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RESEARCH ARTICLE

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Unpacking wastewater reuse arrangements through a new framework: insights from the analysis of Egypt

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ABSTRACT

Wastewater reuse is identified as strategic to help ameliorate scarcity in water-stressed regions around the world. However, to develop it, there is a need to better understand the social, institutional and technological contexts in which it takes place. This article develops a novel socio-technical framework to inform such an analysis and applies it to current wastewater reuse in Egypt. Our analysis highlights the different actors, management activities and practices that shape wastewater collection, transfer, treatment, discharge and/or reuse in different social, technological and environmental contexts in Egypt. It points out bottlenecks of current wastewater reuse policies and programmes.

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Introduction

Wastewater production worldwide reached an estimated volume of 380 billion cubic metres (BCM) per year, equivalent to five times the amount of water that passes through Niagara Falls every year (Qadir et al., 2020). Though not always accounted for, large quantities of this wastewater (treated and untreated) are directly and indirectly reused in irrigation across the globe, and this trend is expected to increase. However, the actual role and future potential of wastewater reuse for irrigation at global and regional scales is still an understudied topic (Qadir et al., 2020). Several studies have explored the economic, environmental, health and social benefits of wastewater reuse, as well as the challenges that prevent the materialization of these potentials (e.g., Mateo-Sagasta et al., 2015; Otoo & Drechsel, 2018; Thebo et al., 2017). Among these obstacles, we recognize the institutional exclusion of informal reuse arrangements which limit its capacity to strategically include and govern this wastewater reuse in a safe, sustainable and equitable manner at different scales.

This paper contributes to this discussion by first developing an analytical framework to analyse wastewater reuse and then using it to develop a better understanding of the different formal and informal wastewater reuse arrangements in Egypt. Our analysis is guided by the following main research questions:

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- What theoretical framework can elicit a better socio-technical understanding of the wastewater reuse sector and its practices?
- What new insights does such a framework offer when analysing the current wastewater reuse sector of Egypt?

This paper is based on available official and unpublished documents; personal communication with official and international experts; and on the baseline study prepared by the Egyptian–Swiss Research on Innovation in Sustainable Sanitation (ESRISS) project (2011–15) (Reymond et al., 2014). For more details on the data collection methodology, see the ESRISS project website.[1]

The paper is structured as follows. The next section sets out the theoretical framework and notions that inform our analysis. A background section on Egypt's water resources and its management challenges is then presented. It shows the drivers of the increased demand for wastewater reuse in Egypt and presents how the formal wastewater sector is managed by centralized state agencies that have overlapping responsibilities. After presenting this overview of the formal wastewater reuse sector, it illustrates some of the challenges this sector and current wastewater polices face through the case study of Marsa Matrouh. The paper then presents reuse practices in the Nile Delta based on the case study of two villages in rural Egypt. The villages are representatives of the heterogenic wastewater management and reuse arrangements that exist in the Nile Delta. The established framework and its application shows that in the formal – mainly urban – sector almost all tasks in the different wastewater reuse stages, technologies and practices are dominated by state institutions; while in the informal rural sector, all water flows and technologies are managed through household and community practices and institutions. This analysis shows how in Egypt the formal (mainly urban) and informal (mainly rural) sectors coexist alongside each other, but with little or no collaboration between the two. We pose that closer collaboration between the formal and informal sectors could lead to safer and more socially just wastewater reuse practices in Egypt. A first step in this direction is the need to recognize the informal sector and decentralize some of the state functions to open new paths for collaboration in the wastewater reuse sector. Finally, we argue that the established framework offers a valuable lens through which to analyse the wastewater reuse practices.

Theorizing wastewater reuse arrangements and their control

We conceive wastewater reuse arrangements as socio-technical processes that take shape through water flows, technologies, practices, institutions and individuals that engage in the different stages of the wastewater reuse cycle. We have identified these different stages and the processes that take place within and around these by adapting Uphoff's (1986) model to analyse irrigation systems and applying it in a modified framework to wastewater reuse systems. This adapted model is presented in Table 1.

In it we divide the wastewater reuse processes into three different elements: (1) wastewater flows; (2) technologies and their operation; and (3) the institutions and practices that regulate these wastewater flows and technologies. Though these elements are separated for analytical purposes, they are intrinsically interrelated to each other.

Table 1. Wastewater management and reuse activities.

Wastewater flows	Technological management				Institutions and practices
Containment/collection	Design	Construction	Operation	Maintenance	Regulation and norms
Treatment					Conflict management
Conveyance					Resource mobilization
Discharge/reuse					Decision-making

Source: Authors' own elaboration based on Uphoff (1986).

The wastewater reuse cycle consists of four stages: containment, treatment, conveyance and water delivery/reuse. These stages are not necessarily sequential and are not all necessarily present in wastewater reuse arrangements. The different stages are mediated through the use of diverse and specific technologies in each stage. Usually, the first stages are wastewater conveyance and containment through which wastewater is collected and/or transported away from the point of generation (e.g., household) to a point where it poses fewer health risks for those who generated the wastewater flows. This point is ideally a wastewater treatment plant where the social and environmental threats of this polluted water are minimalized through the removal of pathogens, parasites, and organic and inorganic elements. However, it can also be a water body such as a river, an irrigation canal, a drain, a lake or the sea. If and when the wastewater is reused, the treated or untreated wastewater is redistributed through a conveyance network (e.g., drainage network as in the Nile Delta) that takes the water flows to the place where these will be used, which in most cases is for agricultural purposes (Van Steenbergen & Dayem, 2007).

The above-mentioned processes are mediated through formal and informal institutional, normative frameworks and practices. Institutional arrangements define the rules and regulations (norms in case of informal arrangements) for wastewater flows and reuse as well as which organizations are responsible for its implementation and control. These same arrangements regulate how resources are mobilized in the wastewater reuse process, how conflicts are mediated and resolved, and finally how decisions are made.

We recognize that in these processes both formal and informal wastewater reuse arrangements coexist and mingle. Formal arrangements are those established by national laws that are implemented, regulated, and controlled through state agencies and recognized by donor agencies. In contrast, the informal are often socially embedded arrangements that get shaped through the daily practices, negotiations and discussions in specific contexts. These are not codified or structured according to written legal or contractual commitments, which means that in some spaces these informal arrangements receive more compliance than externally imposed formal regulations (Cleaver, 2017). The latter stems from the fact that these are usually socially embedded arrangements that are shaped through the daily practices, negotiations and discussions in very specific contexts.

Finally, we recognize that technologies mediate social relations and resource flows between different institutions and actors (Pinch & Bijker, 1984; Latour, 1996). These play a key role in controlling, facilitating or hindering specific wastewater reuse practices by delegating specific roles and attributions to specific actors. These relations are embedded in specific social constellations. In such constellations, in many countries, there is a tendency for formal arrangements to discredit and render invisible informal arrangements (Boelens & Vos, 2014). This despite the fact that informal arrangements play a crucial role in providing sewerage and sanitation services to urban and rural marginalized populations, while also importantly contributing to the reuse of wastewater. This is of particular importance in water-stressed river basins as in these they play a key role in covering irrigation demands and increasing wastewater reuse as is explained below for the case of Egypt.

