamation, including groundwater recharge, and reviewing of all proposals for such projects in the State. There is a memorandum of understanding among these agencies that ensures corporation and collaboration in achieving successful projects. While champions may be required to achieve successful farm projects in which treated wastewater is deployed for irrigation, the overarching policies, regulations, and guidelines executed through these mandated institutions ensure that success is replicated from one project to another. This approach sets precedence for global South countries in leapfrogging to achieving such successful farm projects.

4.2 European Union

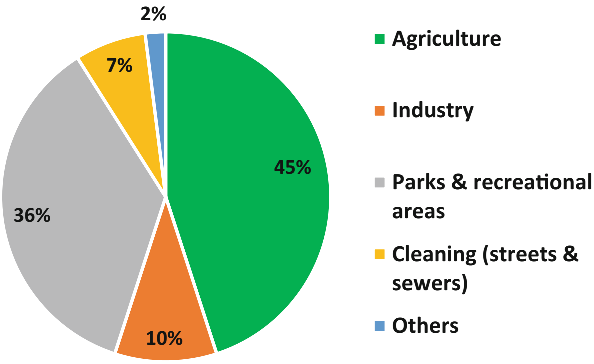
The potential of treated municipal wastewater reuse in the EU has continued to gain recognition, necessitating its embeddedness within EU's Water Framework Directive (WFD). The acknowledgement by the EU of the importance of treated municipal wastewater reuse found expression in the European Innovation Partnership on water of 2012 that supports innovative solutions to water challenges, along with the report by the European Commission (COM, 2012 – 673) that provides a blueprint on how to safeguard Europe's water resources. The WFD promoted the establishment of legal frameworks among member states to ensure the protection of public health, the environment, and natural water bodies within their jurisdictions. Spain, one of EU's member states, is regarded as the pacesetter in treated municipal wastewater reuse among the states [7], and for this reason, we explore the Spanish legal framework development for treated municipal wastewater reuse in irrigated agriculture.

4.2.1 Spain

The use of treated municipal wastewater in agriculture in Spain started in 1970 from a wastewater plant in Las Palmas [21]. This practice was extended to other cities and regions before the enactment of the Water law in 1985 and Spain joining the EU in 1986. These years of 1985 and 1986 were notable with respect to wastewater reuse in agriculture. The Water law of 1985 established that "the Government shall fix the basic conditions for the water reuse based on the purification process, its quality and the planned uses" (Article 101) and served as the basis for regulations and guidelines for wastewater reuse. With Spain joining the EU in 1986, the regulations and guidelines had to be modified to align with the EU environmental directives contained in the WFD and other directives for habitats, birds, marine, and floods. The strategy for Spain to align with EU directives required authorisation for effluents from wastewater plants that ensured that there are mitigation measures against impacts on the environment, coupled with penalties for noncompliance. Between 1986 and 2007, there were pieces of legislation that were enacted and repealed, culminating in the Royal Decree 1620/2007 which established that "the Government shall establish the basic conditions for the water reuse, specifying the quality required for treated wastewater based on their expected uses". This is the current piece of legislature that regulates the reuse of wastewater for agricultural production. It contains permissible microbiological and physio-chemical parameters of treated wastewater used to irrigate crops that could be eaten raw, those not eaten raw, those which might undergo industrial processes, pastureland for milk or meat producing animals, tree crops where the treated water does not encounter the fruits that can be consumed by humans, ornamental flowers, nurseries and greenhouses, silo fodder, cereals, and oilseeds. In essence, the regulations and guidelines are comprehensive and mirror those of the State of California. The total volume of treated wastewater that is reused in Spain varies significantly depending on the sources of the data, and it is between 370 and 500 Mm^3/year [21], and the distribution of its use is presented in Fig. 2. The fact that the highest user of treated wastewater is agriculture underscores its importance to the Spanish economy.

As previously stated, pieces of legislation do not exist in a vacuum. They require institutions and adequate human capacity to translate them into successful wastewater reuse projects. In the case of Spain, the Spanish Ministry of Agriculture, Food and Fisheries together with the Ministry of Health issued the Royal Decree 1620/2007 legal framework. Project proposals for treated wastewater use in agriculture must be approved by public health authorities to ensure that they comply with the provisions of the decree in terms of technical and water quality aspects, and that there are in place self-monitoring and risk management programmes [22].

