Ecological Indicators 145 (2022) 109660

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

# Landscape-based regeneration of the Nile Delta's waterways in support of water conservation and environmental protection

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ARTICLE INFO

*Keywords:*
Waterways
Environmental degradations
Pollution
Littering
Water deficit
Public perception
Regeneration
Nile Delta
Environmental landscaping

ABSTRACT

Waterways' regeneration is proposed as one of the main mitigation strategies for addressing the alarming water budget deficit in the populous, hyper-arid Egypt, relying primarily on the Nile as its most important water source. The latter is increasingly under pressure from a rise in internal consumption, droughts, and upstream damming. We perform herein a review of the state of knowledge of waterways in the Nile Delta and the environmental drivers that resulted in their degradation. We evaluate how these degradations are associated with the decadal changes in their socioeconomic context and how these changes impacted the public perception of the waterways' functionality from irrigation canals to sewage sites. The above led to littering, pollution, and negligence toward their preservation, which consequently accelerated their gradual landfilling as a response to their contamination triggering severe public health and ecosystem degradation concerns. The extensive landfilling further compromised their role in crop production, water conservation, and ecosystem integrity. We review and compile several published reports and perform field investigations to assess the current state of knowledge on the physical degradation of waterways in the Nile Delta for the last 60 years. Our results suggest that the alarming increase in informal settlements, resulting from multiple economic shifts and rapid urban sprawl, is the primary cause of waterways degradation and landfilling as well as the reduction in their total area by ~30 % from ~207,912 ha in 1987 to ~146,381 ha in 2019. We suggest a landscape-based design built on the Nile's natural heritage to efficiently regenerate the areas surrounding these waterways to enable their role in addressing the water budget deficit and ensuring sustainable ecosystem services.

## 1. Introduction

The United Nations Climate Change Conference in Glasgow (COP26) in 2021 drew global attention to the impacts of climate change on inland historic waterways and their role in addressing water stress (Green WIN, 2021). In Egypt, the nation's rising water budget deficit has been the subject of international concern considering the alarming growth of intrinsic consumption and the increased damming activities upstream of the Nile basin; both requiring rapid implementation of waterways regeneration among other water conservation strategies. In response to the current intrinsic water budget deficit ranging from 40 to 54 BCM/yr (billion cubic meters per year) (Nikiel and Eltahir, 2021; SSCHR, 2022) and its expected increase due to the construction of the Grand Ethiopian Renaissance Dam (GERD) (Heggy et al., 2021), the Egyptian authority

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https://doi.org/10.1016/j.ecolind.2022.109660
Received 9 August 2022; Received in revised form 1 November 2022; Accepted 8 November 2022
Available online 15 November 2022
1470-160X/

implemented several measures including the adaptation of less water consuming crops, the lining of waterways and the expansion of irrigation water reuse (Elnmer et al., 2015; Khadr et al., 2017; Dessalegn et al., 2022). These mitigation efforts are severely compromised by the increase in the heavy metal pollution in the waterways, the incremental increase in water consumption, littering, and public misuse, and the high implementation cost of regeneration. The increase in heavy metal pollution is primarily attributed to the expansion of the reuse of untreated irrigation return water, which is rich in fertilizers due to the high cost of drainage water treatment. This water source amounts on average to 11 BCM/yr (El Shazly, 2019; Morsy et al., 2020; Tawfik et al., 2021). Moreover, the increase in water consumption is a consequence of the rapid population growth and the large-scale developments in both the industrial and agricultural sectors. For instance, the withdrawalof the Nile water, ranging from 0.872 to 4.5 BCM/yr, mixed with drain water to Sinai Peninsula through El-Salam canal ('Abdelwahab et al., 2020; Assar et al., 2019; Othman et al., 2012).

However, the reasons for the littering and public misuse of the Nile waterways remain largely unquantified let alone understood, as historically, Egyptians were highly preservative of the Nile, with a strong sense of cultural and socioeconomic attachment to the river ecosystem. The historical significance of the Nile River and its associated waterways in Egyptian public perception can be attributed to several cultural, political, and religious reasons. First, culturally, the Nile River has long been considered the source of prosperity as its flow in the harsh hyper-arid desert creates a unique and sustainable harvest that protects its inhabitants from outer invasions (Oestigaard, 2018). Second, politically, the governance of the Nile's flow in ancient Egypt was one of the sources of the king's strength, requiring careful dedication to the river's health (Weber, 1993). Third, religiously, ancient Egyptians considered the Nile "Nylus" as the artery of life and the greatest of all Gods (Heliodorus, 1895) and therefore, the flooding season was a time of feasting and other religious rituals (Siculus et al., 1947). The later religious value of the Nile River has also extended through the Roman and the Greek eras as well as more recently in Christianity and Islam, where the Nile River was considered a holy water (Oestigaard, 2018). In terms of sustenance, Egypt began its first agricultural activity around 5200 BCE, by sowing seeds and relying on the Nile for watering and fertilizing the soil (Gad, 2008). As a result, the Egyptian culture has always been defined by its reliance on Nile River water rather than rainfall (Hmdan, 1967). Today, the mitigation efforts to preserve the Nile and its associated waterways, which are one the oldest and largest waterway systems known in human history (Tayia et al., 2021) are compromised by severe large-scale degradations due to rapid urbanization, littering, public misuse and inefficient regeneration strategies.

The environmental status of any natural system is expected to change over time depending on the socioeconomic settings and development levels of its society (e.g., (Meybeck and Helmer, 1989; Garcier, 2007). Following the natural evolution of the hierarchy of needs theory (Maslow, 1943), it is assumed that humans will consider complex needs, only when their basic needs are fulfilled. This theory has been approved in different environmental-related problems in different showcases worldwide, where environmental interests are consistently ranked after human health and economic needs (de Haan et al., 2014; Arden and Jawitz, 2019; Wachholz et al., 2022). The Nile River basin is not an exception in this regard, as the rapid population growth, rising food prices, stagnant GDP, and increase in poverty in Egypt during the last decade made the Egyptians less protective of the river ecosystem.

Egypt is the most downstream riparian of the Nile River basin, which is composed of separate sub-basins sharing water resources among 10 nations where more than 500 million inhabitants are residing (NBWRA, 2022). Among all the Nile riparian countries, populous Egypt is the most arid country and the one relying almost exclusively on the surface water from the Nile River, for 98 % of its renewable water resources (FAO, 2016). The latter is subject to significant flow fluctuations due to natural and anthropogenic drivers which can trigger substantial water deficit downstream of the Aswan High Dam (AHD) (Heggy et al., 2021) and thus the Egyptian authorities are encouraging all efforts to explore new unconventional resources of water to support the national water needs such as defining and locating new groundwater aquifers (Abotalib et al., 2021; Attwa et al., 2021; Khalil et al., 2021a), expansion in desalination (Kotb et al., 2021) and reuse of irrigation water (Tawfik et al., 2021), and adopting strategies for waterway regeneration as a method of water conservation (Khalil et al., 2021a).

Of particular interest is the Nile Delta, in the upper northern part of Egypt, which is the country's primary source of agricultural production (Redeker and Kantoush, 2014). It is also one of the largest river deltas in the world with its surface area of ~22,000 km$^2$ and its high vulnerability to sea level rise and seawater intrusion in soils and shallow aquifers, change in land use, subsidence and the socioecological implications of these drivers (Hamza, 2009; El-Ramady et al., 2013; Rateb and Abotalib, 2020). The above natural and anthropogenic hazards are augmented by the unsustainable land management practices in the Nile Delta, where only 14 % of the Delta's area adopts sustainable land use management practices (El-Nahry and Abdel Kawy, 2013). Moreover, Egypt's rapid population growth in recent decades at an average annual rate ranging from 1.9 to 2.7 % during the period of 1961-2020, resulted in a reduction of the per capita water share to a quarter through these forty years (UN DESA, 2019; The World Bank, 2022). Today, Egypt is classified as a zone of "severe water stress" as the annual water supplies drop below 500 m$^3$ per person, categorized as dangerously close to "absolute scarcity". The above water stress is mitigated to some extent through importing virtual water (i.e., water is imported indirectly through food, hence is called virtual water), in the form of primary and secondary agricultural crops and animal products (The World Bank, 2000). Furthermore, the repeated reuse of agricultural drainage water is also widely used to mitigate the water shortage. This, in turn, negatively impacts the quality of water by increasing its salinity and pollutant concentration (Khalil et al., 2021b). According to Omar and Moussa (2016), Mazzoni et al. (2018), and Bekhit (2019), Egypt is already facing an intrinsic water shortage between 18.5 and 21 BCM/yr and will continue to exacerbate water stress conditions leading to doubling their water demands by 2040 (Nikiel and Eltahir, 2021). The current, significant increases in food prices due to severe water scarcity per capita could increase the socioeconomic instability over the next 30 years (Terwisscha van Scheltinga et al., 2021). Moreover, under current global warming, future global predictions of river flow (up to 2100) using daily data of river discharge from high-resolution general circulation climate models suggest that the frequency and intensity of prolonged droughts will significantly increase (Hirabayashi et al., 2008; Abdelmohsen et al., 2020). The above reasons are alarming and cast a grim outlook on water resources for downstream nations in the Nile basin and for Egypt in particular.

Under such water stress conditions, preservation strategies are crucial to providing minimum sustainability of water resources. Heggy et al. (2021) presented the feasibility indices of various mitigation measures needed to avoid severe water deficit in Egypt, especially during the filling period of the Grand Ethiopian Renaissance Dam (GERD), such as using the strategic reserves at the AHD reservoir, expanding groundwater extraction from shallow aquifers, and regenerating the waterways. For example, shading and lining of the irrigation canal network of ~31,000 km can reduce the Nile flow water loss from both seepage and evaporation by 10 to 40 % (Omar and Moussa, 2016); (Molle, 2018a). On the other hand, the currently implemented design using the impermeable concrete lining of the canal will significantly reduce recharge to the surrounding shallow aquifers (Khalil et al., 2021b). The importance of lining the 31,000 km long irrigation canals is materialized in a new governmental infrastructure campaign and water regeneration plan (i.e., the 2017–2037 plan) that was announced in 2020. As a first step, the Egyptian authorities are implementing a two-year plan to upgrade and reinforce the lining of 7,000 km of irrigation canals at a cost of one billion USD (Enterprise, 2020). The latter includes reinforcing the canals to prevent seepage, promoting the use of efficient irrigation techniques as well as incentivizing farmers to use these techniques. However, even though several canals were lined, they have been degraded in just a few months by littering and solid waste dumping by the local inhabitants (Abou Elnasr, 2021; Elsahy, 2021). Therefore, the technical solutions to the Nile waterways' regeneration are not sufficient by themselves to achieve their sustainability. Instead, efficient regeneration needs to include a landscape architectural intervention to increase the inhabitant's connectivity for the cultural value of their living environment, which significantly supports preservation. The rationale for considering the importance of cultural landscape regeneration through aesthetics together with the functional aspects is the consideration of landscape as an integrative system including multiple ecosystem functionalities with direct and indirect benefits. In this, the cultural landscape is defined as *"a composition of man-made or man-modified spaces to serve as infrastructure or background for our collective existence"* (Jackson, 1984). Accordingly, the intent here is not to adopt the historical solution that attempts to bring the landscape to its original functionality while ignoring multiple societal and urban developments, but rather to establish a balance between both expectations to achieve sustainability. Consequently, the waterscape in Egypt that is currently undergoing major large-scale degradation requires a holistic long-term interdisciplinary regeneration strategy, as described above, to enforce its role in water conservation and food security. It is important to note that, in climate-vulnerable cities, such as those in the Nile Delta, waterways are the most important components of the natural life support system (Dolman, 2021).

Herein, we provide a state of knowledge of the Nile Delta waterways' system and investigate the socioeconomic drivers that led to its degradations as well as addressing the challenges for its preservation in order to support water conservation and suggest design solutions. In particular, we assess the evolution of the local inhabitants' physical connectivity and visual perception of waterways, which plays an important role in their response to water awareness campaigns addressing the nation's rising water deficit. This connectivity relies on two main benchmarks: the visual characteristics of landscape as an aesthetic factor resulting from urban expansion, and the socioeconomic activities connecting the inhabitants and the landscape settings.

## 2. Methods

Our analysis to assess the degradation and effective regeneration of Nile Delta waterways is carried out, following three steps. The first, is an assessment of the physical degradation of the waterways and its correlation to urban and socioeconomic settings in the last seventy years. The latter is investigated through establishing a historical record of the evolution of waterways and the socioeconomic status of Egyptians using compiled data from peer-reviewed literature and analysis of multi-temporal high-resolution photogrammetric satellite images accessible on Google Earth in a GIS environment.