Egypt's water resources crisis and the increase of wastewater reuse

Egypt's water demand is 114 BCM/year, with about 60 BCM/year available, of which more than 90% is supplied by the Nile River (Holding Company for Water and Wastewater (HCWW), 2011). The agricultural sector consumes around 76% of Egypt's water share, whereas only 13% is used for domestic purposes and 7% for industrial use (The Road Map, 2017). In this context, wastewater reuse can form a valuable practice that can help to deal with some of the future agricultural water demands and other water-related challenges.

At present, Egypt's 409 wastewater treatment plants attend 59.7% of the country's population, which covers 90% of urban areas and 12% of rural areas (HCWW, 2019). The Nile Delta has 289 wastewater treatment plants, which in sum have a total treatment capacity of 0.0087 BCM/day, an amount the government aims to increase to about 0.019 BCM/day by 2037 (The Road Map, 2017).

Egypt's water resources management, including the management of wastewater and its reuse, is characterized by strong centralized state control (Reymond et al., 2014). The irrigation and drainage system in the Nile Delta that is built and managed by centralized state agencies is a vast network of connected irrigation canals and drains. The drainage system was designed to collect and recirculate the irrigation drainage water back to the irrigation canals while discharging relatively small amounts into the Mediterranean in the lower basin (Nardini & Fahmy, 2005). With the lack of fully conventional wastewater collection and treatment schemes in the Delta, this extensive drainage system became a conveyance system that carries mostly untreated domestic and industrial wastewater along with the irrigation drainage water (Figure 1). Accordingly, in this article we consider drainage water reuse as a synonym of untreated wastewater reuse, since the quality of drainage water has been significantly deteriorated by wastewater flows in most the Egyptian drains (Japan International Cooperation Agency (JICA), 2016).

Delta farmers' reliance on drainage water for irrigation started in the 1950s and 1960s, first as a 'back-up' source of irrigation water. With time, drainage water reuse for irrigation increased as pressure on water resources has become more acute. The drainage water quality dramatically deteriorated as the quantity of untreated domestic and industrial wastewaters increased from the 1970s. Much of this increase came from waste discharge from domestic (and, to a lesser degree, industrial) sources that were expanding due to population growth and the related expansion of domestic water supply networks in the Delta. This happened in a context in which water supply networks grew much faster than the sanitation services and corresponding wastewater treatment plants that were needed to treat the increased flows of effluents. In relation to the industrial effluents, small and mid-size industrial sources have become one of the main sources of pollution. This pertains to the fact that large-scale industries are required by law to be equipped with industrial wastewater treatment units and assumed to be adequately monitored, though in practice this monitoring and related compliance is low.

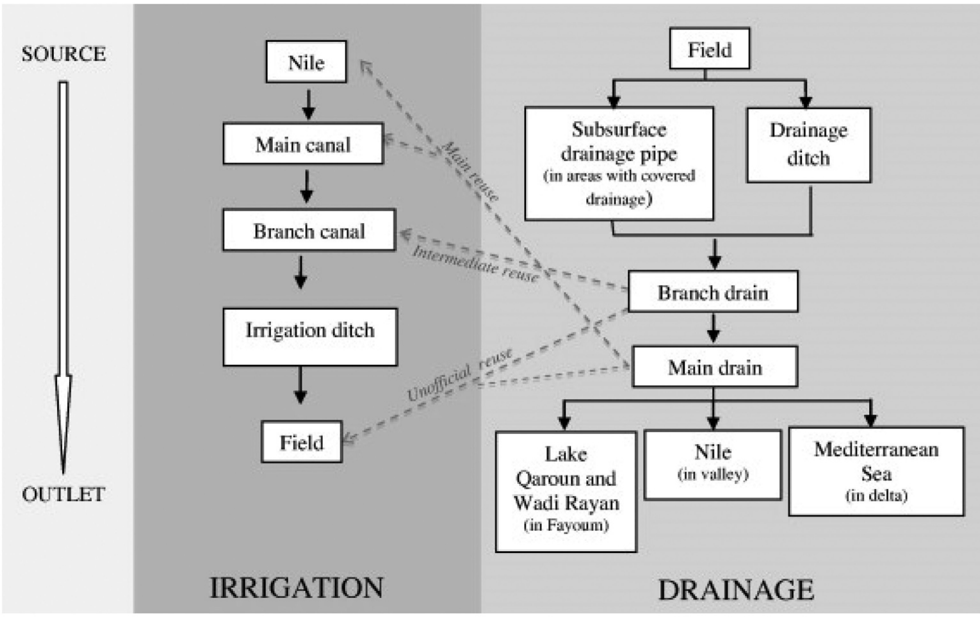


Figure 1. Schematic representation of the drainage water flow through the Nile Valley and Delta. Source: Barnes (2014, p. 185).

Despite the strategic importance and widespread use of the polluted drainage water as a source for irrigation, its reuse is an illegal practice in Egypt. For it to be legal the Egyptian code of reuse (501/2015) prescribes that wastewater must be treated and mixed with fresh water in the irrigation canals before it can be used (officially) for irrigation only. Similarly, the direct discharge of untreated sewerage in drains is illegal unless the effluent abides by the strict standards of Law 48/1982. However, in most instances the state decides to turn a blind eye to informal sewerage and other wastewater discharge and reuse practices in the Delta (Barnes, 2014); a strategy that carries serious health, environmental and economic risks. In this context, it is alarming that the discharge of highly polluted agriculture drainage water back into the Nile north of Kanater Barrage is common practice. Examples, include, but are not limited to, the El Rahawi drain discharging highly polluted water directly into the Nile Rosetta Branch and the Zarkoun Drain discharging into the Mahmoudiah Canal. This practice results in water with low levels of dissolved oxygen, high biological oxygen demand, and undesirable concentrations of nitrates, ammonia, phosphate, persistent organic micropollutants and trace metal residues (Japan International Cooperation Agency (JICA), 2016; El-Agha et al., 2020). These mixed waters are the source for water treatment plants that supply millions of people with domestic water. As many of these plants use conventional treatment processes such as coagulation, sedimentation, filtration and chlorination, their capacity to remove micropollutants (trace metals, pesticides, chlorinated hydrocarbons, trihalomethanes, etc.) that come from domestic, industrial and agricultural wastewater discharges upstream is limited.

