SUSTAINABLE REGENERATION OF URBAN GREEN AREAS IN EGYPT'S DESERT CITIES

ADOPTING GREEN INFRASTRUCTURE STRATEGIES IN NEW BORG EL-ARAB CITY

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DECLARATION OF AUTHORSHIP

To the best of my knowledge I hereby declare that I have written this thesis submitted in part of the fulfillment of the Master of Science degree in Resource Efficiency in Architecture and Planning to the Hafencity University, without any help from others and without the use of documents and aids other than those cited according to established academic citation rules, and that it has not been submitted at any other university for any degree.

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ABSTRACT

Desert urbanization in Egypt has been going on over 40 years by establishing generations of new desert town. Urban green areas are essential for well-functioning and the livability of those towns. They play a recreational role in everyday life, contribute to the cultural identity, help to maintain and to improve the environmental quality. However, Egypt now is at the threshold of the water crisis and the arid environment of desert cities does not support the existence of greening activities.

The existing employed planning and design approach of urban green spaces considering the non-sustainable use of water resources and the lack of water reuse strategies can be severely detrimental to the environment and human population. Green space elements ranging from larger woodlands and public parks to private gardens, golf courses, and green roofs, should be integrated with sustainable strategies such as stormwater management, wastewater & greywater reuse, in order to overcome the raising urban and environmental challenges. Simultaneously, to offer a solution to the chronic technical problems of wastewater management in remote desert cities

This study aims to analyze and investigate current characteristics of planning and management of green areas in Egypt's new desert city, assessing the challenges and shading the light on the potential of adopting green infrastructure strategies; identify the areas of deficiency and develop a comprehensive vision and optimized scheme for the development of green area in new desert cities.

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ACRONYMS

AWCO	Alexandria water company
CBA	cost benefit analysis
CW	Constructed wetland
EJUST	Egypt-Japan University of Science and Technology
ET	Evapotranspiration
FWS	Free Water Surface Flow
GIP	Green Infrastructure Partnership
GIS	Geographic information system
GI	Green Infrastructure
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HFCW	Horizontal Flow Constructed Wetlands
ILS	Interactive Landscape Surfaces
LEIS	Lima Ecological Infrastructure Strategy
NBC	New Borg El-Arab City
NPV	Net Present Value
NUCA	New Urban Communities Authority
NWRC	National Water Research Center
O&M	Operation & Maintenance
PE	population equivalent
ROM	Rough Order of Magnitude Estimate method
SFS	Subsurface Flow System
TWW	Treated Wastewater
UGA	Urban Green Area
VFCW	Vertical Flow Constructed Wetland
WRRI	Water Resources Research Institute
WWTP	Wastewater Treatment Plant

CHAPTER 1 : INTRODUCTION

1. INTRODUCTION

Egypt has been witnessing a rapid population growth since the 70's. In an urge for a solution, and considering the topography of Egypt, developing these deserts was apparently the hope to pull peoples away from the increasingly populous Nile valley. In accordance, 22 new towns were established over half a century on desert lands [1]. In the year 1979, national development goals were set by the government in form of The National Urban Policy in order to attract the increasing population along the Nile valley to new development areas, includes both new desert settlements and land reclamation projects. The aim of the new towns besides attracting population was to create an industrial base urban growth outside the valley by establishing communities with high economic growth and living standards, which will contribute to reduce the rapid decline of agricultural land areas and to set an equal opportunities among individuals by attracting public and private investment [2], [3]. However, the achievements this urbanization process was noticeably limited, due to the speculative planning policies and lack of a comprehensive evaluation and monitoring of the progress of those towns with respect to original objectives. Additionally, environmental and urban threats were imposing challenges to the development of the new towns, including the degradation of urban green areas and its implications in such harsh environment.

1.1 DESERT CITIES IN EGYPT

The desert of Egypt comprises the Western and Eastern Deserts, and the Sinai Peninsula, which all makes up about 95% of the country's total area. Much of which is empty plain lands with stone plateaus, sand sheets, and sand dunes, with exception of some depressions, isolated hills, and both Red Sea and Sinai Mountains. Most of these desert regions are characterized as hyper-arid with less than 5 mm of annual rainfall, except a strip of land exist in the north-west part of the country, extends along the Mediterranean coast. This region can be described as a semi-arid climate that receives relatively enough winter season rain to support basic cultivation activities [1].

The Egyptian New Cities Program led by socio-economic objectives was structured based on a number of interlinked alternative schemes. Of which was first to support the expansion of the two main metropolitans (Cairo and Alexandria) with independent and self-sufficient satellite towns. Second, was to establish development corridors extend on desert lands in the periphery of the Delta, connecting Cairo- Alexandria, and Cairo- Sues Canal regions. Following this was to build twin cities of existing major ones that attract the population. However, the program was implemented on phases which had led to a serious of cities were categorized in generations according to which scheme and time were the cities built. The first generation cities were the ones around Cairo and Alexandria as an implementation of first desert development scheme [2]. Recent programs are promoting the development of North West Coast region and the pole of Suez Canal.