The second, is an evaluation of the decadal changes in the ecological indicators of the waterways performed using the DPSIR (Drivers-Pressures-States-Impacts-Responses) framework. The DPSIR framework was developed in the early 1990s and was adopted by the European Environmental Agency (EEA) in 1999 as a conceptual cause-effect relationship for environmental assessment (Smeets and Weterings, 1999). Since then, the DPSIR framework has been further extended as a knowledge production tool using an appropriate combination of indicators in a meaningful manner for decision-makers (Organisation of Economic Co-operation and Development (OECD), 2003). Furthermore, the DPSIR framework allows a holistic explanation of mutual interactions between the environmental states with their controlling drivers and pressures, including the socio-economic dynamics (Lundberg, 2005). Therefore, the DPSIR framework is used in our study as a unique assessment tool connecting the states of waterways degradation to their drivers and impacts and their required management options in a simplified manner for multidisciplinary target audiences, including researchers, policy-makers, and key stakeholders for supporting decision-making. One of the advantages of the DPSIR framework is its flexibility in terms of indicators and in-situ data availability requirements compared to modeling and data-driven analyses, which are well-known as data-dependent approaches. This criterium is crucial in our investigation as the Nile Delta is an in-situ data-limited area.

Third, we use architectural landscape design to propose an effective nature-based solution for the sustainable regeneration of waterways functionalities, ensuring their multiple benefits and roles in water conservation and ecosystem services. The latter was achieved using the water-sensitive urban design (WSUD) approach. The WSUD approach involves using natural elements such as soil, water, and plants to address environmental, economic, social, and climate concerns. The design of the conceptual regeneration model is created through Adobe Illustrator and AutoCAD version 2022. The design integrates water surfaces to build healthy and more liveable urban areas, that fuse with nature along the riverbanks.

## 3. Results

### 3.1. Current state of knowledge on waterways evolution in the Nile Delta

The changes in the flow dynamics in waterways (such as canals, creeks, and rivers) in arid areas, such as the Nile in Egypt, provide the public with a visual measure of water stress as these water bodies cross dense urban areas. Historically, the public perception of the seasonal state of the Nile waterways constituted an important part of their awareness of the magnitude and extent of the wet, normal, or dry conditions in the Nile basin, where the changes in flow level and water quality (inferred from the water color, smell and Nile vegetations) built the public's perception of the sustainability of their water resources and associated conservation schemes (Ouda et al., 2021). With an above world average illiteracy rates, lack of constructive media coverage of environmental challenges, and absence of continuous educational programs on water conservation, the state of waterways has always been the metric for the public when it comes to understanding water stress (Benameur et al., 2021). To a lesser extent, the public perception of water stress is also impacted by municipal resource management practices including conservation scenarios, water reuse, and pricing (Cauberghe et al., 2021). The success of the above elements in raising public awareness to mitigate water stress is often dependent on the inhabitants' cultural values, and educational levels as well as their perception of water value (Reed and Buckmaster, 2015). Furthermore, economic drivers have a quantifiable impact on public behavior towards their natural assets, including waterways (Dopico et al., 2022). Several analysts suggest a U-shaped relationship between wealth and environmental sustainability (Tang and Koveos, 2008; Cox et al., 2011; Tranos and Zeleke, 2018), where positive environmental attitudes are highest in both the wealthiest and poorest nations, but the decline of these attitudes become clear as richer nations enter a recession, i.e., "the environmental Kuznets curve" (Cole et al., 1997). Still, other studies suggested that there is no proof at present that society's interaction with the water environment has been significantly affected by the economic aspects (Dopico et al., 2022).

Waterways management in Egypt went through several phases that were highly impacted by the rapid changes in urban and demographic morphology. These phases could be summarized in five main transformation eras: (1) the initiation of the modern waterways' system, which occurred during the Ottoman era in 1839, (2) modernization of the waterways in the 1960s during Nasser presidential initiative to achieve national agricultural sufficiency and industrialization (Daef, 1986), (3) the rapid increase in population, urban growth and the reliance on imports to address the local deficit in agricultural production in the 1970s and the beginning of the degradation of waterways (Waterbury, 1985a), (4) in response to the later, the Ministry of Water

Resources and Irrigation launched a series of irrigation improvement projects that spanned the 1980s and 1990s in collaboration with Colorado State University and the USAID to establish continuous flow in the secondary branches (canals) and introduce collective pump stations (El-Agha et al., 2011; Molle, 2018b), (5) beginning of the urban sprawl and launching the first waterway conservation campaign in the 1990s (GreenCOM, 2000), (6) the expansion of the irrigation improvement projects with the aim to involve the farmers in the design, implementation and maintenance of the waterways' structures and the allocation of water share, which resulted in the improvement of 52,000 feddan in 2014 (Molle et al., 2019), (7) the begining of deriving water from the Nile River and drains during the 2000s through newly developed canals to irrigate desert lands in south Egypt (e.g., Sheikh Zayed canal to reclaim 550,000 feddans (El Baradei and Al Sadeq, 2019) and in north Sinai (e.g., El Salam canal is planned to reclaim 620,000 feddans (Barnes, 2012; Othman et al., 2012), (8) a 2-year project for lining Egypt's irrigation canals across the whole nation was launched in 2020 to improve water resources management in both the Nile Delta and valley and contribute to addressing the intrinsic water deficit (Abd-Elaty et al., 2022), and finally (9) the current status, which witnesses severe degradation of the water share per capita, urban sprawl and large-scale irreversible pollution of the water and soil in the waterways associated with dumping and littering solid wastes in the newly lined canals (Abd-Elziz et al., 2022; Dessalegn et al., 2022; Shabaka et al., 2022). Since the construction of the current Nile irrigation waterway system in the 19th century, it has been based on the non-systematic management approach, where a comprehensive and integrated approach to water resources management is lacking. In such a system, many agencies are involved in water resources management, with unclear responsibilities, which leads to duplication of effort, lack of comprehensive data, and an inadequate plan for sustainability (Dayrit, 2022).

Moreover, the priority in the waterways planning system is given to their functionality as irrigation or drinking resource over aesthetics for the purpose of an efficient cost effective implementation (Haug, 2021). Thus, Young (1974) stated that "*real urban or regional planners (deserving of the name) must consider the area being planned as a system, must understand its connectedness, its interrelatedness with its parts and those exterior to it, must understand the flow of inhabitants, energy, and materials into and out of it, must understand the design essentials based on environmental characteristics and human needs. But they do not*." (Young, 1974, p. 54). Unfortunately, the continuous implementation of functionalism in urban expansion results in societal dysconnectivity with the established infrastructures, which triggers public misuse and hence degradation. The wide use of the functionalistic approach despite the multiple transformations in the cultural and socioeconomic contexts over time has led to negative consequences on the inner cities' waterways. As the historical function of waterways for agricultural irrigation has changed, the public perception of their role also transformed. Today, most Egyptians in urban areas perceive the waterways as sewage or dumpsters due to the degradation of the urban sprawl landscape surrounding their presence that replaced the scenic crop fields.

### 3.2. Socioeconomic changes impacting waterways evolution in Egypt (1960–2000)

The construction of the Aswan High Dam (AHD) between 1960-1970 brought major changes to Egypt's water and agricultural management due to its significant role in flow regulation, and drought management in addition to the hydropower generation (Smith, 1986). The country's agricultural production boomed in the 1960s as part of the national plan for modernizing the agricultural and industrial sectors, along with the development of local technical capacities (Wahdan, 2007). In this era, several new urban settlements were established, thus leading to a substantial internal migration wave to cities. Consequently, urban population expanded from 37.4 % in 1960 to 45 % in 1995 at the expense of decreasing the rural ones primarily working in agriculture (UNDP, 1998).

In the 1960s, the Egyptian economy was mainly agriculture-based, where the agricultural sector employed ~47 % of the total workforce and provided ~30 % of the gross domestic products and more than ~50 % of exports (Waterbury, 1985b). Moreover, the industrial sector was also heavily dependent on agricultural products such is the case for textile and food processing. In 1974, Egypt became a net importer of agricultural commodities for the first time in its history (Richards, 1980). Simultaneously, the economic liberalization (open-door policy/ *Infitah*) was announced in 1974 after the socialist experiment, suggesting substantial changes from being a closed self-sufficient communist economy to a more open and global trading one with western countries, attracting international investments and establishing a large private sector (Daef, 1986). Yet this necessary economic liberalization has been poorly implemented, leading to the decline in national production, and hence a strong reliance on exports, and the beginning of the deterioration of the domestic agricultural sector along with internal migration waves to new urban areas. The fast expansion of these urban areas coupled with the rapid population growth raised the demand for potable water beyond the capacity of existing facilities and the authority's technical and financial abilities to improve the water infrastructure at that time (Tahoon, 2020). The situation became more alarming during the late 1970s when the Nile flow decreased during the prolonged drought from 1978 to 1987, bringing Lake Nasser's reservoir level to an all-time low (Molle, 2018a). Based on a detailed study conducted in the summer of 1979 as part of the Egyptian Government's Metered Water Service Connection Program, 25 % of Cairo inhabitants lacked direct access to the city's water supply system (Nadim et al., 1980). Another unintended consequence of the economic liberalization strategy was the authority's recognition of the country's lack of sufficient water-related infrastructure and its impacts on the ability of new economic policies to attract international investments. Due to the deficiencies in the authority's investment in the water services sector, excessive inflation occurred in the prices of agricultural products, erosion of public services increased, and the majority's standard of life deteriorated (Ikram, 1980).

Overall, the economic reforms in the 1970s had adverse impacts on the social scale in Egypt, widening the gap between the top and bottom socioeconomic classes and hence widening the gap in water consumption and availability for different parts of the population. Additionally, in the 1980s, the massive eastward outflow labor migration to rich oil-producing countries in the Persian Gulf resulted in several farmers abandoning their lands for a better economic perspective. The abandoned agricultural areas soon turned into dense urban sprawls. Furthermore, in the remaining farming areas, irrigation has become a more complex process under the rising adjacent urban water demands and the degradation of the waterways now running through sprawls further compromising the efficiency of the irrigation system (Molle, 2018a). For instance, the urban sprawl on both agricultural lands and waterways (e.g., canals and drains), together with climate change and continuous damming along the Nile River decreased both sediment and flow supply and thus affecting the revenue of land cultivation (Redeker and Kantoush, 2014). In response to the reduced flow, local farmers adopted inappropriate practices by either over-irrigating their lands when water is available to store water in the soil profile (Molle et al., 2019) or abstracting water from drains and shallow aquifers (Molle et al., 2018). However, these practices my deprive downstream farmers from their water shares and also introduce salinity, heavy metals and other contaminants that are often more concentrated in shallow aquifers to the soil, which ultimately affect the crop productivity and food security and add more costs on the local farmers (Elnmer et al., 2015; El Shazly, 2019; Morsy et al., 2020).

### 3.3. The degradation of waterscape urban fabric in the Nile Delta

The loss of several agricultural areas in the Nile Delta occurred due to rapid urban growth (Fig. 1) (Radwan et al., 2019), causing severe degradation in the soil organic carbon content between 1972 and 2017 and significantly degrading crop productivity (Abd-Elmabod et al., 2019). In response, agricultural areas expanded into the elevated desert fringes of the Nile Delta to compensate for the rising demand of the delta land for residential uses (Rateb and Abotalib, 2020). This led to soil maintenance by intense fertilizers and irrigation usage, putting more pressure on the water consumption (El-Ramady et al., 2013; El-Saadawy et al., 2020). Therefore, increased urbanization has resulted in the loss of soil fertility and a shift in agriculture from productive to marginal soils, requiring higher capital inputs and, eventually less sustainable and higher costs (Abd-Elmabod et al., 2019).

To assess these large-scale changes, we examine the evolution of the irrigation canals in the Nile Delta between 1980 and 2020 using multi-temporal high-resolution photogrammetric satellite images accessible on Google Earth and published geospatial reports (Figs. 1a and b). Visual interpretation, tracing and digitizing of the waterways are achieved based on the distinctive spectral absorption of water bodies to electromagnetic waves in the visible range (approximately 0.4 to 0.7 μm) and thus their appearance as dark bodies compared to the surrounding landscape. Tracing of the irrigation canal in the Nile Delta shows that numerous canals have been partially or completely landfilled (Figs. 1a and b and 2d), where the total area covered by these canals has been reduced from 207,912 ha in 1987 to 146,381 ha in 2019 (about 30 % reduction in the canals' surface area in the Nile Delta (Fig. 1c). This reduction has been accompanied by a dramatic urban expansion from 90,700 ha in 1990 (which is equivalent to 907 $km^2$) to 240,800 ha in 2019 (which is equivalent to 2408 $km^2$) (i.e., more than 250 % for almost the same period) (Fig. 1d).