Fig. 2 Users of treated wastewater in Spain. Source: [21]



4.3 Mexico

In Latin America, Mexico has made significant progress in treated municipal wastewater reuse in irrigated agriculture. The success of Mexico can be attributed partly to its policy process and detailed regulations and standards. The policy process which dates to the 1857 Constitution in the colonial era under the Spanish Crown, followed by the 1957 Constitution that empower the Federal Congress to enact laws that pertain to waters under its jurisdiction, current water legislation is derived from the Nation Water Law enacted in 1992 [23]. However, with specific reference to treated wastewater reuse in irrigated agriculture in Mexico, this has been informed by publications and revisions of several standards and regulations from 1991 to the publication of NOM-001-ECOL-1996 and NOM-003-ECOL-1997 guidelines. The former specifies permissible limits for pollutants for water reuse activities, as well as the characteristics of effluent discharge into national water bodies, while the latter specifies the conditions, such as sampling criteria, testing and disposal, and the maximum permissible limits of physio-chemical and microbiological parameters, for various treated wastewater reuse activities [24].

One of the strategies that the Mexican government is prioritising to optimise water usage and avert compromising crop production is treated municipal wastewater reuse in irrigated agriculture. To realise this strategy the Mexican government adopted the 2007–2012 National Water Program (Conagua Programa Nacional Hidrico, 2007–2012). Following which in April 2014, another programme PNH was launched for the period 2014–2018 (Conagua Programa Nacional Hidrico 2014–2018). The main objective of these programmes is to strengthen integrated and sustainable water management, with an emphasis on treated municipal wastewater reuse and treatment of municipal wastewater to fit-for-purpose standards (Conagua PNH, 2014–2018). It was during the implementation and assessment of these programmes that wide application of treated municipal wastewater reuse across the agricultural sector was reported (The Mexican National Development Plan 2013–2018). It is worth noting that the government directed significant funding to municipal wastewater treatment infrastructure for Mexico to realise these positive developments. An increase of wastewater treatment investments of 132% between 2007 and 2011 was reported [25]. By 2012, over 90% of the population was connected to the wastewater network. Mexico is ranked first place in Latin America in terms of volume of treated wastewater reuse in irrigated agriculture, with a consumption of 1,640 Mm^3/year [26]. Despite several lingering challenges, Mexico has continued to be a pacesetter in deployment of treated municipal wastewater reuse in irrigated agriculture in Latin America.

4.4 China

For the past three decades, China has experienced rapid economic growth that has significantly altered its socio-economic landscape but with considerable adverse consequences on its water resources. Consequently, natural water bodies are remarkably polluted. An estimated one-third of lakes and rivers are highly polluted to a degree that the water cannot be utilised for human consumption [27]. Exacerbating the mismatch between the population size and water resources availability, are reports indicating 20% of the world's population residing in China and yet only 7% of the world's freshwater resources is in China [28]. Albeit China's 1st position ranking in untreated municipal wastewater in irrigated agriculture globally, since 1958, the Chinese government has promoted treated municipal wastewater reuse. This has been advanced through its inclusion in the national key scientific and technological projects of the 7th (1986–1990), 8th (1991–1995), and 9th (1996–2000) Five-Year plans. At the inception of these projects the main drawback was the absence of infrastructure for collection and treatment of municipal wastewater, resulting in the reported wide application of untreated wastewater in irrigated agriculture. Between the 10th (2001–2005) Plan and the 12th (2011–2015) Plan, considerable increase was experienced in the amount of wastewater discharge (increase in domestic wastewater discharge from 26.1 billion tons in 2004 to 48.5 billion tons in 2013), reclaimed water (increase from 1.3 billion tons in 2011 to 2.4 billion tons in 2013), and the number of treatment plants (5,364 municipal wastewater treatment plants in 2013). However, in 2013, it was reported that the amount of reclaimed water was still abysmally low at 5% of the total domestic wastewater produced, indicating a huge potential for domestic wastewater reuse in China [29].

The policy and regulatory framework are very important for China to realise its enormous potential in treated wastewater reuse to address its water scarcity, social and economic challenges. The developments of these frameworks are presented in Table 1, while the regulations and standards issued for various wastewater reclamation and reuses can be found in [29]. These include the regulations and standards issued by the Ministry of Construction and Standardization Administration for the engineering of municipal treatment plants (GB 50334-2002) and the reuse of urban reclaimed water (GB/T 18920-2002). These were accompanied by water quality standards issued by different government agencies for various wastewater reuses (GBT 18921-2002 – environment reuse), (GBT 18920-2002 – miscellaneous urban

Table 1 Chinese wastewater reclamation and reuse policies at national level. Source: [29]