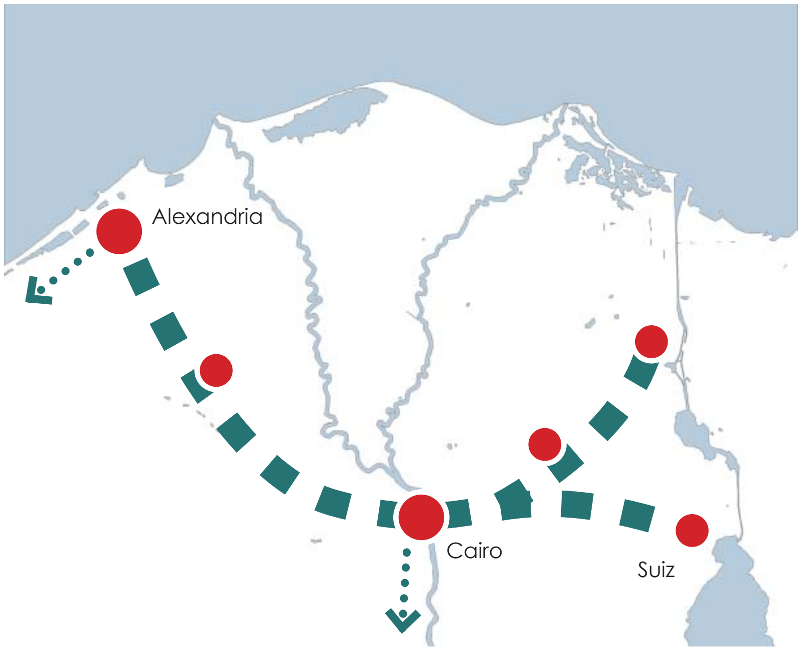


Figure.1: Development corridors of New Cities Program

Source: Author

All of Egypt's new towns have been built, have similar trates of planning norms and their layout. New towns structure do not refer to any norms of the Egyptian context. In contrast to the typical Egyptian urban form, the layouts of new towns imply an enormous scale of land divisions on extended desert lands with low density and huge distances between different elements. The land use was segregated by encouraging the separation of residential, commercial and service areas. The density of a residential neighborhood in new towns was very low with an average of 50- 70 persons per hectare, 60 % of the area was dedicated to open spaces, green areas and other services [3]. This greening structure was driven by the belief that the shortage of green spaces in the existing cities should be compensated in the new developments. The streets are planned with a distinct hierarchy having main arterial streets defined by wide-open spaces; on the other hand, residential streets with a restricted access in order to reduce traffic load in residential areas. The new towns also have almost all the commercial activities in the city center together with public services and governmental buildings, on the other hand, having very limited commercial activities within the neighborhoods. This concept was driven from western urban planning modern model, which has totally opposite structure than the traditional cohesive Egyptian cities and also unsustainable according to the planning principles for the desert environment [4]–[6].

The planning practices adopted by the Egyptian government for the new towns have a remarkable environmental cost. The nature of desert environment with the high level of solar radiation and temperature was ignored by the absence of shading aspects and albedo effect consideration. The remote distance to the cities, besides the large commuting distances within it, caused by the low density encourage an extensive use of vehicles. The scarcity of water is an essential cost to be included as well. Most of the new towns are located on elevated desert plateaus with lower water table. Thus, the limited water resources and rainfall cannot support the minimum requirement of greenery in such arid urban context. This can not be seen separately from the current national concern of exploited surface-water resource supplied from River Nile and the regional conflict over upstream development projects that can reduce Egypt's share of the river's water. Moreover, the irrigation needs will be increased under a changing climate by experiencing further warming in Nile region and sea-level rise will also increase pressure on water resources [7], [8]. Regardless of these facts, enormous areas of lawns, golf courses, parks, green belts and swimming pools were planned and built. Moreover, the consumed water for irrigating the extensive green areas and for the other potable uses are discharged wastely in the desert since these new towns have no access to any water bodies. The discharged water is mostly Prone to evaporation.

The present scene of the new towns shows serious negative effects regarding social, economic and environmental aspects. The goals have been set for these towns were not achieved by any means; Neither saving agriculture land, relieving the population pressure on major cities nor reducing the inequality gap among regions, which suggest that the new towns scheme in Egypt was a kind of speculative urbanism rather than a social, economic and environmental plan based process. Most importantly, the emerging water crises in Egypt imposing a serious challenge to the development of those new towns.