The significant degradation of agricultural land inevitably resulted in a loss of the aesthetic quality of the agriculture landscape (Khalil et al., 2014). Another challenge for farmers is the reduction of silt transported downstream by the Nile River, which is necessary to maintain fertile soil. This reduction is caused by the entrapment of the suspended sediment load of the Nile flow in the Aswan High Dam reservoir and thus further degrading the fertility of the agricultural land in the Nile Delta (Rashad, 2018). This has led to crucial changes in the urban morphology of the Delta cities and a strong degradation of the visual and cultural landscape qualities (Gouda et al., 2016). From the 1980s to the present time, local inhabitants gradually lost the connection with their urban landscape, which adversely affected their social communication through a process that can also be described as a significant weakening of sentimentality toward one's environment, i.e., place attachment (Brown and Raymond, 2007). For centuries, the visual image of the Egyptian landscape communicated a positive relationship between man and the cultivated environment, valuing especially the presence of water for irrigation and drinking. This rich image of the landscape enforced the place attachment of the inhabitants, but with the change in the landscape's character, the sensitivity of the locals to their environment as well as the sense of belonging has been significantly weakened (Keleg et al., 2021).

Due to the degradation of cultural landscape attributes and poor maintenance of the waterways, several canals in the Nile Delta suffered from continuous littering, becoming an illegal solid waste estuary, resulting in further visual and sanitary degradations (Figs. 2c and g). Pollution severity varies across the Nile waterway system based on flow,

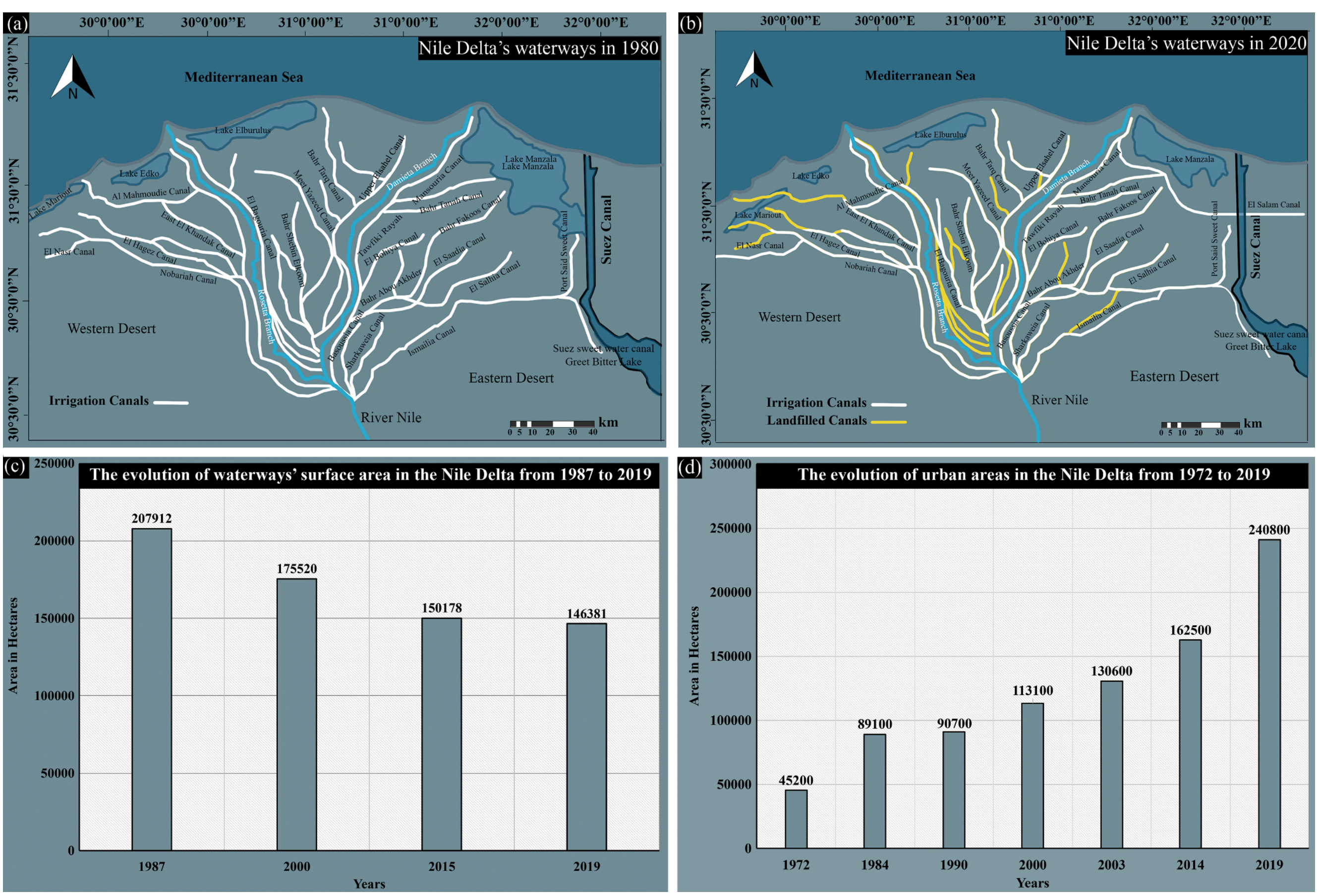


**Fig. 1.** (a) Tracing of the man-made waterways used for irrigation in the Nile Delta in 1980. (b) Tracing of the same in 2020, revealing that ~30 % of the waterways have been landfilled in the last four decades. (c) The evolution of the surface area of waterways in the Nile Delta in Egypt from 1987 to 2019. (d) The increase in urban areas in the Nile Delta that led to the decrease in the green/blue spaces from 1972 to 2019. Figures based on data from Roest, 1999; Abd-Elmabod et al., 2019; Abd El-kawy et al., 2019; Radwan et al., 2019; Abd El-Hamid, 2020; Elagouz et al., 2020; Ramadan et al., 2021.

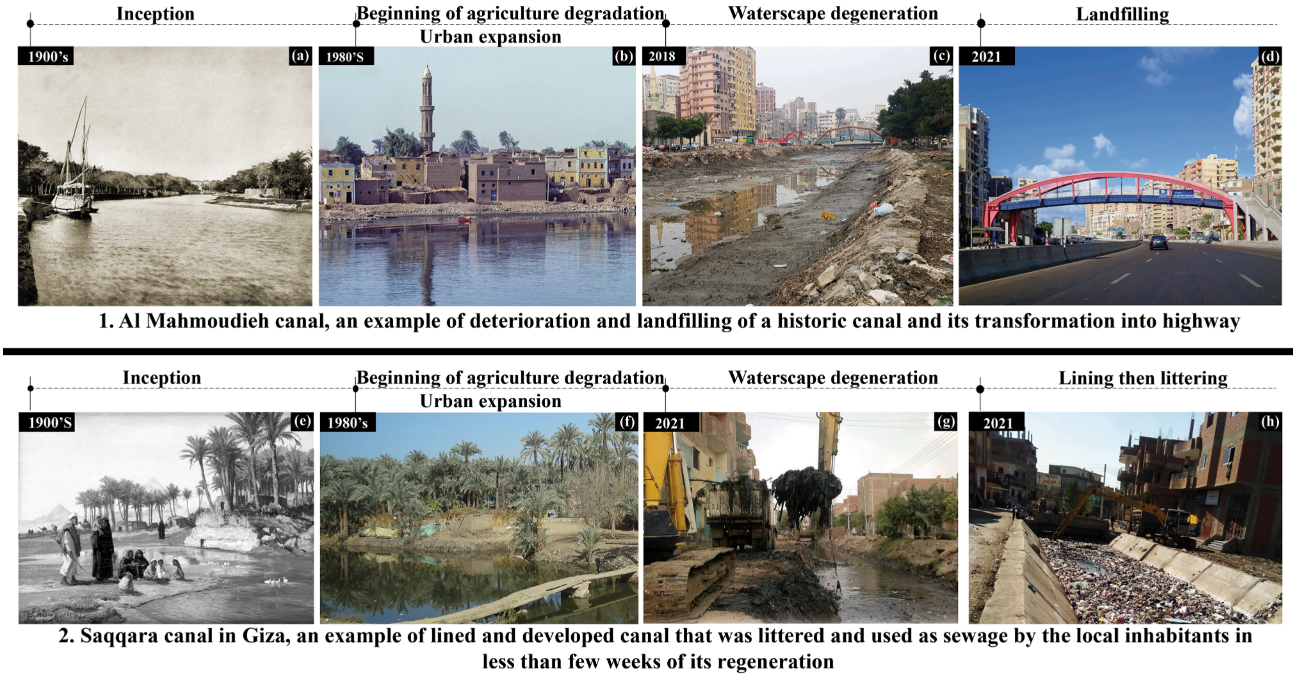


**Fig. 2.** The two main waterscape transformation processes in Egypt (upper row: case 1; and lower row: case 2) are exemplified by the two cases of Al Mahmoudieh canal in Alexandria, and Saqqara canal in Giza (landfilling or lining while ignoring landscape design in both cases). (a-d) The degradation of Al Mahmoudieh canal started by the end of 1990 s due to difficulty of landscape maintenance, leading to a disconnect from its inhabitants and its perception as a destination of municipality waste that led to its landfilling in 2018 (one of the major landfilled canals connecting the Nile Delta to the Mediterranean port). (e-f) The deterioration of the 11-km Saqqara canal due to inefficient urban expansion on agricultural lands; the canal was lined in 2021 and filled by waste discarded by local inhabitants after being developed at a cost of ~1.6 million USD. Source: (Abd El-kawy et al., 2019; Abou Elnasr, 2021).

usage patterns, population density, sanitation system availability, and other socioeconomic and geological factors (Abdel-Satar et al., 2017; Hegazy et al., 2020). Untreated or partially treated industrial and domestic wastewater, residual fertilizer leaching, solid waste disposal and navigation are all major contributors to the observed pollution. However, lining of the irrigation canals has reduced the contamination of surrounding shallow aquifers in the Nile Delta and in the newly reclaimed desert fringes (Khalil et al., 2021b). Consequently, the Nile's poor water quality became the primary source of public health degradation, including a surge in terminal diseases, such as cancer and kidney failure (Dakkak, 2021). The Nile River receives drainage water from 67 agricultural drains, 43 of which are major drains, from Aswan to the Delta. Only ten drains, however, meet Egyptian standards for drainage water quality released into the Nile. The surge in pollution will be aggravated by the potential reduction of the Nile flow resulting from upstream damming and drought periods (Abdel-Satar et al., 2017). The intensive reuse of drain water to compensate any expected irrigation deficit in Egypt during the filling of the GERD (Heggy et al., 2021) or drought period could also increase the concentration of contaminants of both Nile water and soil by fertilizers and heavy metals.

## 4. Discussion

### 4.1. *Waterways regeneration as a measure for water conservation in Egypt*

With a rapidly growing population and severe climate vulnerability, the future of Egypt's water sufficiency is challenging. While the Nile Basin is currently receiving more rainfall, it is also experiencing more hot and dry years on average (Coffel et al., 2019) with projected increases in the frequency and magnitude of prolonged droughts (Abdelmohsen et al., 2022). Currently, the Egyptian Ministry for Water Resources and Irrigation (MWRI) has established that one of its highest priorities for water conservation is to ensure that the national canals remain functional and well-maintained (MWRI, 2021). Under the supervision of MWRI, this objective is enforced by implementing a new Egyptian Law on Irrigation and Drainage (Law No. 12) and establishing regulatory bodies to monitor violations by inhabitants. In 2019, 1,300 violations have been reported in the Nile Delta canals, and 1,203 of these cases witnessed litigation procedures (Abd-Elaziz et al., 2020).

Egypt's 2017–2037 national development plan was publicly released in April 2019 and has a primary focus to address the nation water scarcity (Mostafa et al., 2021). The 50 billion USD development approach is built on multiple pillars, including increasing water quality, optimizing water use, and creating a productive environment in which state agencies may collaborate (FAO, 2017). The initiative includes encouraging farmers to employ modern irrigation systems, collaborate with research institutions to develop water-efficient crops, cooperate with African states on water-use research, and, of special interest to private sector investors, build new wastewater and desalination plants. The authorities had already finished 26 of the 52 planned sewage-treatment plants by the start of 2020, with a total capacity of 418 million $m^3$ per year and will service an estimated 8 million inhabitants in the Nile Delta (Kwasi et al, 2022). Moreover, the Egyptian authorities started lining irrigation canals that will result in a significant reduction of approximately 5 billion $m^3$ in seepage loss. The national project's goal is to line 20,000 km of the 55,000 km of Nile valley irrigation canals (Minister of Planning and Economic Development., 2020; Oxford Business Group OBG, 2020). Although the project is already underway, there is very little information available about how it will affect the groundwater levels in the Nile Delta, or how the Delta's water resources will be managed conjunctively (Abd-Elaty et al., 2022). The construction project, which will focus on canals of the Nile Valley and Delta, has already begun in numerous Egyptian governorates (Takouleu, 2022). The lining of these waterways will require an investment of ~5 billion USD. Nevertheless, the Central Bank of Egypt announced an ambitious plan to mobilize 3.5 billion USD for the modernization of irrigation systems, including waterways in Egypt (Magoum, 2021).