The lack of compliance to formal regulations can be partly explained if one recognizes that ‘illegal’ sources of wastewater quelled the discontent of local farmers who have a drinking water supply, but do not have conventional sanitation systems and do not have enough water for irrigation (Barnes, 2012; Helmke & Levitsky, 2004). Therefore, informal reuse became part of the 'governance' strategy that 'stretches' Egypt's annual fixed quota of Nile water (Allam & Allam, 2007). In doing so, it maintains the livelihoods of smallholder farmers in the Delta and preserves an otherwise contested – even weak – state control over wastewater resource flows and its ability to deliver basic needs through its formal (bureaucratic) institutional arrangements.

Egypt's formal wastewater reuse sector

The responsibility for domestic water delivery and sanitation services in Egypt was distributed until 2004 among various organizations. The Construction Authority for Potable Water and Wastewater (CAPW) was operating in Cairo and Alexandria, while the National Authority for Potable Water and Sanitary Drainage (NOPWASD) was providing services to the other governorates. At the same time local administration units (LAU) were responsible for water and sanitation services provision in their jurisdictions (i.e., rural areas). Similarly, the New Urban Communities Authority (NUCA) was another water and sanitation service provider in new cities and industrial clusters. This fragmentation in the sector was linked to the financial deficit (US$1.3 billion in 2003) and the inadequacy of the water and sanitation services, which in turn prompted calls for sectoral reforms. These took place in 2004 by establishing the Holding Company for Water and Wastewater (World Bank, 2016).

Since 2004, the HCWW has the responsibility to collect, treat and safely discharge wastewater in Egypt through its 25 affiliated companies in 27 governorates (HCWW, 2019). Despite the establishment of the HCWW, the other entities (NOPWAS and CAPW) are still operating as key players in the sector, particularly concerning investment and infrastructural development. This has resulted in project delays and increased costs of development projects and the sector's inefficiency (World Bank, 2016).

Nevertheless, these transfers of responsibilities and assets (i.e., 25 affiliated companies in 27 governorates) entrenched the centralized position of the HCWW as the only legally responsible entity for wastewater collection, treatment and discharge/reuse. This has made all other arrangements for wastewater disposal, treatment and reuse illegal/informal in the country.

These sectoral reforms were prerequisites by donor agencies (e.g., European Union (EU) and World Bank) to reinvest in the water and wastewater sector in Egypt (see Cambaza et al., 2020; and Hoogesteger et al., 2017, for similar examples in the irrigation sector). The new investments were aimed at improving the sector's efficiency (e.g., achieve cost recovery) and remove institutional bottlenecks (World Bank, 2016). However, these objectives were not achieved and the HCWW is still operating under deficit.

Nevertheless, these shifts in responsibilities have given the HCWW and other state agencies a 'monopoly' position in the sewerage and wastewater sector. The HCWW has received almost exclusive faculties in relation to data collection, availability and accessibility concerning sewerage and wastewater quantity, quality and reuse potential (Table 2).

In Table 2 we apply the developed analytical framework to analyse the formal wastewater reuse sector. It shows how the HCWW as an institution is involved in all the activities related to wastewater collection, treatment and discharge/reuse through its affiliated companies in the different governorates of Egypt. While the HCWW does not

Table 2. Wastewater flow management analysis of the formal indirect wastewater reuse – mapping of organizations and their responsibilities.

Wastewater flows	Technological management: Design	Construction	Operation	Maintenance	Institutions and practices: Regulations/norms	Conflict management	Resource mobilization	Decision-making
Containment/ collection	*Ministry of Housing, Utilities & Urban Communities (MoHUUC)* Wastewater is collected by the conventional sewerage network. Its design and construction are the responsibility of the MoHUUC		*Holding Company for Water and Wastewater (HCWW)* Operation and maintenance (O&M) are carried out by the HCWW		*Egyptian Water Regulatory Authority (EWRA)* Responsible for the regulation, monitoring and evaluation of all activities related to water supply services and wastewater disposal. Although the EWRA exists, it is not functional and the regulatory role is partially filled by other organizations, including the Ministry of Environment, the Ministry of Health and the Ministry of Agriculture	*No clear conflict management mechanism* Usually, each institution refers to a law, code or standard that support its position and mandate. Often these laws, standards and codes are difficult to implement (e.g., Law 48/ 1982, reuse code 501/2015) and/or contradictory	*NOPWASD* *Construction Authority for Potable Water and Wastewater (CAPW)* *New Urban Communities Authority (NUCA)*	*MoHUUC* *Project Management Unit (PMU)* part of the MoHUUC
Treatment	*National Organization of Potable Water and Sanitary Drainage (NOPWASD)* Carries out the investment component of designing and constructing new treatment plants. Overlapping with the HCWW (World Bank, 2016)						Overlapping with the *HCWW*	*HCWW*
Conveyance	*Ministry of Water Resources and Irrigation (MWRI)* The design, construction, O&M of the conveyance network (drainage network, main and branch irrigation canals, irrigation ditched, and mixing stations) is conducted by the MWRI (Barnes, 2017).						*MWRI* Through the annual maintenance budget (Barnes, 2017)	*MWRI*
Delivery/ reuse	*Farmers and/or water users associations (WUAs)* Responsible for the maintenance of irrigation ditches (*Mesqa*) (Barnes, 2017; Rap et al., 2019)						*Farmers* Responsible for maintenance work (Barnes, 2017)	*Ministry of Agriculture*

have a regulatory role, the limited role of the Egyptian Water Regulatory Authority (EWRA) has given the HCWW more space to inspect and monitor the various wastewater management activities.

As such, the HCWW is ensuring that the discharged effluent into the drains complies with the Egyptian standards (even if it is not the case for some treatment plants). This takes place by the HCWW role in (1) treating wastewater discharges (as is done with most wastewater from larger cities and urban areas); and (2) overseeing other wastewater discharges through a system of permits and fines. However, both the former as well as the latter are poorly implemented and incomplete.

Formal indirect reuse arrangements in Egypt

Indirect wastewater reuse policy has been in place since the late 1970s and early 1980s. The indirect reuse of wastewater in the Delta was estimated at 9.31 BCM in 2015, and the target is to increase the amount to 16.26 BCM by 2037 (NWRP, 2037). This is to take place through a number of mixing stations that transfer wastewater from drains to feed the ends of the main (and branch) irrigation canals. The mixing process is organized by the Ministry of Water Resources and Irrigation (MWRI) to meet the needs of the agricultural sector (Barnes, 2014). However, the high concentrations of pollutants in the discharged untreated wastewater forced the ministry to close many mixing pump stations (Figure 2). This has hindered the reuse of an estimated 2370 MCM/year (The Road Map, 2017).