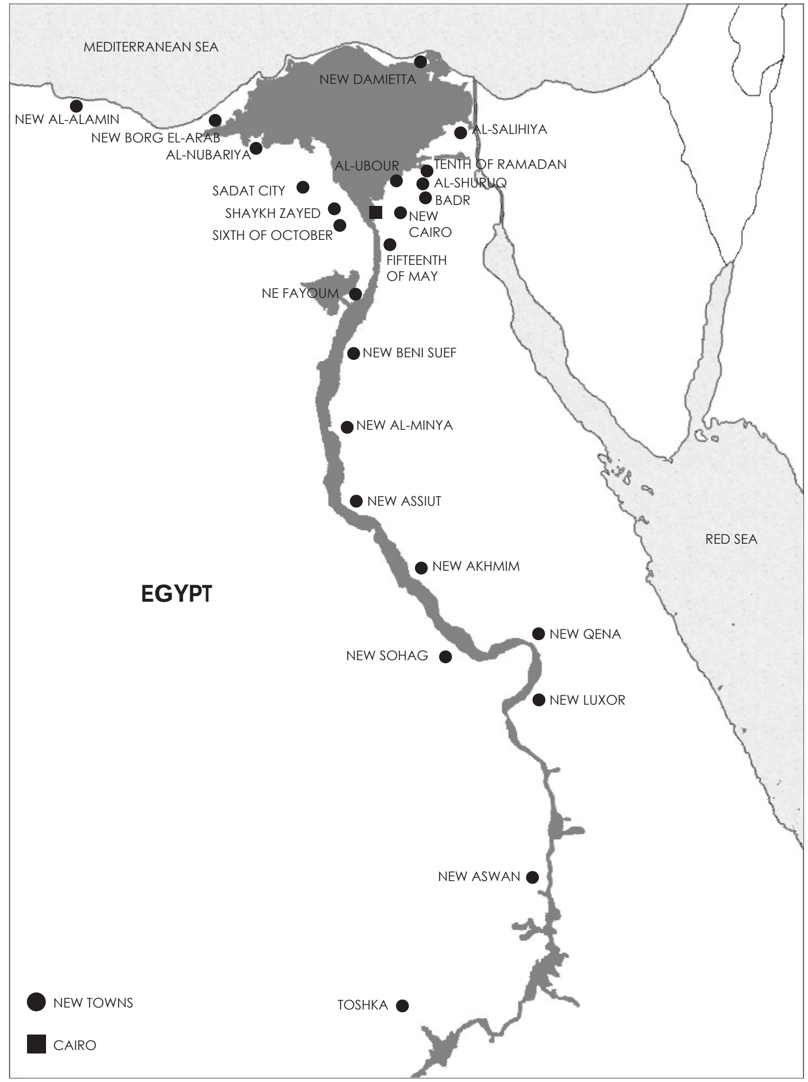


Figure.2: Location of the new towns in Egypt

Source: Adapted from Egypt's Desert Dreams 2015 [1]

1.2 PROBLEM STATEMENT & RESEARCH OBJECTIVES

A properly designed and managed urban green areas are fundamental to the sustainable future of the new towns in Egypt, reflect the desired quality of life and environment. The value of the green area in the urban built environment of such arid climate is to provide critical ecosystem services, where Parks, community gardens, and green roofs can reduce carbon footprint, control microclimate and protect water quality. Also to provide space for physical activity and social interaction in order to promote the sense of belonging and support the health of residents.

The legislation of planning and design new Egyptian cities state that public spaces (parks and public gardens) should be around 20- 25% of the total area. For public and private housing developments, green areas to be 50- 55% of the development or plot area. The result is the total green areas are exceeding 50% of the districts or neighborhoods total areas [9]. This extensive greenery, however, lacks a proper management and application of landscape principles suite the environmental setting where the cities built. Thus, large green areas were assigned to low-income housing developments has become abandoned and neglected. On the other hand, exclusive greening projects have been rapidly established in luxury gated community developments in form of Golf courses and enormous landscape.

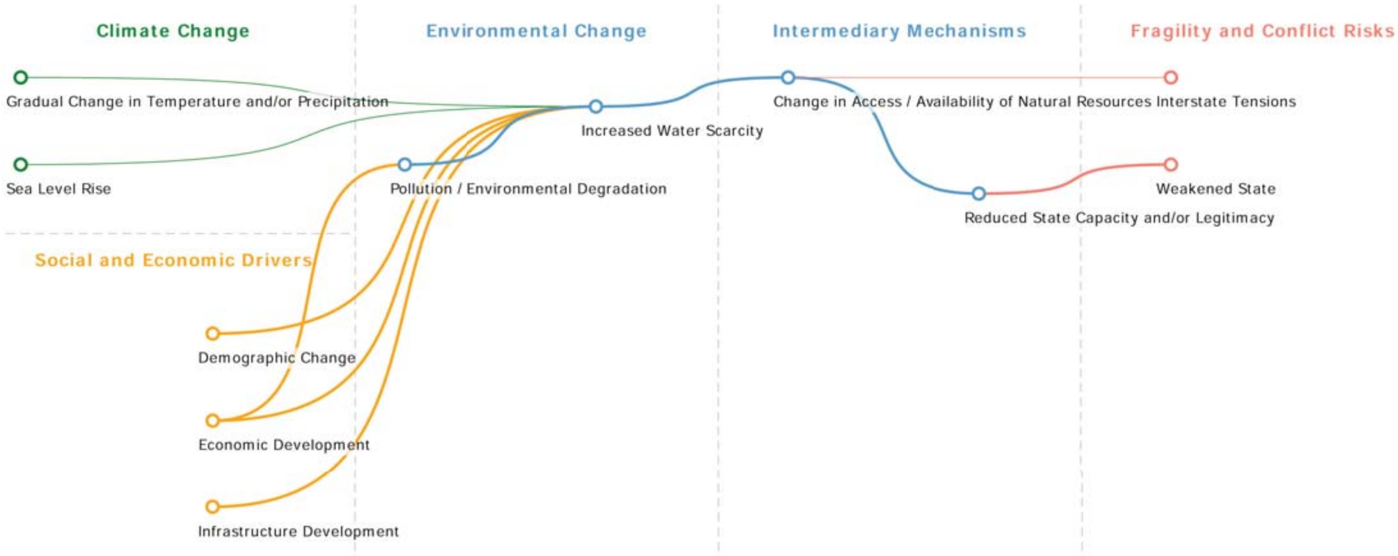


Figure.3: Model of environmental conflicts implications of growing water scarcity in Egypt