### *4.2. Modern public perception of waterways in the Nile Delta*

Despite the multiple regeneration initiatives of local waterways, their public perception and connectivity remain poor. A significant number of the lined canals were littered with solid waste a few months after their regeneration. This can be attributed to the reinforcement of the functionality concept implemented in the current waterways' development projects in Egypt that does not emphasize on the aesthetic of these regenerations. The important role of the waterways as a landscape infrastructure with significant historical, ecological, aesthetic, and structural values is systematically ignored in regeneration projects that only focus on the functionality. Because of adopting the functionality concept, the transformation of waterways is perceived by developers (i.e., the local authorities) as a utility that should be functionally efficient without any regard for its sociocultural and visual importance as an environmentally sustainable blue infrastructure.

"Al Mahmoudieh canal" in Alexandria, provides an important example for the above ineffective urban water transformation. The canal that connects the Nile River with the Mediterranean Sea, is the oldest freshwater source for Alexandria and its main in-land transportation logistic vein. For the last four decades, the canal underwent severe degradation due to the absence of preservation policies and planning regulations for controlling the informal settlements and slums expansion along the canal and decreasing agricultural lands. The latter led to the degradation of the canal's surrounding landscape and was consequently perceived as a dumpster (Figs. 2b and c). In 2020, this ~21 km long of the canal was landfilled and replaced with a highway (Fig. 2d). On the other hand, the "Saqqara canal" located in the Badrashin area in Giza governorate, ~10.7 km long, is a significant example that reflects the functionality concept followed in the current national development projects to protect the deteriorated waterways along the Nile Delta. The canal suffered from many years of neglect, littering and pollution until it was sanitized and lined at the beginning of 2021 at a cost of ~1.9 million USD. Within few weeks, the local inhabitants littered the regenerated canal (Fig. 2h).

Results showed that there are causal chain relationships between the anthropogenic effects of population growth in the Nile Delta and their associated pressures such as the urban expansion on the decrease of waterways' area (Fig. 3). This situation has generated a rise in wastes and wastewater production from domestic and industrial activities causing increased water pollution and sediment contamination as reflected by the increased heavy metals concentration. Even though there is an increase in the population using an improved sanitation facility, point source control remains insufficient (in 2019 only 66.32 % of the population used proper sanitation systems (The World Bank, 2022) (Fig. 3). Reusch et al. 2018 have reported that tackling point sources of nutrients or contaminations represent the "low hanging fruit" when addressed rapidly and efficiently, which is an essential first step that can lead to considerable environmental improvements, especially under the increased knowledge and accessible technologies.

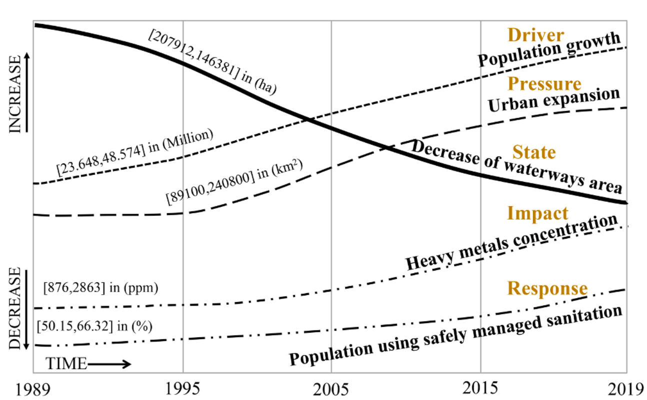


**Fig. 3.** Schematic representation of Driver, Pressure, State, Impact and Response (DPSIR) of the Nile Delta's waterways. Note that plots are not drawn to scale. Driver: Population growth is taken from (CAPMAS, 2015; The World Bank, 2021; CAPMAS, 2017); Pressure and State: Urban expansion and Decease of waterways area, respectively, are taken from (Roest, 1999; Abd-Elmabod et al., 2019; Abd El-kawy et al., 2019; Radwan et al., 2019; Abd El-Hamid, 2020; Elagouz et al., 2020; Ramadan et al., 2021); Impact: Heavy metals concentration is taken from Abd-Elmabod et al. (2019); Radwan et al. (2019); Gu et al. (2013); Radwan et al. (2019); Metwally (2019); Nasr et al. (2015); Galal (2021), and Response is taken from worldbank.org, 2022.

Though, the main reason for the continuous littering and pollution of waterways is the inability of waste management services and infrastructure to keep up with the continuous generation of municipal solid waste, which is exacerbated by population growth rates (Abou Elnasr, 2021). Only circa 60 % of the waste generated is currently collected, and less than 20 % of it is professionally disposed off or recycled. While public spaces in some cities are kept clean, in other parts of the country the situation is problematic. A large part of the total waste is disposed off in canals, rivers, streets, or open areas without any preventive measures to reduce the impacts on the environment. The environmental risks associated with this practice are significant, including water, soil, and air pollution, as well as landscape degradation. There are obvious issues in the legal framework, including the lack of a strategic plan and the unclear division of responsibilities (Fig. 3). Additionally, there is a great need for sustainable investment and services in the waste disposal sector, which is significantly underfunded (NSWMP, 2022).

In Egypt, 8.4 million inhabitants do not have access to improved sanitation, mostly in rural areas. Overall, 10 percent of the Egyptian population, did not benefit from access to improved sanitation, with marked geographical and socio-economic disparities in 2014 (UNICEF, 2017). This adverse public behavior toward waterways results in polluting and clogging several irrigation waterways, further compromising the agricultural activities and endangering public health. Farmers in these impacted areas have to rely on digging costly groundwater wells (Abou Elnasr, 2021) that often suffer from contamination. Moreover, groundwater irrigation does not provide enough nutrients for crops nor replenishes the soil with fertile sediments as do the waterways.

In such a challenging waterscape, improving the landscape quality of these waterways can contribute to their sustainability and connectivity with the community through a network of green/blue infrastructures. This green/blue infrastructure represents a network of green open spaces connected by the waterways resulting in preservation of the Egyptian's threatened natural ecosystem values and functions and providing related benefits to the community, including aesthetic and recreational ones (Benedict et al., 2006). Moreover, the top-down solution will solve the problem only for a short period. If residents' behaviour will not positively change through innovative governance and living labs as social learning spaces and bottom-up engagement processes, the situation will not be sustainably improved. Civil society and NGOs should be more active as neutral moderators organizing public awareness workshops among different stakeholders. Egyptian youth that constitutes the largest portion of the active population (Janischewski, 2021) should be targeted through effective and creative social media campaigns to raise the public awareness on the vulnerability and sustainability of waterways. In this sense, the characteristics of urban green spaces can provide co-benefits and link with societal aspects, such as retaining or developing a sense of place. As shown in the two examined case studies, their design, implementation, and monitoring can provide many opportunities for the involvement or increasing awareness of stakeholders through aspects of interests for many participants and the broader public. Thus, a sense of ownership over their solution can evolve, leading to more acceptance and implementation of measures and potentially overcoming bottlenecks more easily. The successful engagement of civil society, the openness of administrations, the multi-scale and multidisciplinary round tables, the neutral mediation to overcome conflicts and build trust and confidence between the stakeholders are all important factors in creating successful outcomes (Lupp et al., 2020).

In addition, inefficient municipal solid waste management and sewage systems negatively impact current waterways development projects in Egypt. Many villages in the Nile Delta and upper Egypt lack sewage networks and safe municipal solid waste collection systems, which results in a significant proportion of waste that is being disposed in the waterways, including canals and rivers (NSWMP, 2022). Overall, ~10 % of the Egyptian population did not have access to improved sanitation, with marked geographical and socioeconomic disparities in 2014 (UNICEF, 2017). In rural areas, on average, the share of the population without access to adequate sanitation was ~15 % in 2014, compared with ~1 % among urban dwellers. In rural areas lacking access to proper sanitation systems, septic tanks are the most common disposal facility where a limited amount of excreta and sludge water can be collected for biological digestion. The excess digested excreta leaches into the soil surrounding the tanks and hence exposes the shallow groundwater in the Nile aquifer to pollution (Abdel-Shafy, 2002; Hegazy et al., 2020). The MWRI stated 10 procedures to protect the regenerated canals that all are concerned with waste management and enhancing the engagement of city inhabitants and supporting youth initiatives to finance projects in the field of waste collection and recycling through purchasing the necessary equipment and tools, raising public awareness through educational institutes and non-governmental organizations in waste recycling process and water conservation, and low implementation against any violation towards waterbodies including drainage, solid and industrial waste. Unfortunately, the authority did not consider the cultural connection between residents and water streams (MWRI, 2020; Abo Ammra, 2021).

In 2022, Egyptian authorities started their first campaign to forcefully remove informal settlements on the banks of the Nile (Shaker, 2022). The campaign triggered a wide controversy on the demolishing of what was considered historical boathouses and relocation of thousands of inhabitants to alternative housing in new urban development areas tens of kilometer deep inland away from the river. That said, the above steering measures will show positive outcomes on the long run and improved urban and environmental landscape can accelerate and sustain these regeneration procedures as described below.

### *4.3. Toward an environmental regeneration of waterways in Nile Delta*

To achieve sustainable waterway conservation that reduces water evaporation and prevents water pollution, it is important to include environmental landscaping approaches in restoration projects. This approach, known as water-sensitive urban design (WSUD), involves using natural elements such as soil, water, and plants to address environmental, economic, social, and climate concerns. This design integrates water to build healthy and more liveable urban areas, collaborating with nature along the water's edge. The implementation of WSUD is an effective multi-water edge solution that creates social and ecological values along the perimeter of the waterbody, where inhabitants, water, and aquatic wildlife intersect (ADB, 2019) for two reasons. First, landscape-based solutions take the ecological and economical aspects into consideration, but especially the social ones since every city is permanently shaped by social processes and is the result of social progress (Sassen et al., 2016). Second, taking the complexity of the city as a living superorganism into serious consideration, it is short-sighted to regenerate waterways only as technical parts of the blue infrastructure, separately from green infrastructure, since "the structural systems of the environment are complementary and reinforce each other by interdependence, overlay and mutual permeation" (Weilacher, 2016). In this sense, the control of waste collections and management simultaneously with implementing a landscape-based urban regeneration approach is crucial to reconnect control of waste collections and management waterways in the Nile Delta to the complex city structure, based on locally compatible landscape design strategies (Scannell and Gifford, 2014) such as using trees and shrubs that are commonly present in cultivated areas of the Nile Delta (i.e., Tamarix aphylla, Populus nigra and Salix babylonica) drought tolerant, and generally very well adapted to Mediterranean climate conditions (Fig. 4). Moreover, soil restoration is a vital component of nature-based solutions that use the natural environment to address a wide range of environmental, economic, social, and climate challenges. Accordingly, this regeneration approach takes advantage of the natural flow of water to create more livable urban environments (Scottish Government, 2021). Belts of water-conserving and drought tolerant vegetation along the waterways create shadowed areas that help to prevent high flow evaporation, hence contributing to minimizing water budget losses. Moreover, waterscape as a key element in the city's image and the mental map of the inhabitants (Lynch, 1964) consolidates the aesthetic and environmental orientation system and strengthens the social ties of the inhabitants to their city, the local sense of identity, place attachment and social well-being (Georgieva, 2014; ESH, 2018). This will also improve the inhabitants' willingness to preserve the waterways environment, for example by reducing littering. The regenerated landscape along the waterways will provide a wide range of additional ecosystem services and functional benefits, such as direct water access areas for inhabitants. Hence, a multi-disciplinary landscape design solution is required to achieve a sustainable regeneration strategy for the Egyptian waterways. The following two landscape-based design strategies, to be implemented simultaneously, are crucial to successfully integrating the cultural and functional contexts of these waterways. Both strategies are based on the awareness that there are no generally valid standard solutions for integrating water channels into the landscape. Rather, the different local landscape's urban and social context determines the respective planning and design approach. The main aim of both strategies is the combination of social and ecological revalorization methods, sensitive to the cultural context.

The first conceptual design strategy is applied herein along waterways located in the high-density inner-city in the Nile Delta (Figs. 4a and b and c). The reconfiguring of water banks will interweave the city's urban structure with the waterscape, transforming the degraded waterways into a prominent part of the townscape. This results in restoring the sociocultural connectivity of the inhabitants to the Nile and its associated local water bodies through the installation of new recreational spaces along the water sides. These spaces will increase the visibility and accessibility of the waterways. The fluctuation in water level as well as many other changing characteristics of the water body can be locally experienced and appreciated again (Prominski et al., 2017). The seating steps and stairs along the side offer a visual metric of the Nile flow level, promoting inhabitants' water conservation behaviors, especially during droughts. The proposed conceptual design alternatives, as shown in Figs. 4a and b and c, are also based on creating differences in water banks' levels, which are exploited to create distinctive places partially protecting the inhabitants against direct environmental pollution, such as traffic noise, dust, or exhaust emissions. The selection of materials for these linear waterway green connections is based on nationally available resources, and ties in with classic, sustainable building traditions from the region as far as possible. The choice of materials and designs is not only crucial for the ecological and aesthetic quality of the waterscape but also has an influence on the acceptance of the landscape transformation measures by the local population. The second conceptual design solution also aims at the reconsolidation of place attachment by providing outdoor spaces to the inhabitants that can be used on a daily basis.