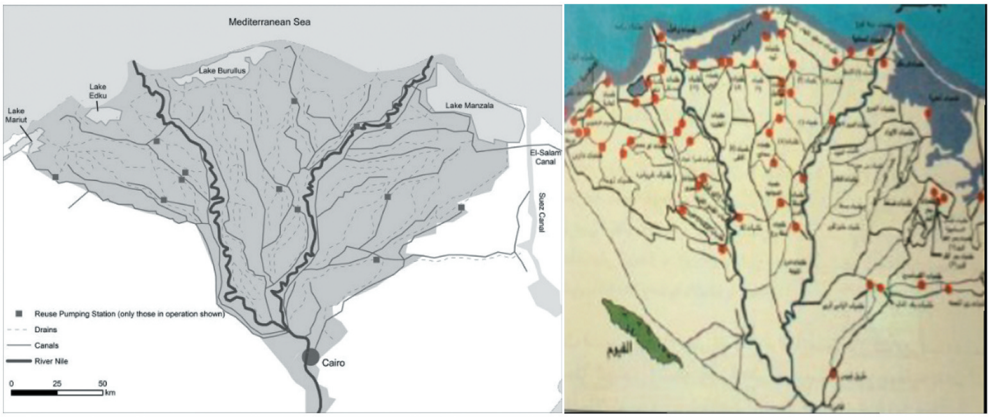
Formal direct reuse arrangements

The HCWW has been responsible for establishing direct wastewater-reuse models according to the Egyptian reuse code of treated wastewater. Recent data show that the treatment of 1 cubic metre of wastewater costs the HCWW around 2.6–3.0 Egyptian pounds (LE) (around three times more than the current water tariff per cubic metre for domestic use), yet there is no investment strategy to maximize the benefits form the treated wastewater. Particularly for treatment plants far from agricultural drains (i.e., in desert-front governorates), where indirect reuse is not applicable. Therefore, those plants must adopt a direct reuse arrangement that complies with the Egyptian reuse code.

The current direct wastewater reuse model set by the HCWW is to grow timber to reduce wood imports that cost about US$1.7 billion a year in 2020[2], in addition to other non-edible crops to produce biodiesel. The HCWW has expanded its timber plantations and prepared a list of potential lands for timber production in 18 governorates, with a total area of 42,250 ha. At present, almost 4500 ha are cultivated using treated wastewater (Figure 3) (HCWW data, 2019). The land identification process in the governorates, as well as the selection of tree types, is led by the HCWW headquarters in Cairo. Below we expand on one of these afforestation projects.

Direct reuse in Marsa Matrouh

The Marsa Matrouh governorate is one of the desert-front governorates on the western border of Egypt. The HCWW has an affiliated company (henceforth, HCWW-Matrouh) that is responsible for wastewater treatment and reuse in this governorate. The HCWW-



(a) (b)

Figure 2. (a) Map showing the functioning reuse (mixing) pumping station located on the main drains-canals conjunctions in the Nile Delta; (b) A screenshot from the Road Map for wastewater reuse (unpublished draft, 2017) showing the total number of the drainage pumping stations in the Nile Delta.

Source: Barnes (2014, p. 186).

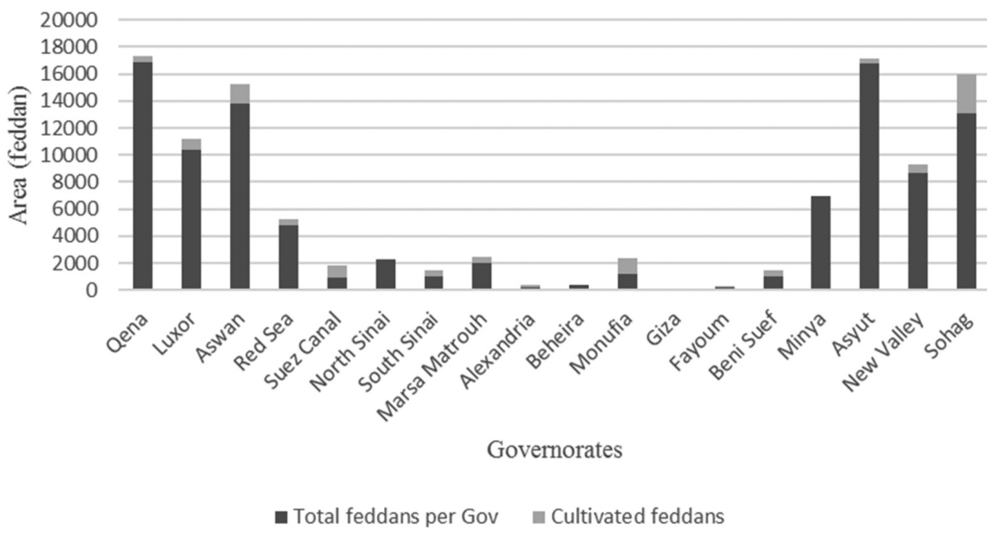


Figure 3. Formal wastewater re-use for timber production in Egypt (HCWW, 2019).

Matrouh case is a representative example for wastewater treatment plants in Egypt. The facility is designed to treat the urban wastewater of the city of Marsa Matrouh at a rate of 25,000 cubic metres/day. However, in summer it often receives 60,000–70,000 cubic metres/day because of the increased water flows caused by the arrival of holidaymakers to the coastal city of Marsa Matrouh. An expansion of the treatment plant is expected to increase its capacity to 60,000 cubic metres/day in the near future.

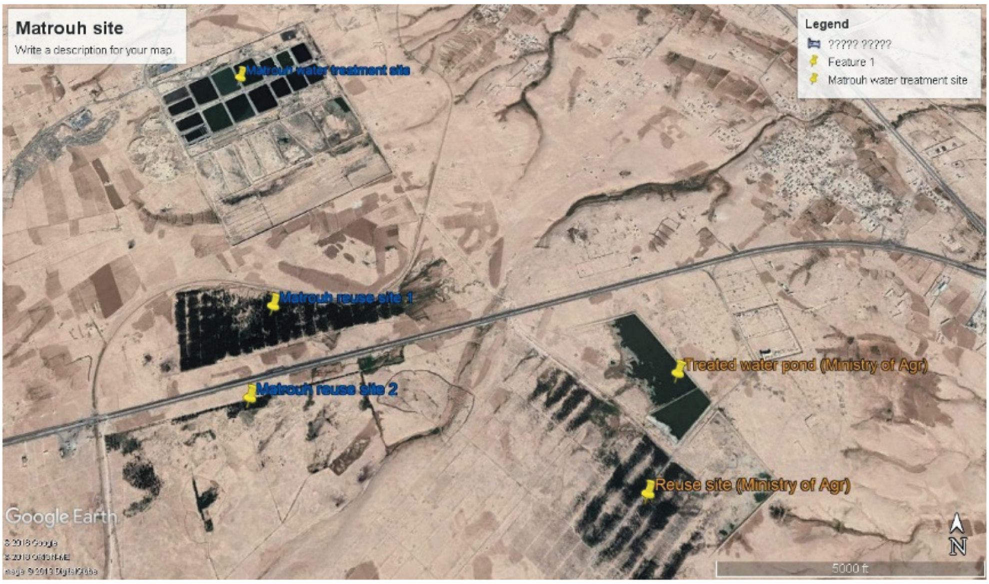


Figure 4. Matrouh wastewater treatment plant and its two re-use sites, Marsa Matrouh, Egypt.