Source: Environment, Conflict & Cooperation 2017, www.ecc-platform.org

After the water scarcity issue in Egypt became increasingly recognized on the government level and among the commons, it is questionable the exploiting use of water resources in new urban settlements. The areas of greeneries with inefficient irrigation methods have been practiced in most of the cities are increasing the demand for freshwater for irrigation. The current urban situation shows that the authorities in many new towns cannot afford the water requirements for existing green areas as well as establishing new ones. Wide areas of greenery are deteriorating because of the lack of water for irrigation. In addition, the predicted climate change threats will change the water consumption of green areas in response to the higher temperatures [10]. Such non-climate resilient green areas are having a high negative impact on the environment, raise the demand for energy and water and affect the community integrity and health. Therefore, the concept of sustainable and water neutral green areas planning need to be demonstrated for assessment and implementation.

Therefore, the primary aim of this research is to draw guidelines and recommendations for adopting green infrastructure strategies that can help planners, officials and developers to acknowledge the sustainable regenerating potentials of urban green areas in desert cities. The focus is to tackle the rising challenges and sustain the future of green spaces; preserve water resources and offer alternatives; to improve the quality of urban areas; enhance the well-being and health of local residents. These efforts are not only to rectify the present situation, but also to suggest a foundation of green areas planning for urban expansion in the Egyptian deserts.

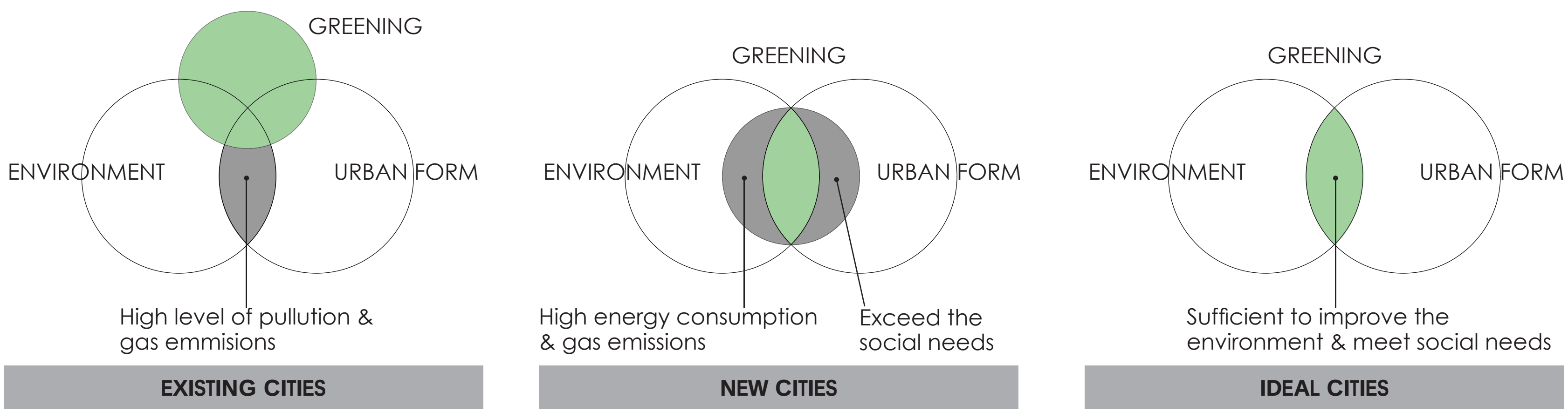


Figure.4: Conflicts between greening, environment & urban form

Source: Fallacy of Greening the New Egyptian Cities 2013 [9]

A proposed demonstration project will test and measure the effects of intervention concepts in the context of New Borg El-Arab City. The objective of intervention cycle is to provide a clear insight into the problem of deteriorating urban green areas and analyze the factors behind this situation. After the problem analysis and diagnosis process, the solution to be developed by designing an intervention framework plan. Then, putting the change into practice by proposing a serious of applications according to the analysis and design stages, and finally making an assessment of the implemented changes in order to verify its reliability to the regeneration process.

Figure.5: Intervention cycle

Source: Adapted from Design a Research Project 2007 [11]

1.3 RESEARCH QUESTIONS & HYPOTHESIS

A set of research key question has been formulated in order to address the concerned knowledge that is necessary to achieve the research objective. Some of these core questions are unraveled in sub-questions as follow:

(1) 1. How planning green areas of new desert cities affected by climate and the water crisis in Egypt?

(2) What are the implications of green infrastructure in arid and semi-arid climate?

- What is green infrastructure?
- What are constraints and characteristics of green infrastructure could be taken into consideration in such Climate?
- How can other successful world experiences with similar climate condition be replicated in Egypt?

(3) How sustainable are the urban green areas in Borg EL Arab city and water efficient?

- What is the feature of Water supply and demand of green areas?
- Are there any current practices of stormwater management or reuse of treated wastewater?
- What are the aspects of current landscape design and irrigation system in the city?

(4) Is it effective and feasible to adopt green infrastructure strategies in the planning of Sustainable urban green areas in Egypt's desert cities?