The proposed landscape design recalls the historic image of the Egyptian unaltered, scenic waterways, with visual attributes that are connected to the nation's golden era of sustainable agricultural development (UNESCO, 2019). This design concept is represented through a landscape-based solution, based on urban forestry, which was one of the main agricultural landscape characteristics along the Nile stream in Egypt. This agriculture-related landscape concept could be implemented

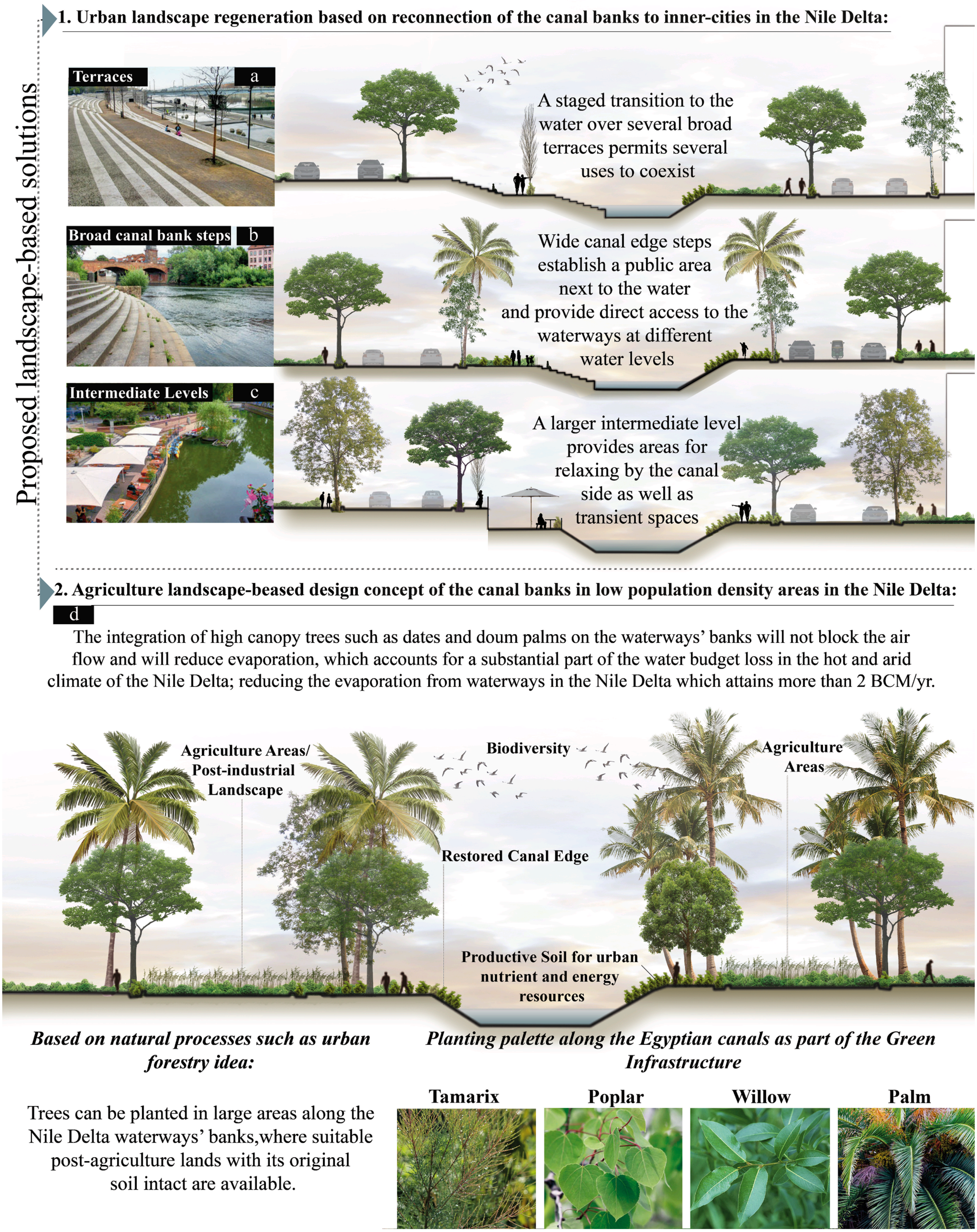


**Fig. 4.** Conceptual design solutions of urban waterways in the Nile Delta based on regeneration of the cultural connection to landscape by integrating natural and urban landscapes; enhancing public interaction with their environment; and consequently, enhancing conservation and environmental protection.

in the post-industrial or agricultural context with low-density residential communities. Throughout human settlements' history along the Nile, doum and date palm forests are locally acknowledged as landmark trees that have been cultivated as part of the natural heritage (Wisser, 2009; Ismail et al., 2016). Accordingly, a conceptual landscape and nature-based design solution is suggested in Fig. 4d focussing on reforestation with drought-tolerant trees and shrubs along the Nile Delta urban canals' banks (Fig. 4d). The implementation of urban forestry will add significant ecosystem services while saving on water treatment costs through the reduction of the cost of maintenance, wildlife corridor provision, and visual diversity creation (UNESCO, 2019). Additionally, urban forestry is considered to be an ecosystem-based adaptation strategy, offering an opportunity to enhance water security, climate-resilient livelihoods and social cohesion, simultaneously (Rodríguez de Francisco et al., 2018). The cultivation of a native and naturalized plant-associated system is an efficient way toward developing a climate-resilient waterways regeneration of the Nile Delta, as the tree canopy minimizes evaporation during droughts and cools the air in increased-temperature periods (Fig. 4d). The integration of high canopy trees such as dates and doum palms on the waterways' banks will not alter the airflow and will reduce evaporation, which accounts for a substantial part of the water budget loss in the hot and arid climate of the Nile Delta. The evaporation from waterways in the Nile Delta alone attains more than 2 BCM/yr (Molle, 2018a) which is on average ~10 % of the nation's intrinsic water budget deficit.

The above amount accounts for ~3.6 % of the Egyptian's share of Nile water. The costs required for adopting an urban forestry improvement to the waterscape in the Nile Delta have been estimated at ~7,210 USD per kilometer (MWRI, 2021); which, considering the length of the waterways network in the Nile Delta of 31,000 km, would roughly require ~0.223 billion USD (Diab, 2022). Yet, it is important to mention that the calculation of landscape-based solution budget is calculated based on a similar project which is implemented in Giza governorate along a petroleum pipeline (Diab, 2022).

On the other hand, water reuse and treatment caused by waterways degradation amount to an annual cost of ~2 billion USD, equivalent to

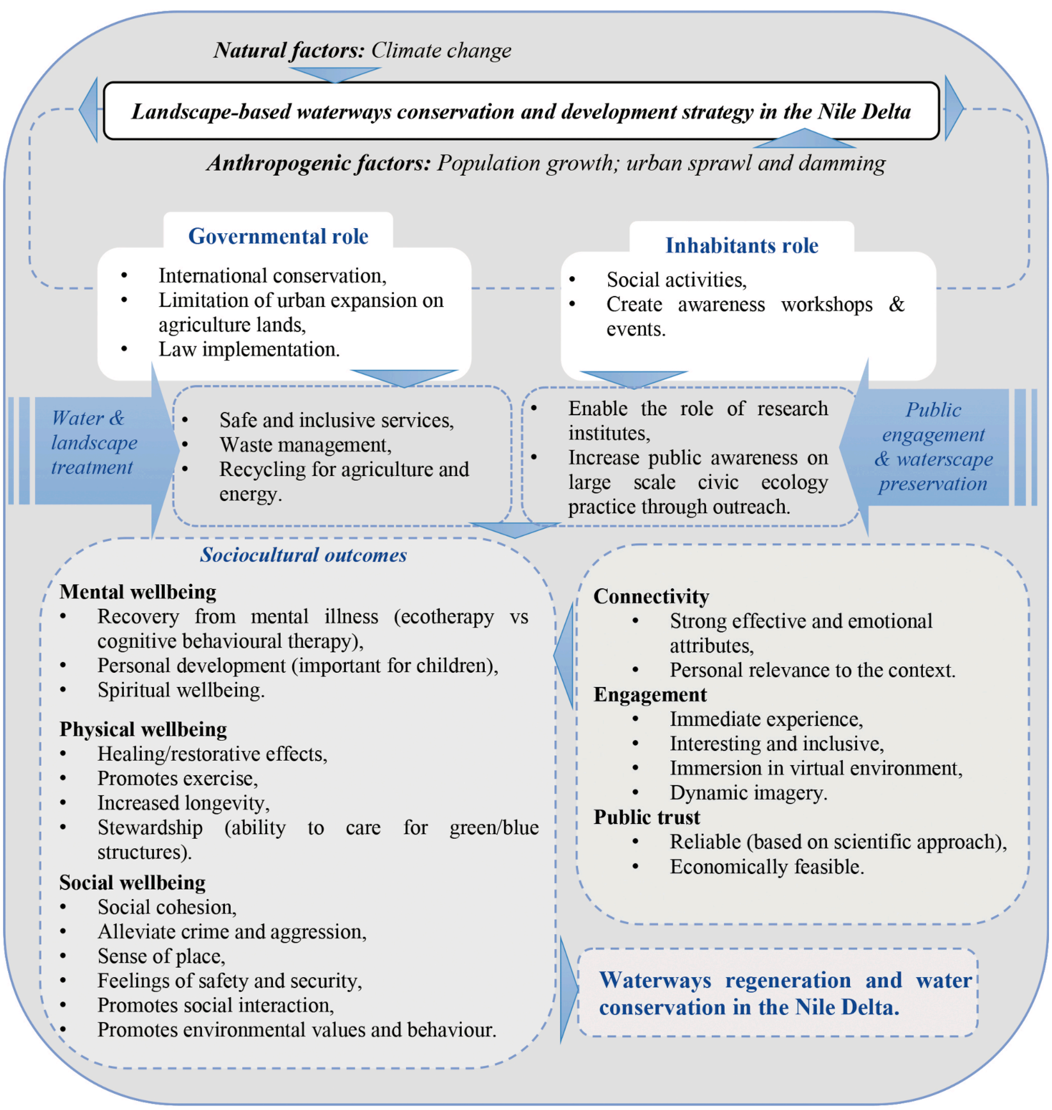


**Fig. 5.** The main factors affecting waterways conservation and development strategy in the Nile Delta. These factors are classified as natural factors, including climate change and environmental drivers; and anthropogenic factors, including unsustainable water consumption patterns associated with high population growth as well as negative impacts of upstream damming along the Nile River. To implement a sustainable waterways regeneration strategy in the Nile Delta, both authority and inhabitants have a crucial role. From the authorial side, the formulation of a framework for sustainable water-related services is an essential part of urban and political policies. However, local engagement through workshops and educational programs is essential for sustaining the waterscape regeneration strategy. The above results in the improved mental, social and physical well-being of the local inhabitants by changing the perception of their natural environment through a cultural landscape solution that simultaneously results in sustainable waterways regeneration and water conservation in the Nile Delta.

1.14 % of the national GDP (Larsen, 2019) a number that is suggested to increase to ~4 billion USD as more treatment for water reuse is planned to address the rising water budget deficit (Abotalib et al., 2022). The above validates the economic importance of implementing an efficient landscape-based solution that within a few years would be a cost-effective solution from both water quality and water budget perspectives and will also carry the benefit of improving the well-being and sanitary conditions of the large population that lives in close vicinity to these waterways in the Nile Delta.

### *4.4. Natural and anthropogenic drivers governing Nile's waterways conservation*

Considering the recently suggested water security strategies to achieve sustainability goals (UNESCO, 2019), the main factors affecting the waterways conservation and development strategy in the Nile Delta are formulated as shown in (Fig. 5). These factors can be classified as natural factors, including climate change related hydrological and environmental drivers, and anthropogenic factors, including unsustainable water consumption patterns associated with the high population growth, the increased informal urban expansion, and the impacts of upstream damming along the Nile River. Therefore, there is an important international governmental role to formulate a sustainable framework of water-related services as an essential part of urban and political policies, taking into account the rising disagreements on water shares that threaten regional socioeconomic sustainability (Varis et al., 2017).