Government sectors	Wastewater reclamation and reuse policies	Wastewater reclamation and reuse policies prescriptions
The State Council	The 12th Five-year Comprehensive and Emission Reduction (2011); The 12th Five-year National Urban Sewage Treatment and Recycling Facilities Construction Plan (2012)	1. Adopting reasonably the price of reclaimed water which should be lower than that of conventional water, providing the privileged policies of tax and fee reduction for reclaimed water producers 2. Encourage reclaimed water to be used in industries, carwash, urban facilities, and landscaping, forcing certain water users to use reclaimed water
MOHURD MOST	The interim Procedures of Reclaimed Water Facilities Management in Urban (1995); The Regulation of Saving Water Management in Urban (1998); The Policy of Wastewater Reclamation and Reuse Technology in Urban (2006); the 12th Five-year Development Plan of National Science and Technology (2011)	1. Using actively reclaimed water, issuing the technology policy of wastewater reclamation and reuse 2. Considering preferentially the landscaping use of reclaimed water, using the secondary effluent from municipal wastewater treatment plants in agriculture irrigation 3. Making policies to encourage wastewater reclamation and reuse by related central and local governments, offer financial supports for wastewater recycling by local government 4. Establishing gradually reasonable water price system and water utilisation structure
MEP GAQSIQ	The 12th 5-year National Environmental Protection Regulation and Environmental Economic Policy Construction plan (2011), Series water quality standards for different reclaimed water reuse	1. Making the water quality standards for different reclaimed water uses
MOF NDRC	The Notice of Implementing the policy without value-added Tax for Reclaimed Water and Others (2008), The Notice of Suggestion about Supporting the Investment and Financing Policy of the Circular Economy Development (2011)	1. Reaching to wastewater reuse rates of 20–25% for the cities with water scarcity in North China and 10–15% for coastal areas of South China in 2015 2. Encouraging wastewater reclamation and reuse to increase water resource development efficiency

MOHURD, MOST, MEP, GAQSIQ, MOF, and NDRC mean the Ministry of Housing and Urban–Rural Development, the Ministry of Science and Technology, the Ministry of Environmental Protection, General Administration of Quality Supervision, Inspection and Quarantine, the Ministry of Finance, and the National Development and Reform Commission reuse), (GBT 19923-2005 – industrial reuse), GB20922-2007 – farmland irrigation reuse), and (GB/T 25499-2010 – green space irrigation reuse). In support of the issuance of these regulations and standards on reclaimed water by the Chinese government, significance investments were made for the construction of wastewater treatment and reclamation projects to the tune of 30.4 billion CNY the 12th Five-year National Urban Sewage Treatment and Recycling Facilities Construction Plan. Despite all these efforts treated municipal wastewater reuse is still in its infancy and confronted with several challenges that limits its deployment [30].

4.5 *Africa*

On the African continent the study reviewed Egypt in the north and South Africa in the sub-Saharan Africa.

4.5.1 Egypt

Egypt is an arid country estimated to cover an area of one million square kilometres, and for the past 50 years has continuously experienced a rapid population growth from a population of 19 million in 1949 to 83.5 million in 2012. It is projected that the population of Egypt will be 100 million by 2025 [31]. This exponential population growth poses significant challenges to Egyptian authorities in managing their water resources. Presently, the Nile River is the major source of water, with Egypt receiving an annual fixed share of 55,500 Mm^3, which meets about 80% of its demand, and 95% of the Egyptian population resides along the banks of the Nile valley and delta – an area which constitutes only 4% of the country land. Coupled with low rainfall of at most 200 mm annually, Egypt's freshwater challenges require innovative initiatives to augment water supplies, one of which is the use of treated municipal wastewater in agriculture – a sector that contributes 11.1% to its GDP and employs about 23.8% of its labour force [32]. Egypt is ranked 1st in volumes of treated wastewater reuse in irrigated agriculture in Africa. The Egyptian National Water Plan of 2017 projects a possibility of an annual deployment of 1.4 billion m^3 of treated wastewater in irrigated agriculture. The legislative framework for treated wastewater reuse in agriculture is still deficient in many respects related to very restrictive standards, unclear institutional arrangement, lack of technical expertise, and low reliability of the quality of treated water due to poor design and maintenance of wastewater treatment plants. It is reported that only 40% of the wastewater treatment plants provide secondary treatment, while the rest provide only primary treatment, thereby limiting the amount for reuse in irrigated agriculture [33]. There are some decrees that specifically address reuse of wastewater: Decree 44/2000 (addresses restricted irrigation for the safe use of wastewater on selected crops, and the water quality requirements for unrestricted and restricted irrigation), Decree 603/2002 (prohibits irrigation of traditional field crops with treated or untreated wastewater and limits reuse to timber and ornamental trees, taking into account the protection of the health of agriculture workers), Decree 171/2005 (reviews the standards for the reuse of treated effluents and sludge in agriculture, with standards for reuse in agriculture presented in ECP (Egyptian Code of Practice) 501/2005), and Decree 1038/2009 (prohibits use of treated or untreated wastewater to irrigate food crops).