- Which green infrastructure applications can fit the different urban settings of NBC?
- To what extend stormwater management, landscape design, wastewater and greywater reuse can contribute to the sustainability of green

spaces?

- What are the limitations and challenges of implementation?
- What is the cost-effectiveness of applying those strategies?

The main hypothesis is that the deterioration of urban green spaces is driven by the improper planning and management practices in such water scare conditions and that adopting green infrastructure approach is an efficient and feasible solution to tackle the challenge of desert urbanization in Egypt. This hypothesis will be examined in this research study in order to draw a holistic perspective of the problem and mitigation strategies.

1.4 RESEARCH METHODOLOGY

The primary research methodology used to accomplish this study combines qualitative and quantitative strategies. A broad overview of green infrastructure practices and depth analysis of a desert city case will be used to gain an understanding of the available knowledge in the discipline, and to provide insights into the problem. This approach is to be used as a base for quantitative research that can develop potential measurable solutions for real practices, in order to evaluate the results, then, enables a generalization of the result to the overall Egyptian case.

In this section, the procedures and steps which adopted throughout the research will be presented as a research framework, in addition to the case study selection criteria and process. The organization of the study will be explained in research structure. Data collection methods and concept are then asserted.

1.4.1 Research Framework

The research framework is structuring the appropriate steps that need to be taken in order to achieve the overall research objectives. It shows the interconnection among the different phases of the research. The framework has main three divisions; first, is constructing a conceptual model of sustainable green areas by conducting a general study of related literature in the topic of green infrastructure in arid and semi-arid climate, including stormwater management, wastewater reuse, and sustainable landscape design. Besides, demonstrating two best practice cases in form of successful existing experiences that can be replicated. The second division is a close analysis of the overall context of urban green areas in New Borg El-Arab City, and specifically analyzing the current and potential aspects of stormwater management, wastewater reuse, and landscape design. Then, confronting those aspects of the city's green areas with the conceptual model has been drawn by the knowledge gained in the first division. The results from the confrontation process would be the primary input in the third division, which is the intervention. In this phase, an intervention structure will be proposed