According to the operations staff, the treated wastewater is a burden for HCWW-Matrouh since there are no agricultural drains nearby, and the far distance of the treatment plant from the sea hinders the safe discharge of the treated effluent into this water body. Since 2015, the treated wastewater from HCWW-Matrouh is reused to irrigate two timber plantations on lands owned by the company. One plot is 63 ha; the other is 147 ha (Figure 4). According to the interviewed staff, the two reuse plots are facing technical challenges due to the wastewater high salinity (3000 ppm), and the shallow depth of the soil (the bedrock is very close leaving 40 cm of arable soil to support tree growth). The staff reported that some trees have already fallen due to the shallow soil layer. Additionally, the trees to be cultivated are limited to a few species identified by the HCWW, most of which are either sensitive to the high salinity and/or require more soil depth. The centralized decision-making process leaves little room for the staff in HCWW-Matrouh to adapt to the local constraints. The operations staff conclude that there is no economic incentive to drive this reuse model; the main objective is to get rid of the treated wastewater without violating the Egyptian code of treated wastewater reuse, resulting in a very expensive wastewater treatment and reuse system that does not contribute to closing Egypt's water demand–supply gap.

Egypt's informal wastewater collection and reuse in the Delta

In rural areas and peri-urban settings wastewater from different sources is often illegally discharged into agricultural drains (Reymond et al., 2014; Soulie et al., 2013). This wastewater comes from a diversity of sources and through different technologies that render different concentrations of waste and contaminants in the water, which poses a serious threat to public health. To deal with the sanitation challenges, local actors developed and adopted various technologies to collect, convey, discharge (and reuse)

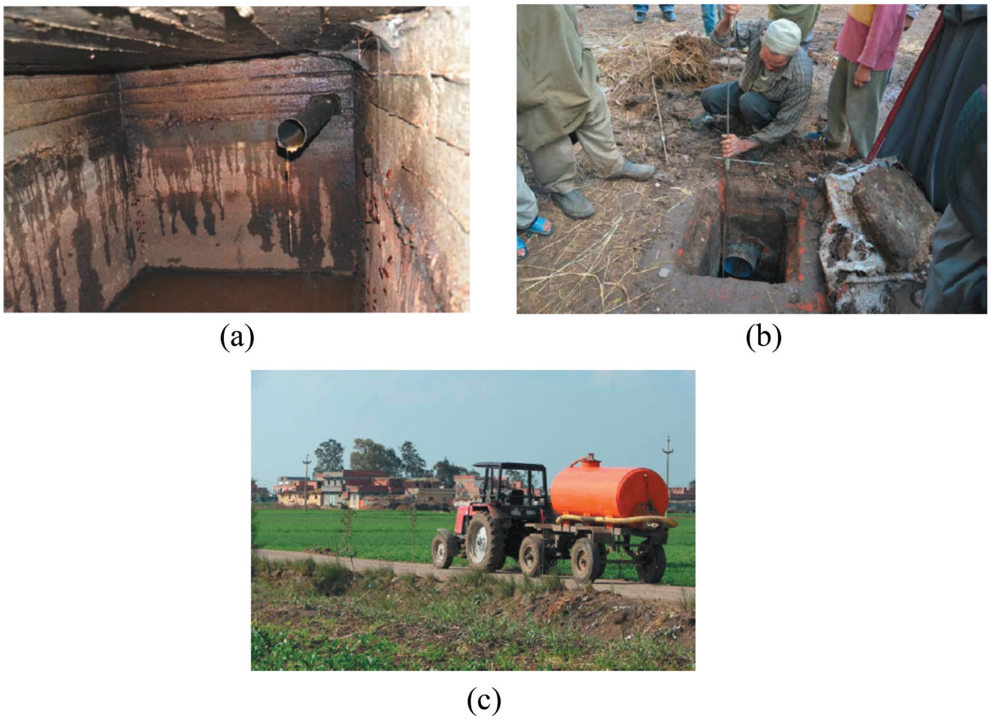


Figure 5. (a) a *bayara* inlet from inside; (b) a villager responsible for informal sewer maintenance; (c) *bayara*-emptying truck (Reymond et al., 2014, pp. 59 and 62).

wastewater. The choice between the different technologies depends on the financial situation, geographical location, village design and the strength of social bonds that promote collective action in different villages. The following are the most common technologies to deal with sewerage in the Delta villages (Table 4):

- *Bayara* or *Biir* is a locally built version of septic tanks, made of brick and concrete, *bayaras* are either sealed or left unsealed depending on the groundwater table. For areas where the groundwater table is low, *bayaras* are left unsealed to percolate wastewater into the soil. In areas with high groundwater, *bayaras* are sealed to prevent groundwater infiltration. The flexibility of technology adaptation can accommodate the different financial capacities in the village. *Bayaras* require additional service to transfer sewerage to a discharging point (usually drains) by mechanized vacuum trucks (Figure 5). Most of these trucks are private businesses while a small fraction is owned by the village council (Reymond et al., 2014). Discharging wastewater from *bayaras* into drains is illegal. By law trucks must discharge the collected sewage/septage in the nearest wastewater treatment plant. However, the long distance and the often inaccessible roads during winter make this unfeasible/less profitable for truck drivers. As a result, discharge is dumped into the nearest drain. This practice is sustained by the lack of law enforcement by local authorities (Verhagen & Scott, 2019).

- Locally constructed 'informal sewer networks' are shallow sewer networks that serve the whole village or part of it (Reymond et al., 2014, p. 3, appx 2). These networks are composed of pipelines running through the village with a slope gradient to discharge wastewater (domestic and industrial) into the nearest irrigation drain. The design of the network is either done by a villager who has experience in that field (e.g., an ex-employee of the HCWW) or a private contractor. Villagers carry out the construction and installation work. The network is maintained and unclogged through manholes constructed at different intervals along with the network. Informal sewer networks are the upgrading stage of villages from the *bayara* system.

Wastewater pumped out from *bayaras* is more concentrated than wastewater discharged from informal sewer networks. As residents tend to limit the use of *bayaras* to blackwater (sometimes liquid manure) while throwing away greywater from dishwashing and laundry into streets or directly to canals and drains. The relatively low operation costs of informal sewers besides the subsidized water tariffs encourage residents to discharge large loads of greywater that dilutes wastewater concentration (Reymond et al., 2014; Verhagen & Scott, 2019).

Despite the regular reuse of wastewater in irrigation (either directly or indirectly through drains), farmers are reluctant to acknowledge wastewater as a water resource. This is because of the environmental and health impacts that farmers notice on soil productivity, and the challenges they face with selling their crops. The long history during which the Delta farmers used to irrigate with fresh high-quality Nile water might also spur the reluctance to acknowledge wastewater as an irrigation source. However, as irrigation water availability decreases, many farmers have turned to the use of wastewater to irrigate despite their reluctance (Table 4).