The institutions involved with water reuse in agriculture are the Ministry of Water Resources and Irrigation (MWRI), Ministry of State for Environmental Affairs (MSEA), Ministry of Water and Wastewater Utilities (MWWU), Ministry of Health and Population (MOHP), and Ministry of Agriculture and Lands Reform. The institutional framework is relatively complete and highly centralised, with the involvement of users and the private sector realised in the implementation of projects and through various public agencies and companies. However, there are still major gaps in the legislative framework and institutional arrangement that considerably curtail the reuse of treated wastewater in irrigated agriculture in Egypt.

4.5.2 South Africa

Following independence in 1994, the South African Legislature enacted the National Water Act (NWA) No 36 of 1998. Within the Act, wastewater reuse for irrigation is considered a controlled activity which involves "irrigation of any land with waste or water containing waste generated through any industrial activity or by a waterwork" (Section 37 (I) (a)). Although the National Water Strategy 1 (NWRS1) of 2004 and National Water Strategy 2 (NWRS2) of 2013 constitute the legal instrument for implementing the NWA and promote reclamation and reuse of wastewater for prudent management of water resources, the only existing regulations and guidelines for deployment of treated wastewater for irrigated agriculture are found in the Government Gazette 36820, Notice 665 of September 6, 2013. It provides standards on the microbiological and physio-chemical parameter limits of the quality of irrigation water based on the volume of wastewater utilised. The standards are for irrigation with volumes of wastewater of 2,000 m^3/day or 500 m^3/day or 50 m^3/day. The institutional arrangement for enforcing these regulations and guidelines has been vested on the Minister of Water Affairs. Although there is no data on the volume of treated wastewater being recycled for farm irrigation, there are a few active farm projects which use the practice.

Although the NWRS2 alluded to reclamation of water gaining social acceptance and proving to be technically viable, however, contradictory aspects of the laws such as the National Water Act (Act 36 of 1998), the National Environmental Management Act (Act 107 of 1998), the National Environmental Management: Waste Act (Act 59 of 2008), and the Water Services Amendment Act (Act 30 of 2004) render water reclamation to be complex. Furthermore, municipalities are legislatively permitted to enact by-laws on wastewater reuse, that may result in multiple legal frameworks, further complicating the process as confidence among stakeholders is eroded. Despite a formal government water management strategy that includes water reuse, deployment of wastewater reuse is not significantly implemented in South Africa. There is a gap in formulation of legal frameworks that comprehensively address treated municipal wastewater reuse in irrigated agriculture at national and provincial levels [34].

5 Challenges in Implementing Municipal Wastewater Reuse for Agriculture

Globally, the main barriers to reuse of municipal wastewater, particularly in irrigated agriculture, can be encapsulated as institutional, technical, economic and implementation in nature. In the global north extensive research in addressing these barriers continues and are at advanced stages, and these can be leapfrogged by global south countries. The State of California in the USA and Spain in Europe are precedent, and their progress have been highlighted.

5.1 Institutional Arrangements

In the previous section of this chapter, we had discussed the legislative framework of the case study countries. Universally, there are no binding international legal frameworks for municipal wastewater reuse in irrigated agriculture. Guidelines on wastewater reuse vary considerably, and institutions are either non-existent or dysfunctional. In the USA, guidelines and regulations of states work in tandem with those of the EPA at federal level. Similarly, the environmental directives of the EU serve to guide the activities of its member states. In developing countries supra-municipal wastewater management is not practised, and an overarching root cause of challenges is the involvement of multiple ministries without well-defined roles in treated municipal wastewater reuse projects [35] reported on Mexico having challenges emanating from lack of co-responsibility and effective communication among ministries responsible for treated municipal wastewater reuse in irrigated agriculture. In China, [36] cite incomplete regulations, lack of supporting policies and laws that enforce reclaimed water reuse, coupled with inconsistent wastewater reuse standards as major drawbacks in deployment of treated municipal wastewater reuse in irrigated agriculture.