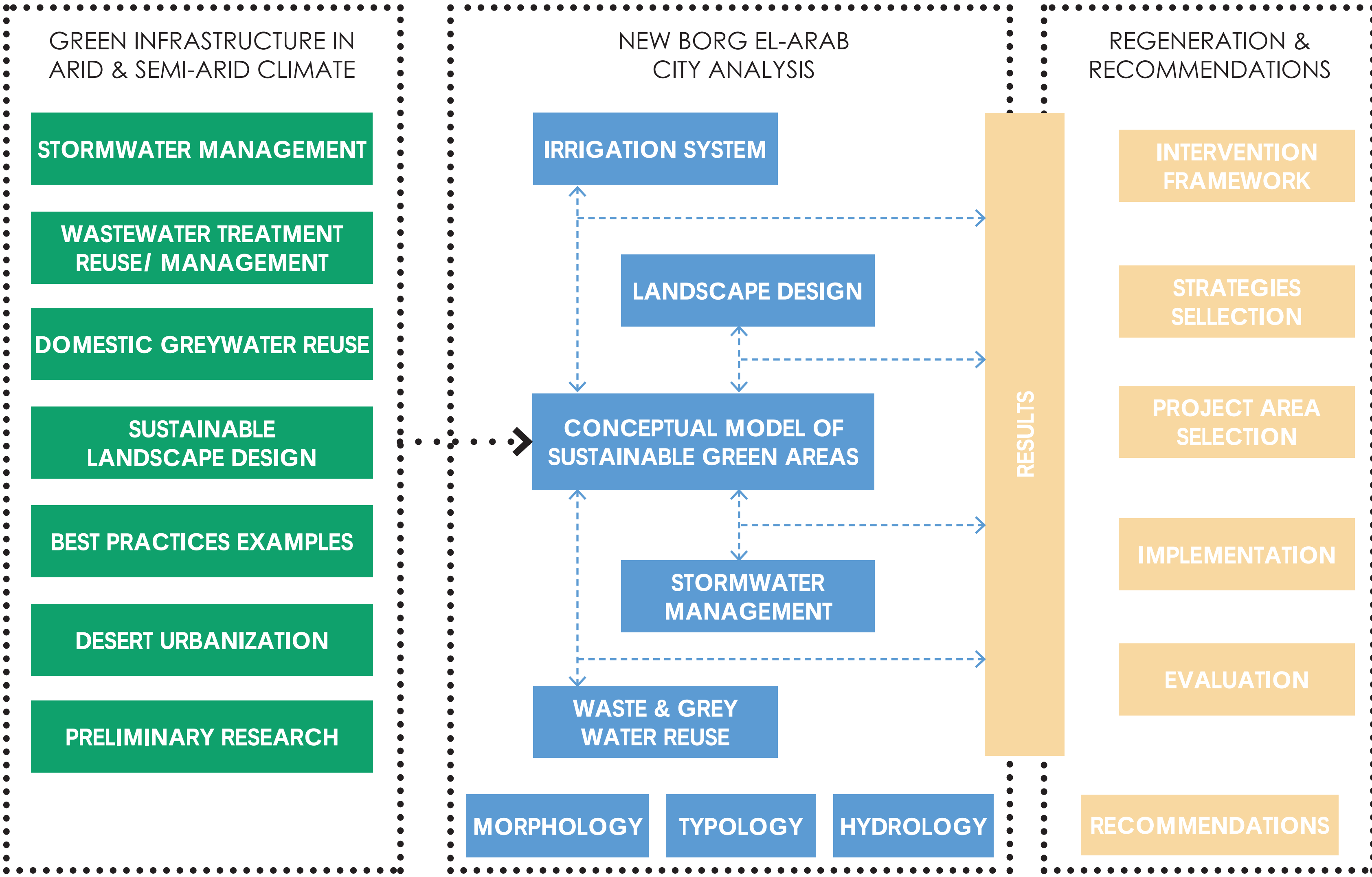


Figure.6: Research framework illustrating the structure of study flow

Source: Author

that introduces various strategies and application for implementation. Finally, a technical and economic evaluation of the quantified outcomes, in accordance with the main objectives of the research, will lead to the final conclusion and recommendations that can be reflected on the general case of all Egypt's desert cities. Every phase of the research is supported by the required data and interviews. The flowing schematic diagram is a representation of the most important research phases.

The selection of Satellite desert city as a case study was determined where the topic of research strongly addressed. New Borg El Arab City has been chosen for the purpose of this study since the city has a wide range of urban green areas typologies and different urban densities. In addition, the demanding situation of the city regarding its great distance from the main source of water (River Nile), and the relatively considerable annual precipitation in that semi-arid region. A detailed explanation of the case study city selection criteria and reasons will be presented in chapter three.

1.4.2 Research Organization

This research study is organized into four chapters according to the introduced framework. Chapter 1 gives a background on the case of Egypt's desert cities and its related problem of urban green areas. The objective of this study, research questions and hypothesis. Also the methodology and design of the research, including framework and methods of research. Chapter 2 reviews the basic knowledge of the green infrastructure concept and its applications, principles, design process and cost. In addition, two examples of best practices will be introduced. Chapter 3 looks closely at the urban green areas in the case of New Borg El-Arab City with a general overview of the conditions of its location, water resources, climate, and layout. Also a deeper analysis of current infrastructure features. Following this, a development of intervention framework and proposed strategies to be presented, in addition to the demonstration of these strategies on a project site, which will be evaluated then according to technical and economic aspects. Chapter 4 interprets the main findings of the research and generalizes them on the overall case of Egypt's new desert cities in order to offer a further recommendation for development and suggestion for future research.

1.4.3 Data Collection

Data collection methods used in this research were meant to cover all aspects of the study while observing the different point of views from related stakeholders. Qualitative data were acquired through literature review, interviews, and a systematic observation of the site, while the quantitative data were retrieved In the meantime as measurement and values that can support the design and evaluation of the proposed intervention.

Literature Review

A primary review of the available literature was conducted to cover three main knowledge areas; the concept of Green Infrastructure and its implications, in addition to best practices. Another area is the literature related to the context of new settlements in Egypt's desert.

Site Excursion

Regular excursions to New Borg El-Arab City were conducted during one month visit to Egypt. The visit was intended to gather the first-hand information and materials along with systematic observation in order to build an analytic image of the site' conditions.

Meetings & Interviews

Semi-Structured interviews were conducted with representative entities like Academics, Officials, Civic Society (NGOs), Investors, environmental consultants. The purpose of conducting meeting was to explore different perspectives of related stakeholders that can build a comprehensive understanding of the topic and discuss the possible solution represented by their interrelated interests. A further description of conducted interviews is elaborated in a late section of this study.

1.5 DEFINITION OF TERMS

'New town', 'New Community', 'New City', 'New Settlement' and 'New Satellite City' are phrases frequently used in this study and generally in the context of Egypt's new urban expansion cities. They refer to the urban developments of desert areas have been established over the past forty years in Egypt. The term 'New'/'Gadida' is apparently added to the given name of most new cities such as New Borg El-Arab City, New Cairo City, New Damietta City, New Fayoum City, etc., as they are twins to existing cities.

1.6 RESEARCH LIMITATIONS

The main limitations of this study were the lack of data and maps available for the public from the city's authority. Data regarding green areas management, especially water consumption for irrigation were given roughly. This has affected the accuracy of the quantitative part of the study. Detailed maps and remote sensing data would have been of a great benefit for this study. The mapping of the project area was developed schematically by the researcher and all areas calculation were based on this map. Due to political and security conditions in Egypt, the circumstances of communication with officials and academics was limited in terms of transparent insights or critical opinions, as well as data availability. Lastly, the lack of elaborated research in the discipline of green spaces in Egypt's desert cities are apparent and the public awareness of the existing problem and future challenges does not prevail.

1.7 OVERVIEW OF NEW DESERT CITY PLANNING IN EGYPT

The consecutive generations of new cities in Egypt have been launched in constraint to the national urban policy and national strategic plan. A legislative and Institutional framework was issued for the new towns by the foundation of New Urban Communities Authority (NUCA) under the New Communities Law (No. 59 of 1979). With a juristic and independent personality, NUCA was the main entity responsible for the establishment and management of new towns, including Reconstruction, Development, Utilities, and Infrastructure, with the right to develop and sell lands within these towns. The framework also specified that the management of each new town would run by a town authority under NUCA. The new town was to revert to the local administration of the relevant governorate, once it is completely developed [1], [2], [12].