From a local perspective, both governmental bodies and inhabitants are responsible for protecting and developing the vulnerable Egyptian waterways system. Sanitary services, in general, and in rural areas in particular, require more attention from authorities, public and civil societies. Despite some progress being implemented, ~85 % of the rural areas still do not have access to public sanitation networks (Elnidaa, 2019). In her study, Elnidaa (2019) suggests procedural solutions to eliminate the littering problem in the Nile waterways. First, developing environmental protection strategies for waterways, agricultural land, and housing environments for rural populations, synchronizing the provision of sanitation services with other environmental protection activities. Second, the overall cost of failing to solve sanitation provision issues should be considered when allocating public investment to projects within the sector. This will result in the conservation of waterways by providing sufficient alternatives for waste and sewage disposal. Finally, there is a need to raise public awareness of the environmental implications of poor sanitation in order to improve hygiene. This can be implemented through educational programs to clarify the minor behavioural changes that can highly impact both, community health and the environment. It is important to note that the inhabitant behavior is not the only source of the littering problem, the local authorities share their part of the responsibility to make littering disposal available and accessible, which is not yet observed in rural areas and in urban sprawls. Furthermore, the garbage collection system should be monitored in areas where illegal dumping in the Nile is observed to increase. The latter is the first step to addressing the littering problem, which is observed nationally on a larger scale beyond the waterways and is expanding to newly developed modern cities with high standards of living (Riad et al., 2020).

The above-mentioned approaches are supported by the International Hydrological Program (IHP) of the United Nations, which is devoted to enhancing scientific, managerial and cultural water matters (UNESCO, 2019). As described above, this collaborative management approach will be based on the community's socioeconomic demands implemented through a proactive unified stakeholders' vision, and thus will lead to the conservation and upgrading of the existing blue and green infrastructures. However, the suggested strategy (Fig. 5) requires creative water management plans to secure the needs and goals of different stakeholders. The physical development of waterways should be part of a socioeconomic regeneration process, enhancing the quality of life to guarantee sustainable landscape-based development, and strengthening the natural life support system in the urban environment.

## 5. Conclusions and recommendations

Waterways have a crucial role in water management, agricultural development, and ecosystem services within the highly vulnerable Nile Delta. However, today they are facing continuous degradation resulting from several anthropogenic factors, mostly those associated with unsustainable and accelerated urban expansion. In its current state, the observed degradation in waterways system in the Nile Delta, are mainly associated with the socioeconomic shifts and the extension of urban sprawl over agricultural areas and landscape deterioration that both have resulted in changing the public perception of the waterways functionality from irrigation canals to sewage.

The public misperception combined with the absence of effective sanitation and waste management systems, especially in rural areas, have aggravated the situation and triggered intensive dumping and littering, leading to a rapid and intensive degradation of the sanitary conditions of the waterways and their surrounding areas. In response, contaminated waterways are being constantly landfilled as a sanitary mitigating measure. The above resulted in a decrease in their surface area in the Nile Delta by ~30 % from 1987 to 2019. Though, alternatives should be created and supported, but also social engagement and public awareness processes should be reinforced simultaneously to achieve a better result in the environmental status of the Nile Delta and reduce its fast degradation trajectory benefiting from experiences of other river basins such as the Elbe river basin in Germany (Wachholz et al., 2022) and the Baltic Sea system (Reusch et al., 2018).

Our findings suggest that implementing multi-disciplinary landscape management, inspired by nature-based solutions, and prioritizing the multi-functionality of the waterways, is crucial to achieving a sustainable regeneration strategy for Egyptian waterbodies. The first conceptual design strategy is suggested along waterways in the high-density inner city, reconfiguring the water banks to regenerate the sociocultural connectivity of inhabitants to local water bodies through the installation of new social activities. The second conceptual design strategy is based on Egypt's natural heritage scenery from the nation's pre-industrial era of sustainable agricultural development. This scenery is reproduced through landscape solutions based on urban forestry, one of the main agricultural landscape characteristics along the Nile stream in Egypt, to be implemented in low-density residential communities. These drought-tolerant forests include doum and date palms, which are part of the country's natural heritage. Both solutions not only support the reconnection of the inhabitants with their living environment but also provide efficient paths toward developing climate-resilient waterways and landscape regeneration of the Nile Delta, as they create shadowed areas that minimize evaporation. The above can contribute to reducing the water budget deficit in Egypt by ~11 % as shown in the discussion section (4.3).

The costs required for adopting the above-described landscape-based regeneration for the Nile Delta waterways areapproximately assessed using a first order model at ~0.223 billion USD, which represent ~4% of the total cost of the planned waterways lining of ~5 billion USD. which will make these investments more sustainable. The above expenditure validates the efficiency of landscape solutions, considering the 2 billion USD spent annually on addressing waterways contamination resulting from degradations. Furthermore, the proposed nature-based landscape solutions will also improve the well-being and sanitary conditions of the large population of the Nile Delta that lives in close vicinity to these waterways and will restore their cultural attachment to these water bodies favouring their conservation, enabling their role in water conservation and agricultural development.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

## Acknowledgment

The research carried out herein benefited from the support of the Alexander Von Humboldt Foundation in Germany and the Zumberge Innovation Fund at the University of Southern California. Part of this research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA) (OASIS-USC-00630).

## References

Abd El-Hamid, H.T., 2020. Geospatial analyses for assessing the driving forces of land use/land cover dynamics around the Nile Delta Branches, Egypt. *J. Indian Soc. Remote Sens.* 48 (12), 1661–1674. http://dx.doi:10.1007/s12524-020-01189-2.

Abd El-kawy, O.R., Ismail, H.A., Yehia, H.M., Allam, M.A., 2019. Temporal detection and prediction of agricultural land consumption by urbanization using remote sensing. Egypt. J. Remote Sens. Space Sci. 22 (3), 237–246. http://dx.doi:10.1016/j.ejrs.2019.05.001.

Abd-Elaty, I., Pugliese, L., Bali, K.M., Grismer, M.E., Eltarabily, M.G., 2022. Modelling the impact of lining and covering irrigation canals on underlying groundwater stores in the Nile Delta, Egypt. *Hydrol. Process.* 36 (1), e14466. http://dx.doi:10.1002/hyp.14466.

Abd-Elaziz, S., Zeleňáková, M., Mésároš, P., Purcz, P., Abd-Elhamid, H.F., 2020. Anthropogenic Activity Effects on Canals Morphology, Case Study: Nile Delta, Egypt. *Water* 12, 3184. http://dx.doi:10.3390/w12113184.

Abd-Elmabod, S.K., Fitch, A.C., Zhang, Z., Ali, R.R., Jones, L., 2019. Rapid urbanisation threatens fertile agricultural land and soil carbon in the Nile delta. J. Environ. Manage. 252, 109668. http://dx.doi:10.1016/j.jenvman.2019.109668.

Abdelmohsen, K., Sultan, M., Save, H., Abotalib, A.Z., Yan, E., 2020. What can the GRACE seasonal cycle tell us about lake-aquifer interactions? Earth Sci. Rev. 211, 103392. http://dx.doi:10.1016/j.earscirev.2020.103392.

Abdelmohsen, K., Sultan, M., Save, H., Abotalib, A.Z., Yan, E., Zahran, K.H., 2022. Buffering the impacts of extreme climate variability in the highly engineered Tigris Euphrates river system. Sci. Rep. 12 (1), 4178. http://dx.doi:10.1038/s41598-022-07891-0.

Abdel-Satar, A.M., Ali, M.H., Goher, M.E., 2017. Indices of water quality and metal pollution of Nile River, Egypt. *Egypt. J. Aquatic Res.* 43 (1), 21–29. http://dx.doi:10.1016/j.ejar.2016.12.006.

Abdel-Shafy, H., 2002. Water issue in Egypt: Resources, pollution and protection endeavors. Central Eur. J. Med. 8, 1–21.

Abdelwahab, H.F., Ramadan, E.M., Negm, A.M., 2020. Modeling in Water Resources Management in East Nile Delta: Review. Acta Marisiensis. Seria Technologica 17 (2), 41–46. http://dx.doi:10.2478/amset-2020-0018.

Abd-Elziz, S., Zelenakova, M., Kršák, B., Abd-Elhamid, H., 2022. Spatial and Temporal Effects of Irrigation Canals Rehabilitation on the Land and Crop Yields, a Case Study: The Nile Delta, Egypt. *Water* 14, 808. http://dx.doi:10.3390/w14050808.

Abo Ammra, M., 2021. Learn about the government's measures to prevent the phenomenon of dumping garbage in the lined canals. Elwatan News.

Abotalib, A.Z., Abdelhady, A.A., Heggy, E., Salem, S.G., Ismail, E., Ali, A., & Khalil, M.M. (2022). Irreversible and Large-Scale Heavy Metal Pollution Arising from Increased Damming and Water Reuse in the Nile Delta, [Paper # 2022EF002987]). Earth's future.

Abotalib, A.Z., Heggy, E., El Bastawesy, M., Ismail, E., Gad, A., Attwa, M., 2021. Groundwater mounding: A diagnostic feature for mapping aquifer connectivity in hyper-arid deserts. Sci. Total Environ. 801, 149760. http://dx.doi:10.1016/j.scitotenv.2021.149760.

Abou Elnasr, A.M., 2021. The inhabitants of Badrashin, on the authority of "Al-Aziziyah Canal": It was the source of epidemics and polluting it is an irresponsible act. Elwatan News.

Arden, S., Jawitz, J., 2019. The evolution of urban water systems: societal needs, institutional complexities, and resource costs. Urban Water J. 16, 1–11. http://dx.doi:10.1080/1573062X.2019.1634109.

Attwa, M., el bastawesy, M., Ragab, D., Othman, A., Assaggaf, H., Abotalib, A., 2021. Toward an Integrated and Sustainable Water Resources Management in Structurally-Controlled Watersheds in Desert Environments Using Geophysical and Remote Sensing Methods. Sustainability 13, 4004. https://doi.org/10.3390/su13074004.

Assar, W., Ibrahim, M.G., Mahmod, W., Fujii, M., 2019. Assessing the Agricultural Drainage Water with Water Quality Indices in the El-Salam Canal Mega Project, Egypt. Water 11 (5), 1013. https://doi.org/10.3390/w11051013.

Barnes, J., 2012. Expanding the Nile's Watershed: The Science and Politics of Land Reclamation in Egypt. Water on Sand: Environmental Histories of the Middle East and North Africa. Oxford University Press, Oxford, https://doi.org/10.1093/acprof:oso/9780199768677.003.0011.

Bekhit, H., 2019. The recently developed Egyptian proposal for filling and operation of the GERD. Paper presented at the Cairo Water Week, Cairo, Egypt.

Benameur, T., Benameur, N., Saidi, N., Tartag, S., Sayad, H., Agouni, A., 2021. Predicting factors of public awareness and perception about the quality, safety of drinking water, and pollution incidents. Environ. Monit. Assess. 194 (1), 22. https://doi.org/10.1007/s10661-021-09557-2.

Benedict, M., McMahon, E., Fund, T., & Bergen, L. (2006). Green Infrastructure: Linking Landscapes and Communities. Bibliovault OAI Repository, the University of Chicago Press, 22, 1-12.

Brown, G., Raymond, C., 2007. The relationship between place attachment and landscape values: Toward mapping place attachment. Appl. Geogr. 27 (2), 89–111. http://dx.doi:10.1016/j.apgeog.2006.11.002.

Cauberghe, V., Vazquez-Casaubon, E., Van de Sompel, D., 2021. Perceptions of water as commodity or uniqueness? The role of water value, scarcity concern and moral obligation on conservation behavior. J. Environ. Manage. 292, 112677. http://dx.doi:10.1016/j.jenvman.2021.112677.

Central Agency for Public Mobilization and Statistics (CAPMAS). (2015). Egypt in figures (environmental monitoring centre). CAPMAS.

Central Agency for Public Mobilization and Statistics (CAPMAS). (2017). Egypt in figures (environmental monitoring centre). CAPMAS.

Coffel, E.D., Keith, B., Lesk, C., Horton, R.M., Bower, E., Lee, J., Mankin, J.S., 2019. Future hot and dry years worsen Nile basin water scarcity despite projected precipitation increases. Earth's Future 7 (8), 967–977. http://dx.doi:10.1029/2019EF001247.

Cole, M.A., Rayner, A.J., Bates, J.M., 1997. The environmental Kuznets curve: an empirical analysis. Retrieved from Environ. Dev. Econ. 2 (4), 401–416. http://www.jstor.org/stable/44379185.

Cox, P., Friedman, B., Iii, T., 2011. Relationships among cultural dimensions, national gross domestic product, and environmental sustainability. J. Appl. Business Econ. 12, 46–56.

Daef, M., 1986. The impact of open door policy on public service provision in urban areas of Egypt: A major factor influencing income distribution since 1974. Development Planning Unit, Univ. Coll.

Dakkak, A., 2021. Water Crisis in Egypt and Degeneration of the Nile. Retrieved April 24, 2022, from https://www.ecomena.org/egypt-nile/.