Egypt also experiences institutional arrangement challenges emanating from the involvement of multiple ministries without well-defined responsibilities and most working in silos, coupled with the lack of political will and policies which explicitly articulate treated municipal wastewater in irrigated agriculture. In South Africa, enacting the Water Services Act of 1997 and the National Water Act No 37 of 1998 to make provision for treated municipal wastewater reuse in irrigated agriculture, the institutional arrangement that entrusts a water services authority with the full responsibility for development of by-laws that govern its deployment discourages and erodes confidence among stakeholders [34]. In essence the absence of national and provincial legal frameworks that explicitly articulates treated municipal wastewater reuse in irrigated agriculture is a major drawback in South Africa.

5.2 Technical Issues

Technical issues in the deployment of treated municipal wastewater reuse in irrigated agriculture start being addressed with effective collection and treatment of the wastewater. This is followed by the reclamation process to treat the effluent from the wastewater treatment work (WWTW) to required standard of its envisaged use. Technical issues vary according to the level of development of a region or country or political jurisdiction. In places such as the State of California, issues related to effective collection and treatment of municipal wastewater have been comprehensively addressed. Current efforts are directed at reclamation processes, and presently the focus is on removal of specific salts with a view of mitigating their adverse effects on the soil, natural receiving water bodies, and crop production. Several treatment technologies have and continue to be developed. The oversight provided by the EU through its directives enables member states to operate their wastewater treatment plants (WWTPs) so that their effluents are compliant. Through planned programmes like the National Plan of Sanitation and Water Treatment (NPSD) Spain had, as at 2010, achieved 84% full compliance with Directive 91/271/EEC, while there are on-going construction and upgrades of WWTPs [21].

In the global north there are increasing concerns on the prevalence of "contaminants of emerging concern" (CECs) in municipal wastewater, whose main source include pharmaceuticals and personal-care products [37]. The challenge CECs poses is that of non-regulatory system and their unknown long-term effects on the environment. In addition, there is consensus among scientists that reclaimed wastewater releases antibiotic-resistant bacteria. These findings render both municipal wastewater treatment and reclamation processes highly complex and expensive [38].

In the global south issues on basic sanitation infrastructure development are prevalent. The Mexican government has made considerable progress in developing its WWTW infrastructure and to adopt treatment technologies that treat the effluent to standards stipulated in NOM-001-ECOL-1996 and NOM-003-ECOL-1997. However, the stringent restrictions, particularly irrigation of vegetables, fruits, and root crops eaten raw, render deployment of treated municipal wastewater reuse in irrigated agriculture economically not feasible. Most farmers are not prepared to invest in high quality wastewater treatment technologies to meet the required water quality standards.

Following the decision by the Chinese government to promote treated municipal wastewater reuse, challenges pertaining to collection and treatment of municipal wastewater received significant consideration, coupled with hi-tech research and development in water reclamation technologies. Presently there are several technologies available to produce effluent with quality standards that meet the intended use. However, the challenge remaining is that public institutions lack the financial capacity to meet the high capital and maintenance costs of these treatment technologies.

Egypt continues to battle with issues pertaining to sewerage networks and treatment facilities, impacting adversely on the effective and efficient collection of municipal wastewaters. There are reports of large volumes of untreated wastewater flowing into natural water receiving bodies [39]. Furthermore, the current large centralised municipal wastewater treatment arrangements are not feasible for effluent reuse in irrigated agriculture. This is due to disparities in operations of several WWTPs resulting in differences in effluent quality produced by these plants, thereby complicating any plans of standardised effluent reuse. In addition, most residents are yet to be connected to the sewerage network.

As already aforementioned in this study, effective collection and treatment of municipal wastewater is the basis for deployment of reclaimed water in irrigated agriculture. However, in South Africa [40] reported 90% of WWTW being non-compliant on more than three effluent determinants. As a result, poorly treated effluents are flowing into natural water bodies, causing huge environmental challenges, and hampering any plans for deployment of treated municipal wastewater reuse in irrigated agriculture. The high population densities in low-income communities further present two major challenges in deployment of treated municipal wastewater reuse. Firstly, sewerage networks are not well developed or absent. Secondly most water service authorities lack the financial and technical capacity to institute treated municipal wastewater reuse projects.

5.3 Economic Feasibility

Deployment of treated municipal wastewater reuse projects highly depends on its economic feasibility, that usually consists of weighing the costs and benefits. One huge operations and maintenance cost is energy consumption which usually accounts for 30% to 55% of the total cost [41]. This cost component has become a major determinant in assessing economic feasibility because of global energy shortfalls. Hence, it becomes necessary to explore cheaper and cleaner sources of energy for treated municipal wastewater reuse projects. Another cost component of concern is the cost of managing challenges that emerge during the water reuse process.