The planning process of new towns in Egypt was exclusively held by NUCA in accordance with the national urban policy. The adapted planning Approach is the Comprehensive Planning Method where integrated solutions are provided in the master plan to achieve the social and economic objectives. The general and detailed plans determine land usages, population, and infrastructure. The targets of full developed cities were planned to be achieved within 20- 25 years and the construction was according to execution phases [13]. However, after forty years, targets of most new towns were not achieved, and the planning method was broadly criticized. An Incremental planning approach was suggested to be more suitable for the case of Egypt as the planning to be a reaction to the gradual growth of the new city.

1.8 EMERGING CONTEXT OF SUSTAINABLE INFRASTRUCTURE IN THE SEMI-ARID CLIMATE

The arid climate of deserts supports limited vegetation cover. The classifications of climate are based, according to Köppen-Geiger system, on data of the annual precipitation, temperature, and seasonality of precipitation. With respect to vegetation, Subtypes of arid climate can be driven by the relation between annual precipitation and evapotranspiration rate. Factors like precipitation, temperature, and sun radiation influence the estimation of moisture measure relative to the needs of plants. This includes hyper-arid, arid and semi-arid

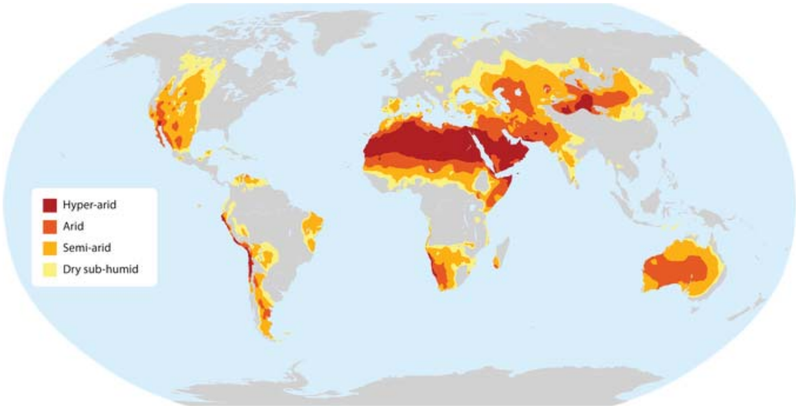


Figure.7: World map of hyper, arid, semi-arid and dry subhumid

Source: FAO 2015 [15]

zones. Egypt is located in the hyper-arid Sahara zone, with exception of a small part along the Mediterranean that is arid to semi-arid zone [14].

The built infrastructure in an urban system is man-made design and constructions meant to support human quality of life by delivering services and products like buildings, open spaces, energy system, transportation system, water system, wastewater and sewage system, and many others. The reliability and sustainability of these infrastructure systems and services are what makes urban areas resilient to inevitable challenges. Environmental risks like climate change and natural resources degradation affect directly the infrastructure within urban system. In such arid region, the increasing challenge of water scarcity in urban areas can be detrimental to its existence, adding the climate effects of extreme rainfall events, sea-level rise and change in average temperature. However, a climate adaptation strategies for infrastructure and urban systems are crucial in order to mitigate the risks and increase development's resilience to possible impacts [16].

Green infrastructure is an approach to land development that offers adaptation strategies to manage water while providing economic and community benefits. Green infrastructure technological practices include green, blue, and white roofs; hard and soft permeable surfaces; green alleys and streets; urban forestry; green open spaces such as parks and wetlands; and adapting buildings to better cope with floods and coastal storm surges. In particular, the techniques addressing stormwater management and conservation are releasing water stress of landscape irrigation in semi-arid regions, by providing rainwater harvesting and storage, recharging groundwater. Application of this approach range in scale from centralized site scale of a project or neighborhood to the centralized scale of the entire city and the whole region. Green infrastructure also builds communities and improve the public health by raising air quality, reducing urban heat island effect and providing proper recreational space for sustainable urban areas and also reduce landscape maintenance costs, reduce water imports and lower energy costs [14], [17].

The characteristics of precipitation and temperature that define semi-arid climate impose a unique consideration of adopting green infrastructure. Most strategies are applicable, others are either not recommended or require modification. Rainfall regime including both total annual precipitation and seasonal pattern, in addition to the higher evapotranspiration rates the area experiences can affect the selection and implementation of green infrastructure strategies [18]. For instance, water retention techniques and exposed conveyance methods could cause a huge loss of water via evaporation due to the high temperature and the high direct sun radiation. Thus, exposed retention ponds and conveying canals are recommended in such climate neither for stormwater nor for wastewater management. Furthermore, collection and storage of rainwater for non-potable reuses is most needed in this context, if abdicable, in order to alleviate the water stress occurs in arid regions, although infiltration for recharging groundwater is always appreciated [17].

CHAPTER 2 : **GREEN INFRASTRUCTURE**

2. GREEN INFRASTRUCTURE

Green infrastructure is a term that is interpreted differently depending on the context in which it is used [19]: according to Firehock, green infrastructure is led by the recognition of the need to plan for conserving our natural assets in and around urban areas that provide improved quality of life or "ecosystem services", in which local communities, landowners, and organizations work together to identify, design and conserve their local land network and to think about natural resources as a critical part of our life system [20]. In other definitions, it refers to the Natural or semi-natural ecosystem that supplements or replaces the water utility services that provided by gray infrastructure [21]. Also, Benedict and McMahon see that Green infrastructure connected to engineered structures, such as stormwater management or water treatment facilities that are designed to be environmentally friendly. In other words, Green infrastructure is an approach to Integrated urban water management that uses natural or engineered systems in order to conserve natural resources, reduce pollution and flooding, enhance environmental quality and provide utility services [22]. For instance, practices such as permeable pavement or constructed wetland could be considered a green infrastructure that helps sustainable communities to develop climate resilience.