Wastewater reuse arrangements in two villages in the Delta

El Hamamee

El Hamamee is a small village in Dmesna district, which includes five other villages overseen by one *Omda* (a traditional community leaders with legal status recognized by the local government). El Hamamee is located on the banks of the Mahmoudiyah Canal which carries Nile water north across the Delta. El Hamamee is densely populated, where houses are separated by narrow lanes in the area between the drain, Mahmoudiyah Canal, and the agricultural land (Figure 6).

The villagers are of low income, mostly relying on labour work in the land of the *Omda* and his relatives, or as workers or civil servants outside the village. El Hamamee enjoys a stable irrigation water supply from the Mahmoudiyah Canal, which makes the direct reuse of wastewater unnecessary. All El Hamamee's inhabitants are connected to a community-built informal sewer network. Each household pays a monthly fee for maintenance, and extra fees to cover emergency maintenance work. Those who cannot afford it are usually exempted or contribute to labour work instead.

Wastewater flows directly to the small drain, then flows 1 km downstream to a main agricultural drain (Figure 7). Although wastewater is not reused directly, its management poses a hurdle for the villagers. Wastewater flow reverses during the summer when water

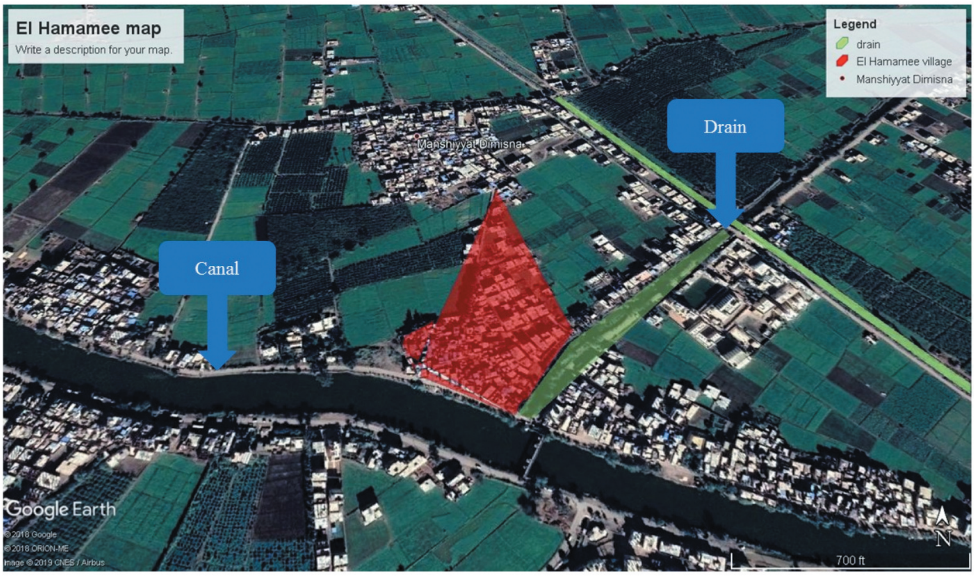


Figure 6. El Hamamee map. Source: Google Earth.

levels increase in the Nile and its branches' canals and drains, which leads to wastewater flooding in the village and flow obstruction in the sewer network (Reymond et al., 2014).

The ESRISS' material flow analysis (MFA) provides an estimate of the amount of wastewater discharged from El Hamamee's wastewater streams (Figure 7).

As shown in Figure 7, almost all the discharged wastewater flows directly into the drain. There is no direct wastewater reuse in agriculture. However, in the semi-closed Nile Delta Basin, the drainage water is inevitably reused for irrigation further downstream. According to the ESRISS study, 68% of wastewater flow from El Hamamee comes from greywater, which dilutes the 11% generated from blackwater. The reminding 20% of the flow comes from groundwater infiltration, which increases during the summer. Additionally, a small fraction of liquid manure is discharged into the drain, while another proportion is directly reused in agriculture.

Al Ashara

Al Ashara is a village in Abo Humous district in Beheira governorate. Most of the villagers are smallholder farmers. Al Ashara is built on the bank of a small irrigation canal and surrounded by agricultural lanz (Figure 8). The houses inside Al Ashara are widely spaced.

All villagers in Al Ashara are connected to *bayaras*, often one *bayara* per house. Unlike villages served by informal sewer networks, *bayara*-served villages have reduced water consumption patterns, where villagers are more aware of their daily water consumption and the way they discharge different wastewater streams (e.g., greywater and blackwater). It was estimated that the average water consumption in Al Ashara is 60 litres per person per day, roughly half the consumed amount in villages with informal sewer networks (110 l per capita per day).

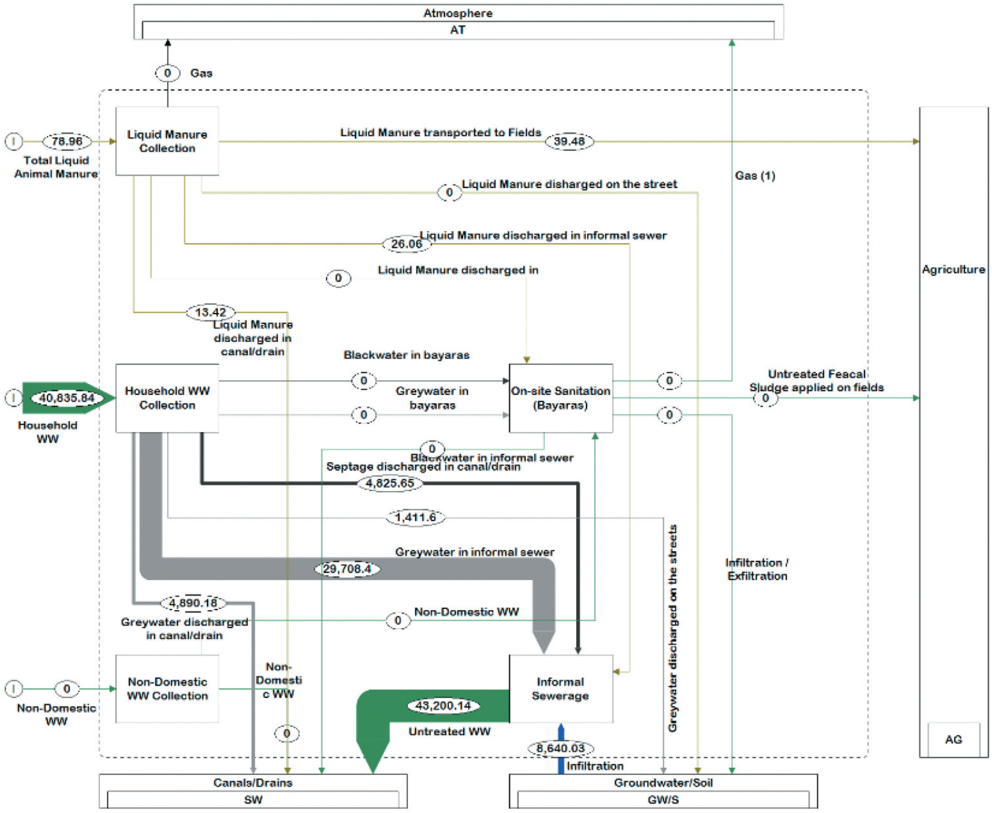


Figure 7. Volume of wastewater discharged from El Hamamee in different compartments. Source: Reymond et al. (2014).