Comprehensive costing of reclaimed water continues to be problematic as multiple and evolving wastewater components need consideration. Apart from the capital cost of infrastructure development of the treatment, storage and distribution, there are additional costs that include operation and maintenance, economic and environmental externality costs that are usually ignored because, in many instances, there are challenges in their quantification and water authorities are unwilling to internalise them. Therefore, it is imperative to formulate a costing structure that takes cognisance of regeneration costs and the management of reclaimed water, to establish incentives that encourage maximum usage of treated municipal wastewater. Farmers are persuaded when authorities introduce financial incentives for reclaimed water usage, while providing assurances that it complies with water quality standards that guarantee the safety of their agricultural products.

The EU funding model, whereby only 50% up-front costs for municipal wastewater reuse projects could be secured through grants and the balance from the water reuse project as stipulated in the WFD, raises the issue of sustainability due to the non-guaranteed nature of wastewater reuse pricing that depends on the demand and supply scenarios. Another option to encourage reclaimed water uptake by farmers is introduction of subsidies. However, subsidies also present another challenge in that they only cover planning, technical assistance, research, and construction costs, but do not factor in externalities such as financial, social, and environmental burdens of effluent disposal to the environment.

Challenges in Mexican funding model for municipal wastewater reuse projects emanate from variable and non-transparent federal water budget [42], posing planning and implementing challenges on treated municipal wastewater reuse initiatives by local authorities. Furthermore, the arrangement of regional and local spheres of government coordinating and mobilising water infrastructure investments and then negotiating with CONAGUA at national level for approval of sanitation funding is complicated and places limitation on their economic viability. In addition, the arrangement of CONAGUA collecting revenue and channelling it into the federal fiscus, after which only 38% of the proceeds are transferred to local authorities for construction, operations, and maintenance cost of wastewater treatment plants limit deployment of treated municipal wastewater reuse in irrigated agriculture. The lack of well-structured water pricing to foster uptake of reclaimed water by farmers exacerbates the situation.

In China, variability in funding impacts adversely on development of water reclamation facilities that in turn influences the level of success in the deployment of treated municipal wastewater reuse projects. Chinese reclaimed water pricing is not comprehensive, with the current pricing only taking cognisance of the economic and operational costs of the treatment facilities [43]. The financial challenges in Egypt emanate from the public institutions not being adequately funded to meet the high capital and operational costs for treatment and reticulation infrastructure of municipal wastewater facilities. Treated municipal wastewater pricing is still a contested matter in Egypt. Whereas in South Africa, the absence of financial backing from both national and provincial governments curtails deployment of treated municipal wastewater reuse by water service authorities. In addition, there is no tariff structure for treated municipal wastewater reuse in irrigated agriculture. Neither are there any incentives to encourage treated wastewater uptake by farmers.

5.4 Implementation Procedures

To advance treated municipal wastewater reuse, the State of California instituted a water recycling funding program (WRFP) under the State Water Resources Control Board. The programme sets out to promote the beneficial use of treated municipal wastewater and provides funding and technical assistance to agencies and other stakeholders in support of water recycling projects and research. This programme has significantly contributed to the success of municipal wastewater reuse projects. In view of water management challenges being dynamic, constant monitoring and evaluation of these projects is imperative to ensure improvement in their implementation, and this is imbedded in the WRFP. In Spain, there are several well-designed projects on treated municipal wastewater reuse in agriculture, an example is the Rincón de León WWTP-WRP.

Mexican treated municipal wastewater reuse model draws on integrated water resources management (IWRM) principles which emphasise stakeholder engagement and public participation. To this end, water users' associations, comprising several groupings of stakeholders, were organised. However, water authorities refer to them as civil society, which limits the participation of these associations in water decision-making processes at local level, as their contributions are not recognised by law [44]. In some instances, agreements on treated municipal wastewater reuse in irrigated agriculture are concluded between farmers and the authorities without consulting the local communities and water users' associations. As a result, public knowledge is not considered in the planning and implementation of these projects [45].

Currently in China, perceptions on wastewater reuse are mixed [30, 46], with a high awareness of reclaimed water ruse and acceptance of non-potable use but considerable concern of the potential public health risks, particularly for agricultural irrigation. Consequently, adoption of wastewater reuse is relatively low but there are indications, with looming water crisis in China and enhanced wastewater treatment technologies, that water reuse will grow significantly in the future.