Dayrit, H., 2022. The philippines: Formulation of a national water vision - hector dayrit. from https://www.fao.org/3/ab776e/ab776e03.htm. [Accessed in: Oct, 2022].

de Haan, F.J., Ferguson, B.C., Adamowicz, R.C., Johnstone, P., Brown, R.R., Wong, T.H. F., 2014. The needs of society: A new understanding of transitions, sustainability and liveability. Technol. Forecast. Soc. Chang. 85, 121–132. http://dx.doi:10.1016/j.techfore.2013.09.005.

Dessalegn, B., Abd-Allah, E., Salem, S., Swelam, A., Yigezu, Y., 2022. Explaining shifts in adaptive water management using a gendered multi-level perspective (MLP): a case study from the Nile Delta of Egypt. Int. J. Agric. Sustain. 1, 1–18. http://dx.doi:10.1080/14735903.2022.2082765.

Diab, M. (2022). At a cost of 40 million pounds. Afforestation and cultivation of the Somid petroleum line in October Gardens. From https://www.elaosboa.com/356989/. [Accessed in: Aug, 2022].

Dolman, N., 2021. Integration of water management and urban design for climate resilient cities. In R. Dinther (Ed.), Climate Resilient Urban Areas (p.p. 21-43). Palgrave Macmillan.

Dopico, E., Arboleya, E., Fernandez, S., Borrell, Y., Consuegra, S., de Leaniz, C.G., Garcia-Vazquez, E., 2022. Water security determines social attitudes about dams and reservoirs in South Europe. Sci. Rep. 12 (1), 6148. http://dx.doi:10.1038/s41598-022-10170-7.

El Baradei, S.A., Al Sadeq, M., 2019. Optimum coverage of irrigation canals to minimize evaporation and maximize dissolved oxygen concentration: case study of Toshka, Egypt. *Int. J. Environ. Sci. Technol.* 16 (8), 4223–4230. http://dx.doi:10.1007/s13762-018-2010-6.

El Shazly, M.M., 2019. The impact of some anthropogenic activities on river Nile Delta wetland ecosystems. Global J. Ecol. 4 (1), 1–9.

El-Agha, D.E., Molden, D.J., Ghanem, A.M., 2011. Performance assessment of irrigation water management in old lands of the Nile delta of Egypt. Irrigat. Drainage Syst. 25 (4), 215–236. http://dx.doi:10.1007/s10795-011-9116-z.

Elagouz, M.H., Abou-Shleel, S.M., Belal, A.A., El-Mohandes, M.A.O., 2020. Detection of land use/cover change in Egyptian Nile Delta using remote sensing. Egypt. J. Remote Sens. Space Sci. 23 (1), 57–62. http://dx.doi:10.1016/j.ejrs.2018.10.004.

El-Nahry, A.H., Abdel Kawy, W.A.M., 2013. Sustainable landuse management on the coastal zone of the Nile Delta, Egypt. *J. Land Use Sci.* 8 (1), 85–103. http://dx.doi:10.1080/1747423X.2011.620994.

Elnidaa, 2019. Rural Sanitation in Egypt. from https://elnidaa.org/app/uploads/2019/07/PB10_rural_sanitation.pdf. [Accessed in: Aug, 2022].

Elnmer, A., Khadr, M., & Zeidan, B.A. (2015). Optimal water production of crop patterns in Central Nile Delta, Egypt. Paper presented at the Eighteen International Water Technology conference IWTCL 8, Sharon El Sheihala 12-14 March 2015.

El-Ramady, H., El-Marsafawy, S., & Lewis, L., 2013. Sustainable Agriculture and Climate Changes in Egypt. In E. Lichtfouse (Ed.), Sustainable Agriculture Reviews (p.p. 41-95). Springer.

El-Saadawy, O., Gaber, A., Othman, A., Abotalib, A.Z., El Bastawesy, M., Attwa, M., 2020. Modeling flash floods and induced recharge into alluvial aquifers using multi-temporal remote sensing and electrical resistivity imaging. Sustainability 12 (23), 10204. http://dx.doi:10.3390/su122310204.

Elsahy, M. (2021). From a random aesthetic appearance, the full story of the pollution of the Azizia Canal in Badrashin after lining it. Retrieved 7 May, 2022, from https://www.elbalad.news/4726262.
Enterprise, 2020. Counting the costs of the govt's USD 50 bn water-saving plan. Retrieved 5 May, 2022, from https://enterprise.press/stories/2020/01/22/counting-the-costs-of-the-govts-usd-50-bn-water-saving-plan-10425/.
Environmental Stewardship for Health, 2018. Re-connecting to landscape and reviving the sense of belonging. Retrieved 6 April, 2022, from https://citieshealth.world/re-connecting-landscape-reviving-sense-belonging/.
Food and Agriculture Organization of the United Nations (FAO), 2016. *AQUASTAT Country Profile – Egypt. Water Resources Factsheet* FAO.
Food and agriculture Organization of the United Nations (FAO). (2017). *National Water Resources Plan 2017*. FAO.
Gad, A., 2008. Water culture in Egypt. Water Culture and Water Conflict in the Mediterranean Area 1, 85–96.
Galal, S., 2021. Poverty rate based on national poverty line in Egypt from 1999 to 2018. from https://www.statista.com/statistics/1237051/poverty-rate-national-line-in-egypt/. [Accessed in: Oct, 2022].
Garcier, R., 2007. Rivers we can't bring ourselves to clean–historical insights into the pollution of the Moselle River (France), 1850–2000. Hydrol. Earth Syst. Sci. 11 (6), 1731–1745.
Georgieva, A., 2014. *Riverbanks redevelopment through sustainable landscape principles-A proposal for the banks of the Havel river in Berlin, Germany* (Master Thesis). Stitutionen För Arkitektur. Chalmers University of Technology.
Gouda, A.A., Hosseini, M., Masoumi, H., 2016. The Status of Urban and Suburban Sprawl in Egypt and Iran. GeoScape 10, 1–15. http://dx.doi:10.1515/geosc-2016-0001.
GreenCOM. (2000). Egypt: Public Awareness on Water Scarcity. from https://rmportal.net/library/content/usaid-greencom/greencom-case-studies/egypt-public-awareness-on-water-scarcity/at_download/file. Accessed March 11, 2022.
Gu, J., Salem, A., Chen, Z., 2013. Lagoons of the Nile delta, Egypt, heavy metal sink: with a special reference to the Yangtze estuary of China. Estuar. Coast. Shelf Sci. 117, 282–292.
Hamza, W. (2009). The Nile Delta. In H. J. Dumont (Ed.), *The Nile. Monographiae Biologicae, vol 89*. Springer.
Haug, B., 2021. Civilizing the Past: Egyptian Irrigation in the Colonial Imagination. J. Egypt. History 14 (1), 59–102. http://dx.doi:10.1163/18741665-12340071.
Hegazy, D., Abotalib, A.Z., El-Bastaweesy, M., El-Said, M.A., Melegy, A., Garamoon, H., 2020. Geo-environmental impacts of hydrogeological setting and anthropogenic activities on water quality in the Quaternary aquifer southeast of the Nile Delta, Egypt. *J. Afr. Earth Sci.* 172, 103947. http://dx.doi:10.1016/j.jafrearsci.2020.103947.
Heggy, E., Sharkawy, Z., Abotalib, A.Z., 2021. Egypt's water budget deficit and suggested mitigation policies for the Grand Ethiopian Renaissance Dam filling scenarios. Environ. Res. Lett. 16 (7), 074022. http://dx.doi:10.1088/1748-9326/ac0ac9.
Heliodorus, E., 1895. An Æthiopian History written by Heliodorus/ Translated by Thomas Underdowne, anno 1587. Charles Whibley, David Nutt.
Hirabayashi, Y., Kanae, S., Emori, S., Oki, T., Kimoto, M., 2008. Global projections of changing risks of floods and droughts in a changing climate. Hydrol. Sci. J. 53 (4), 754–772. http://dx.doi:10.1623/hysj.53.4.754.
Hmdan, G., 1967. Egypt's Identity. Dar el-Helal. Publications.
Ikram, K., 1980. Egypt: Economic Management in a Period of Transition. University Press, The Johns Hopkins.
Greener Waterway Infrastructure (Green WIN). (2021). Nine ways canals can fight climate change. from https://www.nweurope.eu/projects/project-search/greenwin-greener-waterway-infrastructure/news/nine-ways-canals-can-fight-climate-change/.
Ismail, A.A., Mosleh, S.M., Weshahy, E., 2016. Doum-palm in ancient Egypt. J. Assoc. Arab Univ. Tourism Hospitality 13 (1), 1–20.
Jackson, J.B., 1984. Discovering the Vernacular Landscape. Yale UP, New Haven.
Janischewski, K., 2021. Multi-Stakeholder Dialogue and Cooperation Approaches for Employment Services: Key characteristics and selected case studies from Africa. MENA region and Europe. Case Compilation, Global Initiative on Innovative.
Keleg, M., Butina Watson, G., Salheen, M.A., 2021. The path to resilience: Change, landscape aesthetics, and socio-cultural identity in rapidly urbanising contexts. The case of Cairo, Egypt. Urban For. Urban Greening 65, 127360. http://dx.doi:10.1016/j.ufug.2021.127360.
Khadr, M., Ziedn, B.A., Elnmer, A., 2017. On farm water management in the Nile Delta. In: Negm, A.M. (Ed.), The Nile Delta. Springer Press.
Khalil, A.A., Essa, Y.H., Hassanein, M.K., 2014. Monitoring agricultural land degradation in Egypt using MODIS NDVI satellite images. Nat. Sci. 12 (8), 15–21.
Khalil, M.M., Hamer, K., Pichler, T., Abotalib, A.Z., 2021a. Fault zone hydrogeology in arid environments: The origin of cold springs in the Wadi Araba Basin, Egypt. *Hydrol. Process.* 35 (5), e14176. http://dx.doi:10.1002/hyp.14176.
Khalil, M.M., Tokunaga, T., Heggy, E., Abotalib, A.Z., 2021b. Groundwater mixing in shallow aquifers stressed by land cover/land use changes under hyper-arid conditions. J. Hydrol. 598, 126245. http://dx.doi:10.1016/j.jhydrol.2021.126245.
Kotb, K.M., Elkadeem, M.R., Khalil, A., Imam, S.M., Hamada, M.A., Sharshir, S.W., Dán, A., 2021. A fuzzy decision-making model for optimal design of solar, wind, diesel-based RO desalination integrating flow-battery and pumped-hydro storage: Case study in Baltim, Egypt. *Energy Convers. Managem.* 235, 113962. http://dx.doi:10.1016/j.enconman.2021.113962.
Kwasi, s., Cilliers, J., Yeboua, K., 2022. Race to sustainability? Egypt's challenges and opportunities to 2050. https://www.africaportal.org/documents/22413/nar-7.pdf.
Larsen, B., 2019. Arab Republic of Egypt – Cost of Environmental Degradation: Air and Water Pollution. World Bank.
Lundberg, C., 2005. Conceptualizing the Baltic Sea Ecosystem: An interdisciplinary tool for environmental decision making. J. Hum. Environ. 34 (6), 433–439.
Lupp, G., Zingraff-Hamed, A., Huang, J., Oen, A., Pauleit, S., 2020. Living Labs-A concept for co-designing nature-base solutions. Sustainability 13, 1–22. http://dx.doi:10.3390/su13010188.
Lynch, K., 1964. The image of the city. MIT press.
Magoum, I. (2021). EGYPT: CBE and EBA to mobilize $3 billion to upgrade irrigation systems. Retrieved June 15, 2021, from https://www.afrik21.africa/en/egypt-cbe-and-eba-to-mobilize-3-billion-to-upgrade-irrigation-systems/.
Maslow, A.H., 1943. A theory of human motivation. Psychol. Rev. 50, 370–396.
Mazzoni, A., Heggy, E., Scabbia, G., 2018. Forecasting water budget deficits and groundwater depletion in the main fossil aquifer systems in North Africa and the Arabian Peninsula. Global Environ. Change 53, 157–173. http://dx.doi:10.1016/j.gloenvcha.2018.09.009.
Metwally, M.-E.-B.-H., 2019. A Study of Heavy Metals Contamination in the Agricultural Soils along the Highway between Damietta and Cairo in the Nile Delta, Egypt. *Sciences* 9 (01), 125–133.
Meybeck, M., Helmer, R., 1989. The quality of rivers: From pristine stage to global pollution. Palaeogeogr. Palaeoclimatol. Palaeoecol. 75 (4), 283–309. http://dx.doi:10.1016/0031-0182(89)90191-0.
Minister of Planning and Economic Development. (2020). Minister of planning approves egp 750 million for the national canal lining, rehabilitation project. from https://mped.gov.eg/singlenews?id=330&type=next&lang=en. [Accessed in: Oct, 2022].
Ministry of Water Resources and Irrigation (MWRI). (2020). *Continuing to address the violation forms on the canals networks*. MWRI.
Ministry of Water Resources and Irrigation (MWRI). (2021). Retrieved June 16, from https://geoportal.mwri.gov.eg/portal/home/.
Molle, F., Gaafar, I., El-Agha, D.E., Rap, E., 2018. The Nile delta's water and salt balances and implications for management. Agric. Water Manag. 197, 110–121. http://dx.doi:10.1016/j.agwat.2017.11.016.
Molle, F., Rap, E., Al-Agha, D.E., El Hassan, W.A., Freeg, M., 2019. Irrigation improvement projects in the Nile Delta: Promises, challenges, surprises. Agric. Water Manag. 216, 425–435. http://dx.doi:10.1016/j.agwat.2019.02.013.
Molle, F. (2018a). Irrigation policies in Egypt since the construction of the High Aswan Dam. Montpellier.
Morsy, K.M., Mishra, A.K., Galal, M.M., 2020. Water quality assessment of the Nile Delta Lagoons, 1178622120963072 Air, Soil Water Res. 13. http://dx.doi:10.1177/1178622120963072.
Mostafa, K., Allam, M., El-Fiky, S., Issa, S., Mohyeldeen, S., 2021. Water Security in Egypt: Issues and perspectives. The American University in Cairo, A policy paper.
Nadim, N.N., Mehanna, S., Nixon, J., 1980. Living Without Water, Vol. 3, Monograph 3. The American University in Cairo.
Nasr, S.M., Soliman, N.F., Khairy, M.A., Okbah, M.A., 2015. Metals bioavailability in surface sediments off Nile delta, Egypt: Application of acid leachable metals and sequential extraction techniques. Environ Monit Assess 187 (6), 312. http://dx.doi:10.1007/s10661-015-4548-9.
National Solid Waste Management Programme (NSWMP). (2022). Improving waste management in Egypt. Retrieved May 11, 2022, from https://www.giz.de/en/worldwide/22230.html.
Nikiel, C.A., Eltahir, E.A.B., 2021. Past and future trends of Egypt's water consumption and its sources. Nat. Commun. 12 (1), 4508. http://dx.doi:10.1038/s41467-021-24747-9.
Nile Basin Water Resources Atlas. (2022). Estimated and projected total population in Nile Basin Countries. Retrieved May 11, 2022, from https://atlas.nilebasin.org/treatise/estimated-and-projected-total-population-in-nile-basin-countries/.
Oestigaard, T., 2018. The Religious Nile: Water. Ritual and Society Since Ancient Egypt, Bloomsbury Publishing.
Omar, M.E.D.M., Moussa, A.M.A., 2016. Water management in Egypt for facing the future challenges. J. Adv. Res. 7 (3), 403–412. http://dx.doi:10.1016/j.jare.2016.02.005.
Organisation of Economic Co-operation and Development (OECD). (2003). *Environmental Indicators – Development, Measurement and Use*. OECD.
Othman, A.A., Rabeh, S.A., Fayez, M., Monib, M., Hegazi, N.A., 2012. El-Salam canal is a potential project reusing the Nile Delta drainage water for Sinai desert agriculture: Microbial and chemical water quality. J. Adv. Res. 3 (2), 99–108. http://dx.doi:10.1016/j.jare.2011.04.003.
Ouda, M., Kadadou, D., Swaidan, B., Al-Othman, A., Al-Asheh, S., Banat, F., Hasan, S.W., 2021. Emerging contaminants in the water bodies of the Middle East and North Africa (MENA): A critical review. Sci. Total Environ. 754, 142177. http://dx.doi:10.1016/j.scitotenv.2020.142177.
Prominski, M., Stokman, A., Stimberg, D., Voermanek, H., Zeller, S., Bajc, K., 2017. *River. Space. Design: Planning Strategies, Methods and Projects for Urban Rivers*, (2nd ed.). Birkhäuser.
Radwan, T., Blackburn, G., Whyatt, D., Atkinson, P., 2019. Dramatic Loss of Agricultural Land Due to Urban Expansion Threatens Food Security in the Nile Delta. Egypt. *Remote Sensing* 11, 332. http://dx.doi:10.3390/rs11030332.
Ramadan, E., Abdelwahab, F., H., Vranayova, Z., Zelenakova, M., & Negm, A., 2021. Optimization-Based Proposed Solution for Water Shortage Problems: A Case Study in the Ismailia Canal, East Nile Delta. Egypt. *Water* 13, 2481. http://dx.doi:10.3390/w13182481.
Oxford Business Group (OBG), (2020). How irrigation will help Egypt ensure water security. from https://oxfordbusinessgroup.com/analysis/low-tide-modernised-irrigation-systems-and-desalination-plants-are-central-efforts-ensure-water.
Rashad, J. (2018). Opinion: The world's longest river is in trouble. Retrieved Apil 12, 2022, from https://www.washingtonpost.com/news/theworldpost/wp/2018/03/22/egypt/.