Figure 8. Al Ashara map. Source: Google Earth.

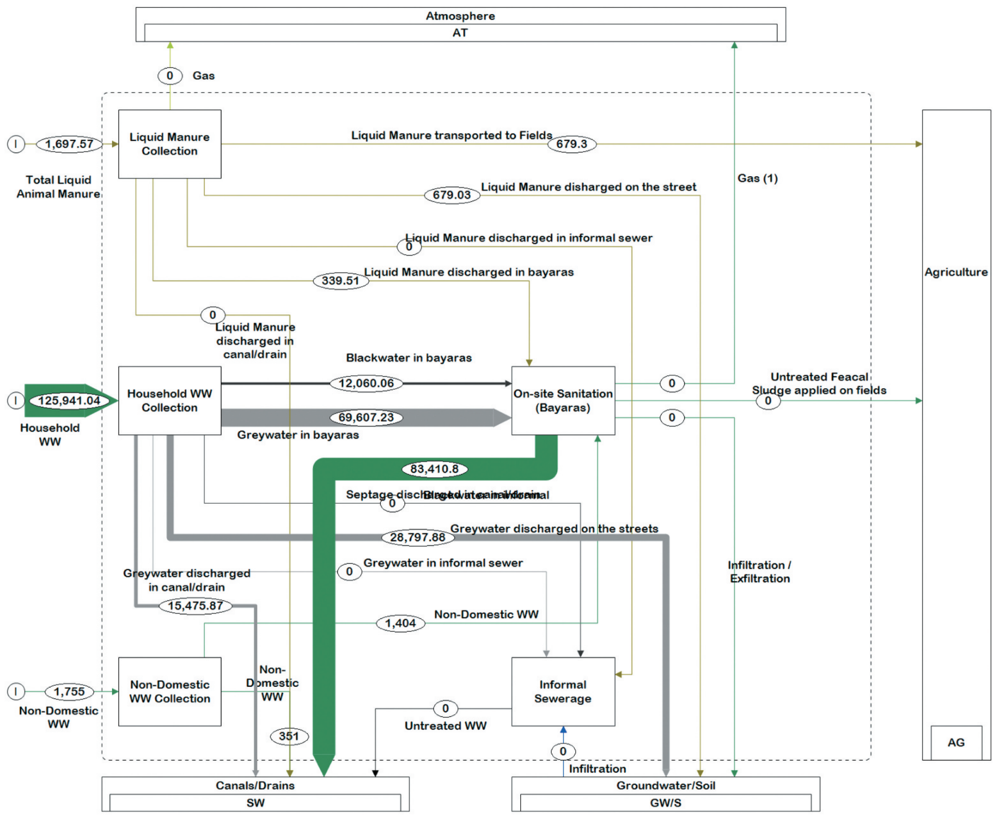


Figure 9. Volume of wastewater discharged from Al Ashara in different compartments (developed from data presented by Reymond et al., 2014).

Greywater in Al Ashara is often discharged into the street, canal or drain. While blackwater from toilets is discharged into *bayaras*. These different discharging methods aim to reduce the frequency and cost of *bayara* emptying. *Bayaras* are emptied on average every 20 days during summer and every 25 days during winter. There are six *bayara* operators' trucks in the village, which serve other places in Besentway. Therefore, the demand for trucks exceeds their capacity. Some *bayaras* overflow due to the inaccessibility of Al Ashara streets during winter as stormwater accumulates in the unpaved streets, which become muddy and inaccessible to trucks. In Al Ashara, 63% of greywater is discharged directly to the drain and on the streets, while 40% of the liquid manure is directly reused in agriculture (Figure 9).

Discussion and conclusions

Wastewater reuse provides an important source of irrigation water that narrows the demand–supply gap for many farmers in the Nile Delta in Egypt. In this paper we discussed two types of wastewater reuse arrangements that take place in Egypt. On the one hand, there are the formal wastewater collection, treatment, and indirect and direct reuse arrangements that are exclusively controlled by the HCWW and associated bureaucratic institutions respectively. On the other hand, the informal reuse arrangements are managed by local actors who organize their activities through socially embedded arrangements, which are illegal and unrecognized by the bureaucratic institutions (Table 4). As plans to increase wastewater reuse emerge, it is necessary to understand the heterogenic arrangements that govern wastewater flows and reuse practices as well as the technical and institutional arrangements that mediate these practices. The failure to understand the informal sector, its wastewater flows and reuse practices, while bringing wastewater collection, treatment and reuse into the formal sphere might, as this article shows, result in overlooking significant quantities of generated wastewater that help or can potentially help to narrow the water demand–supply gap for irrigation in a safe and environmentally friendly manner in Egypt (Tables 2 and 3).

In this paper we analysed three case studies, one in a desert-front governorate, where treated wastewater is reused through the HCWW model of timber plantation which provides low economic incentives and is seen as an 'easy discharging option' for the generated wastewater. Interestingly this wastewater reuse model does not solve existing (agricultural, domestic or industrial) water demand deficits and problems as it only generates new water needs through the expansion of the irrigated frontier with the production of timber. Though this strategy fits within the strict wastewater reuse regulations, it raises very important question marks regarding its social, economic and environmental sustainability; especially in a context of growing water demands.

The two cases in the Nile Delta, where wastewater is often discharged and reused directly from the agricultural drains, show another reality. The use of irrigation drains as a means to dispose of rural wastewater flows seems a cost-effective system that transports wastewater within the Delta. In doing so it supplements downstream users, including farmers, with much-needed irrigation water to maintain their agricultural activities, albeit with high related health and socio-environmental sustainability risks.

In the Delta, drains are shared by the formal and informal reuse arrangements at different abstraction/control points. The formal arrangements established mixing pump stations to control formal reuse practices, while the informal arrangements rely on mobile pumps to abstract drainage water directly to agricultural fields at various points along the drains. This, however, leads to a system where little is known about the quality of reused water in the irrigation sector. As rural settlements directly dispose of their untreated domestic and industrial wastewater to drains, little is known and no control prevails over what contaminants and in which concentrations exist in the drains. This is especially concerning as farmers using water from these drains are constantly exposed to these pollutants with no means to assess the quality of the water they are using to ensure their production. As exposed above, polluted water from agricultural drains is also pumped back into the main Nile system north of Kanater Barrage, which poses an important risk for the quality of domestic water supply of millions downstream.