In Egypt, the implementation process is largely centrally controlled by government water authorities, with minimal stakeholder engagement and public participation. There are a few on-going wastewater reuse projects, but they fall far short of Egypt's potential. Presently in South Africa, there are no significant treated municipal wastewater reuse projects. The national government has entrusted the local governments with development of by-laws for treated municipal wastewater reuse and deployment. However, a major drawback in this arrangement is that public trust in the water services providers is low due to the failure in basic collection and treatment of wastewater. In addition, there is low public awareness on water issues such as freshwater availability, adverse impacts of climate change, and the benefits of treated municipal wastewater reuse.

6 Conclusions and Recommendations

Albeit reported disadvantages in deployment of treated municipal wastewater in irrigated agriculture, the advantages cannot be disputed. This study established several advantages that include increased freshwater availability, sustainable use of water resources, reduced freshwater withdrawals, and an economically viable alternative water source. Agricultural advantages include reduction in crop production costs following reduction in quantities of fertilisers applied, coupled with higher reliability as an alternative water source, thereby enhancing employment in the agricultural sector and contribution to the GDP, along with increased food security. There is also improvement in environmental protection following reduction in nutrient loads to natural water receiving bodies. Hence, deployment of treated municipal wastewater as an alternative water resource in sub-Saharan Africa should receive serious consideration and attention, commencing with institutional arrangements that promote it.

From the global north, this study has established that the effective and systematic involvement of a supranational or regional body in deployment of treated municipal wastewater in irrigated agriculture enhances its deployment. An example is the EU that adopted the WFD from which directives are issued to address specific water matters including deployment of treated municipal wastewater in irrigated agriculture among member states. These directives work in tandem with the national policies, regulations, and guidelines of member states.

In the USA, although each state is fully responsible for formulation and publication of its water legal frameworks for all types of water, the federal government plays its role, through the EPA, in supporting the institutional frameworks of the states. The institutional arrangements of both the EU and the federal US government have proven to enhance uniformity in water management in the respective regions, by fostering confidence and institutional support among stakeholders in management of treated municipal wastewater in irrigated agriculture. In addition, platforms like NORMAN in Europe, ensure interdisciplinary knowledge exchange, in research and development of treated municipal wastewater reuse in irrigated agriculture.

At national level (Spain) and state level (State of California) the study established that the legal frameworks of treated municipal wastewater reuse in irrigated agriculture explicitly articulate the "What", "Where", "When", "Who", and "How". Spain has institutionalised supra-municipal management entities to directly or indirectly, through competent entities, manage the operations and maintenance of WWTPs to ensure uniformity and compliance with the EU directives.

In developing countries, uncoordinated multiple ministerial involvement without clear roles, policy gaps, inconsistent guidelines, and incomplete regulations curtail reuse of treated municipal wastewater in agriculture. However, in Mexico, there have been major institutional reforms that have led to the drafting of legislative framework that articulates treated municipal wastewater reuse, coupled with the political will, expressed through the national administration, that have given recognition to treated municipal wastewater as a viable alternative water source. Whereas

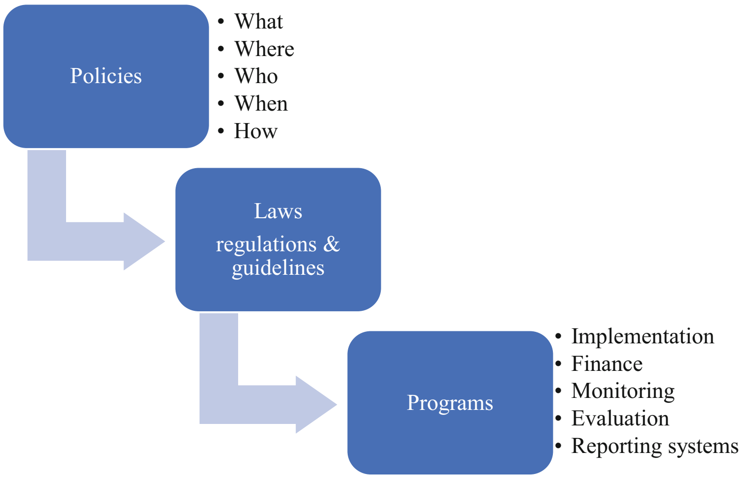


Fig. 3 Enabling institutional processes for effective deployment of treated municipal wastewater reuse in irrigated agriculture

in China, there are prevalent institutional challenges that do not promote widespread deployment of treated wastewater in agriculture.