Rateb, A., Abotalib, A.Z., 2020. Inferencing the land subsidence in the Nile Delta using Sentinel-1 satellites and GPS between 2015 and 2019. Sci. Total Environ. 729, 138868. http://dx.doi:10.1016/j.scitotenv.2020.138868.
Redeker, C., Kantoush, S., 2014. The Nile Delta: urbanizing on diminishing resources. Built Environ. 40 (2), 201–212. http://dx.doi:10.2148/benv.40.2.201.
Reed, M., Buckmaster, S., 2015. Public perceptions and behaviors towards the water environment Lessons for theory. communication and action, WWF.
Reusch, T.B.H., Dierking, J., Andersson, H.C., Bonsdorff, E., Carstensen, J., Casini, M., Zandersen, M., 2018. The Baltic Sea as a time machine for the future coastal ocean. Sci. Adv. 4 (5), eaar8195. http://dx.doi:10.1126/sciadv.aar8195.
Riad, P., Graefe, S., Hussein, H., Buerkert, A., 2020. Landscape transformation processes in two large and two small cities in Egypt and Jordan over the last five decades using remote sensing data. Landscape Urban Plann. 197, 103766. http://dx.doi:10.1016/j.landurbplan.2020.103766.
Richards, A., 1980. Egypt's Agriculture in Trouble. Middle East Report 84, 3–13. http://dx.doi:10.2307/3011462.
Rodríguez de Francisco, J.C., Schoderer, M., Richerzhagen, C., 2018. World water day 2018. Water security and ecosystem-based adaptation to climate change, German Development Institute.
Roest, C., 1999. Regional water distribution in the Nile Delta of Egypt. Paper Presented at the Proceedings of the Wageningen Water Workshop.
Sassen, S., Pieterse, E., Bhan, G., Hirsh, M., Falu, A., Ichikawa, H., Tarchopulos, D., 2016. Chapter 5 –. Cities and Social Progress. International Panel on Social Progress.
Scannell, L., Gifford, R., 2014. The psychology of place attachment. Optimal Books.
Scottish Government. (2021). Consultation on National Litter and Flytipping Strategy Strategic Environmental Assessment Environmental Report. from https://www.gov.scot/publications/national-litter-flytipping-consultation-strategic-environmental-assessment/. [Accessed in: Oct, 2022].
Shabaka, S., Moawad, M.N., Ibrahim, M.I.A., El-Sayed, A.A.M., Ghobashy, M.M., Hamouda, A.Z., Youssef, N.A.E., 2022. Prevalence and risk assessment of microplastics in the Nile Delta estuaries: "The Plastic Nile" revisited. Sci. Total Environ. 852, 158446. http://dx.doi:10.1016/j.scitotenv.2022.158446.
Shaker, N. (2022). Egyptian government plans demolition of Nile's historic houseboats. from https://www.al-monitor.com/originals/2022/07/egyptian-government-plans-demolition-niles-historic-houseboats. [Accessed in: Sep, 2022].
Siculus, D., Oldfather, C.H., Sherman, C.L., Welles, C.B., Bradford, C., Geer, R.M., Walton, F.R., 1947. Diodorus of Sicily, with an English Translation by CH Oldfather. Harvard University Press.
Smeets, E., & Weterings, R., (1999). Environmental indicators: Typology and overview. European Environmental Agency (Technical Report).
Smith, S.E., 1986. General impacts of Aswan High Dam. J. Water Resour. Plann. Manage. 122 (4), 551–562.
Tahoon, K., 2020. Urban growth characteristics of informal riverfront settlements in Egypt. J. Eng. Appl. Sci. 67 (7), 1649–1667.
Takouleu, J.W. (2022). EGYPT: Lining irrigation canals to save 5 billion $m^3$ of water. Retrieved June 17, 2022, from https://www.afrik21.africa/en/egypt-lining-irrigation-canals-to-save-5-billion-m%C2%B3-of-water/.
Tang, L., Koveos, P., 2008. A framework to update hofstede's cultural value indices: economic dynamics and institutional stability. J. Int. Business Stud. 39, 1045–1063. http://dx.doi:10.1057/palgrave.jibs.8400399.
Tawfik, M.H., Hoogesteger, J., Elmahdi, A., Hellegers, P., 2021. Unpacking wastewater reuse arrangements through a new framework: insights from the analysis of Egypt. Water Int. 46 (4), 605–625. http://dx.doi:10.1080/02508060.2021.1921503.
Tayia, A., Ramos Barrado, A., Alonso Guinea, F., 2021. The evolution of the Nile regulatory regime: a history of cooperation and conflict. Water History 13 (3), 293–317. http://dx.doi:10.1007/s12685-021-00287-3.
Terwisscha van Scheltinga, C., de Miguel Garcia, A., Wilbers, G.-J., Heesmans, H., Dankers, R., Smaling, E., 2021. Unravelling the interplay between water and food systems in arid and semi-arid environments: the case of Egypt. Food Security 13 (5), 1145–1161. http://dx.doi:10.1007/s12571-021-01208-1.
The World Bank. (2021). Population, total - Egypt, Arab Rep. from https://data.worldbank.org/indicator/SP.POP.TOTL?locations=EG. [Accessed in: Oct, 2022].
The World Bank. (2000). *Cities in Transition*. The International Bank for Reconstruction and Development / The World Bank.
The Supreme Standing Committee for Human Rights (SSCHR), Technical Secretariat, 2022. Report on National Efforts to Ensure Access to Water On the Occasion of World Water Day on March 22, 2022. https://sschr.gov.eg/media/ysalpy5h/english742022.pdf. (Accessed 22 March 2022).
The World Bank, 2022. Population growth (annual %) - Egypt, Arab Rep.. https://data.worldbank.org/indicator/SP.POP.GROW?end=2021&locations=EG&start=1961&view=chart.
Tranos, Z., Zeleke, W., 2018. Relationship between National Culture and Development. J. Econ. Behav. Stud. 10 (2(J)), 145–154. http://dx.doi:10.22610/jebs.v10i2(J).2224.
United Nations Children Fund (UNICEF). (2017). *Water, Sanitation and Hygiene*. UNICEF.
United Nations Department of Economic and Social Affairs [UN DESA]. (2019). *World Population Prospects 2019 Highlights*. UN DESA.
United Nations Development Programme [UNDP]. (1998). *Egypt Human Development Report*. Oxford University Press.
United Nations Educational Scientific and Cultural Organization [UNESCO], & International Centre for Water Security and Sustainable Management. (2019). Water security and the sustainable development goals. UNESCO.
Varis, O., Keskinen, M., Kummu, M., 2017. Four dimensions of water security with a case of the indirect role of water in global food security. Water Security 1, 36–45. http://dx.doi:10.1016/j.wasec.2017.06.002.
Wachholz, A., Jawitz, J., Büttner, O., Jomaa, S., Merz, R., Yang, S., Borchardt, D., 2022. Drivers of multi-decadal nitrate regime shifts in a large European catchment. Environ. Res. Lett. 17, 064039. http://dx.doi:10.1088/1748-9326/ac6f6a.
Wahdan, D.E., 2007. Planning imploded: case of nasser's physical planning. Retrived from Econ. Polit. Weekly 42 (22), 2099–2107. http://www.jstor.org/stable/4419667.
Waterbury, J., 1985a. The 'Soft State' and the Open Door: Egypt's Experience with Economic Liberalization, 1974–1984. Comparative Politics 18 (1), 65–83. http://dx.doi:10.2307/421658.
Waterbury, J., 1985b. The "Soft State" and the Open Door: Egypt's Experience with Economic Liberalization, 1974–1984. Comparative Politics 18 (1), 65–83. http://dx.doi:10.2307/421658.
Weber, M., 1993. The sociology of religion. Beacon Press.
Weilacher, U. (2016). *Revisiting Structuralism - Revitalizing Living Networks*. Paper presented at the Tasting the Landscape. 53rd IFLA World CongressAt: Turin.
Wisser, U. (2009). City Development Strategy for Sustainable Development - Phase II. Retrieved May 11, 2022, from https://use.metropolis.org/case-studies/egypt-alexandria-sustainable-city-development.
Young, G.L., 1974. Human ecology as an interdisciplinary concept: a critical inquiry. Adv. Ecol. Res. 8, 1–105.