The crux of our analysis in Tables 2–4 is that the informal arrangements in the Delta villages can manage sewerage collection and management, but are unable to treat and reallocate the flows in a socio-environmentally sustainable manner. This leads to a situation in which farmers use and sometimes depend on highly contaminated untreated wastewater that is pumped from agricultural drains posing serious health, environmental and economic challenges at local and national levels. At the same time treated wastewater is being used in desert governorates such as Marsa Matrouh for new costly and poorly functioning timber plantations that generate new water demands. In

Table 3. Wastewater flow management analysis of the formal direct wastewater reuse – mapping of organizations and their responsibilities.

	Technological management				Institutions and practices			
Wastewater flows	Design	Construction	Operation	Maintenance	Regulations/norms	Conflict management	Resource mobilization	Decision-making
Containment/collection	*Ministry of Housing, Utilities & Urban Communities (MoHUUC)* Wastewater is collected by the conventional sewerage network. Its design and construction are the responsibility of the MoHUUC		*HCWW*		*Egyptian Water Regulatory Authority (EWRA)* Responsible for the regulation, monitoring and evaluation of all activities related to water supply services and wastewater disposal. Although the EWRA exists, it is not functional, and the regulatory role is partially filled by other organizations, including the Ministry of Environment, the Ministry of Health and the Ministry of Agriculture	*No clear conflict management mechanism* Usually, each institution refers to a law, code or standard that support its position and mandate. Often these laws, standards and codes are difficult to implement (e.g., Law 48/1982, reuse code 501/2015) and/or contradictory	*Donors*	*MoHUUC* *Project Management Unit (PMU)* part of the MoHUUC
Treatment	*National Organization of Potable Water and Sanitary Drainage (NOPWASD)* Carries out the investment component of designing and constructing new treatment plants. Overlapping with the HCWW (World Bank, 2016)						*HCWW*	*HCWW*
Conveyance	*HCWW* Treated wastewater is conveyed through pumps to the designated land for reclamation, which is often part of the treatment plant land area, or close to the plant						*HCWW* In addition to donor-funding programmes such as the Life programme funded by the USAID in Luxor	
Delivery/reuse	*HCWW* In collaboration with the Ministry of Agriculture and the EEAA (The Road Map, 2017). However, the HCWW did not attract private investors or succeeded to sell the treated wastewater outside its premises (personal communication)							

Table 4. Wastewater flow management analysis of the informal indirect wastewater reuse.

Wastewater flows	Technological management		Institutions and practices			
	Design Construction	Operation Maintenance	Regulations/norms	Conflict management	Resource mobilization	Decision-making
Containment/ collection	*Local actors (villagers/ farmers)* Design and construction depend on local actors' needs and constraints	*Individual household* Each household is responsible for the operation and maintenance (O&M) either through manpower or a monetary contribution	*Community leader(s)* Norms are set to organize the collective effort of the community to build containment structures	*Community leader(s)* Socially embedded norms. For example, it is not acceptable to discharge blackwater in the streets, but acceptable for greywater. However, farmers have little power to challenge national projects	There are *diverse resources* that community taps on, such as manpower, money, land, and expertise	Either *consolidated within one family* or with one person (*community champion*), or a *group of proactive* actors in the village
Treatment	*No treatment before discharge*		*Do not exist*			
Conveyance	Wastewater from *bayaras* is conveyed by *vacuum trucks*. Wastewater collected by informal sewerages is discharged directly to the drains	*Owners* (for private vacuum trucks) *Village council* (for public trucks)	Regulations set by the EWRA, Ministry of Environment, Ministry of Health and Ministry of Agriculture are rarely enforced			
Delivery/ reuse	*Farmers* The delivery of wastewater for reuse takes place through the existing drainage network, where farmers abstract wastewater directly from drains before reaching the mixing stations	*Farmers* O&M of abstraction pumps is carried out by farmers	*Farmers' pumps* The informal reuse from drains is carried out by farmers' pumps at the closest point to their fields			*Farmers* They decide the amount of irrigation water based on crop requirements. Some farmers shift towards inedible crops due to the impact of drainage water on edible crops' taste and soil productivity

doing so formal water reuse policies are potentially increasing pressure on Egypt's water resources rather than using the potential of wastewater to ameliorate the water stress.

Where we consider that there is potential to reduce pressure on water resources and their reuse is in improving and supporting the informal wastewater disposal and reuse practices (e.g., rehabilitating existing structures such as *Bayaras* and informal sewerages); regulatory support (e.g., easing the stringent treatment and reuse regulations); and monitoring (inspection and enforcement) of the discharged effluent's quantity and quality. To advance on this, innovative participatory approaches are needed. These should cross the formal–informal divide and include the already involved stakeholders (often considered illegal).

The formal arrangements have succeeded in providing sanitation coverage to the majority of the urban settings while failing to progress as fast in rural areas. By recognizing and supporting the informal arrangements in rural areas, this could significantly improve wastewater collection and treatment as well as the quality of treated wastewater that is reused in agriculture. Thus, we conclude that a critical bottleneck in Egypt's formal wastewater sector is its inability to recognize the informal sector. This is reflected in the limited – slow pace – progress in adopting less stringent regulations than the current ones (e.g., Law 48), and its reliance on a single institution for the operational activities of wastewater management and reuse.

This recognition must be followed by gradual inclusion through regulatory amendments to the current wastewater sector in Egypt. From the analysis, we noticed that the obstacles facing this recognition and regulatory inclusion are not only technical or institutional since actors from the formal and informal institutional arrangements are aware of each other and in a dynamic interaction that is generated by the dynamic flow and control of wastewater throughout the management activities presented in Table 1. However, these obstacles are mainly due to the stringent regulations and the absence of political will to redistribute responsibilities and power among the formal and informal arrangements. This is apparent from Table 4, where the informal arrangements lack any sort of enforced regulations, which hinders rather than supports the effort of local actors in managing wastewater.

Finally, it would be important for future studies to propose regulatory tools that go hand in hand with a well-planned expansion in the existing collection, treatment and distribution infrastructure to enable better management to take place. Such an approach would have to be innovative, transparent and participatory in nature and lead to new forms of wastewater governance in Egypt. To advance on this it would be equally important for future research to investigate the long- and short-term impacts of recognizing and empowering the informal reuse arrangements on the social, economic and political life in Egypt. As shown in this paper, to adopt safer wastewater reuse practices it is important to analyse the different components and actors engaged in wastewater reuse, including the often-ignored informal sector. Though the use of the developed analytical framework, insights can be generated that can help identify technical and institutional bottlenecks that need to be addressed in order to facilitate the safe and sustainable reuse of wastewater flows.

Notes

1. https://www.eawag.ch/en/department/sandec/projects/sesp/esriss-egyptian-swiss-research-on-innovations-in-sustainable-sanitation/
2. https://tradingeconomics.com/egypt/imports/wood-articles-wood-wood-charcoal

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