In Africa, Egypt in north Africa was considered, and due to the absence of a regional body, Egypt is fully responsible for its water management. The study established flaws in institutional arrangements emanating from uncoordinated multiple ministries responsible for treated municipal wastewater reuse in irrigated agriculture. Policy gaps and lack of stringent regulations and guidelines continue to be problematic. Hence, we recommend a fewer number of ministries with roles and responsibilities enshrined in law to be involved in deployment of treated municipal wastewater reuse. The regulations and guidelines should match the Egyptian socio-economic landscape. In the absence of a regional body, we recommend formation of a network like NORMAN in the EU that could tap on the expertise from other north African countries to foster knowledge sharing.

Southern Africa Development Community (SADC) is the regional body in Sub-Saharan Africa and comprises 14 member states, with the majority falling in the lower-middle income category. In view of the disparities in economic landscape of SADC member states, the role of SADC in deployment of treated municipal wastewater reuse in irrigated agriculture is imperative. We recommend that SADC be effectively involved in drafting of legislative frameworks and designing of programmes that encourage treated municipal wastewater reuse in irrigated agriculture in the region. These statutes should work in tandem with national water statutes.

South Africa was considered in the Sub-Saharan Africa and the study established policy gaps, outdated regulations, and guidelines. Hence, there is an urgent need for drafting of legislative framework that match the South African socio-economic landscape for the deployment of treated municipal wastewater reuse in irrigated agriculture. We recommend effective engagement of relevant government departments and water services authorities with farmers and other stakeholders to implement projects which reuse treated municipal wastewater to conserve scarce water resources. In addition, at national level we recommend supra-municipal management entities to manage WWTP either directly or indirectly utilising highly competent private entities, to depoliticise water management, eliminate skills shortage, and improve accountability. Figure 3 delineates the recommended enabling institutional processes for deployment of treated municipal wastewater reuse in irrigated agriculture for SADC and its member states.

The technical basis for deployment of treated municipal wastewater reuse is effective collection and treatment of wastewater. In the global north, the State of California has effectively dealt with these basics, along with development of tertiary treatment technologies to produce effluent quality with stipulated standards for reuse. In the EU, compliance with the WFD directives on municipal wastewater effluent standards is imperative before reclamation. Several member states are compliant, albeit Spain is yet to achieve 100% compliance, it has made progress with the deployment of treated municipal wastewater reuse in irrigated agriculture. Spanish authorities continue to conduct extensive research on water reclamation technologies to achieve improved economic efficiency, lower energy cost, and reduced volumes of waste disposed into the environment.

The global north is aware of the growing concern of CECs, and treatment technologies for their removal continues to receive extensive research. While these technologies can be imported by global south countries, affordability and appropriateness are still an issue.

Since deployment of treated municipal wastewater reuse is still in its infancy in Africa, we recommend regional research and development units that can provide technical and innovative solutions relevant to regional concerns. These research units should network with other research organisations in the region from both private and public sectors in a systematic manner. Furthermore, the lack of infrastructure for provision of basic sanitation in African countries, particularly in high-density impoverished communities, should be addressed as a matter of urgency. The experience in Egypt to resort to decentralised wastewater treatment systems is well documented as the way forward for African countries. Such decentralised systems become the hub for modular deployment of treated municipal wastewater reuse in irrigated agriculture.

The study established that the global north has adopted well-structured funding mechanisms for initiatives such as deployment of treated municipal wastewater reuse in irrigated agriculture, along with feasible water pricing structures which favour farmers' uptake. However, in the global south, the lack of fully developed water and sanitation infrastructure, low budgetary allocations, and lack of political will make for limited investments in treated municipal wastewater reuse projects. Mexico, on realising the importance of treated municipal wastewater reuse, the government directed significant financial support towards the development of water and sanitation infrastructure, resulting in reported progress. However, there are persistent challenges on comprehensively structured funding from the national government, and lack of a water pricing regime that favours uptake of reclaimed water. A similar trend was observed in China and Egypt. In South Africa, we recommend financial support in the form of subsidies from the national and provincial government to farmers to invest in treated municipal wastewater reuse projects, along with a water pricing regime which favours the uptake of treated municipal wastewater by farmers.

The implementation of treated municipal wastewater reuse projects should be joint responsibility of local, provincial, and national governments in collaboration with farmers and the private sector. By designing programmes and identifying case studies which can be monitored and evaluated within specific timelines, documentation of issues which promote success or lead to failure will be valuable resource material for implementation of future projects. Reporting to a supra-regional body is highly recommended to upscale and out scale such successful projects. To enhance uptake of treated reuse activities among farmers, we recommend effective stakeholder engagements and public participation to earn the trust of end users and the public and be able to manage public perceptions on treated municipal wastewater reuse. In conclusion, education of the end users and the public on the reuse activities is imperative.

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