This study is not committed either to one of these definitions, rather the objective is to elaborate a cohesive view that incorporates all various components, features, and characteristics of Green Infrastructure, which can apply to the case of desert cities in Egypt. In this context, green infrastructure is used as planning, design, and implementation approaches for supporting green space conservation, restoration and water resource management which evolved to meet specific needs that raised from urban development growth in desert environment [22].

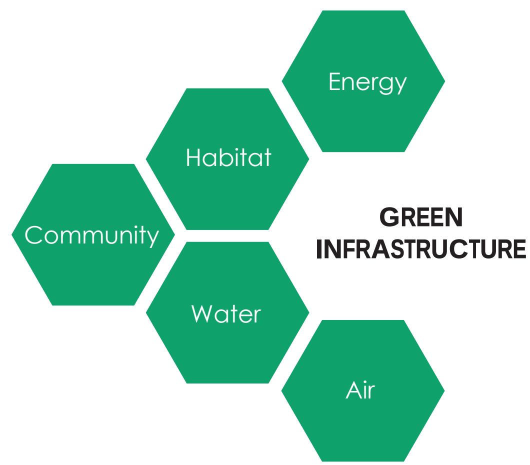


Figure.8: Elements of Green Infrastructure

Source: Adapted from Guidelines for Water Reuses 2012 [43]

Table.1: Advances of the History of Infrastructure

Source: Growing with Green Infrastructure 2013 [23]

ERA	GROWTH ISSUE	INFRASTRUCTURE SOLUTION
MID-LATE 1800's	Public Health and Welfare	Sanitation, Hospitals, Parks, Schools
	Communication	Telegraph
	Industrialization	Planned Communities, Company Towns
	Energy	Coal, Oil, Gas, Electricity
	Transportation	Canals, Railways
EARLY 1900's	Automobiles	Roads
	Food Production	Crop Rotation, Agricultural Practices
	Communication	Radio, Telephone
MID 1900's	Energy	Hydro & Nuclear Power
	Nuisances	Community Zoning and Planning
	Pollution	Air/Water/Sewage Treatment
	Transportation	Interstate System, Airports
	Mass Communication	Television
LATE 1900's	Garbage	Recycling
	Traffic Congestion	Mass Transit, Alternative Transportation
	Flooding	Stormwater Management, Detention
	Information Management	Computers/Internet
2000+	Sprawl, Globalization	Sound Land Use, Smart Growth
	Sustainability	Green Infrastructure

2.1 GREEN INFRASTRUCTURE VERSUS LANDSCAPE

Green infrastructure planning and strategies are to map the areas that supply relevant ecosystem services and then working on connecting these areas into an accumulative network of services [24]. At the same time, Green Infrastructure concept has raised, a recent discourse in landscape architecture has also evolved some new functionalistic strategies in urban green and landscape, e.g., Landscape as Infrastructure [25] and Landscape machines [24], [26]. These concepts are connected to ideas of decentralized and site-specific infrastructure that can create a landscape with the spatial pattern. They are separated from the conventional aesthetic and scenic pattern of landscape and present instead of a new landscape based upon efficiency, which imposes an important compatible concept with green infrastructure [6].

2.2 BENEFITS OF GREEN INFRASTRUCTURE

Green Infrastructure Integration of urban green spaces with the built infrastructure planning through green infrastructure approach is associated with a number of immediate benefits of protecting the environment and human health while providing other social and economic profits [16]. A comprehensive green infrastructure helps conserving water resources and to contribute to low impact development.

Water Quantity and Quality

Green infrastructure based practices capture and store stormwater on site which can be used for outdoor irrigation and other potential uses and can substantially reduce the amount of potable water used [28]. In addition, minimize the negative impact of runoff by utilizing the natural retention and infiltration capabilities of vegetation and soils, by increasing the amount of pervious ground surface that also can help increase the rate at which groundwater aquifers are recharged [29]. That all contribute relieving stress on local water supplies and reducing the need to import potable water. Green infrastructure reduces stormwater discharge entering combined sewer system and prevent pollutants from being transported to water bodies [29].

Climate Resiliency

Green infrastructure can help communities become more resilient to the impact of climate change. Plants and soils serve as a source of carbon sequestration to reduce the amount of atmospheric CO_2, reduce energy demand by mitigating the effect of urban heat islands by reducing air temperatures and consequently, reduce power plant emissions associated with air conditioning [30]. Stormwater infiltration and harvesting also reduce the energy demand required for water and wastewater pumping and treatment [28].

Habitat and Biodiversity

Parks, urban forests, wetlands and vegetated swales provide habitat for a wide variety of flora and fauna. Green infrastructure performs best when urban green spaces are planted with native species [29]. The connectivity of large-scale green infrastructure, enable wildlife habitat to connect and develop [28].

Economic Benefits

Investment in green infrastructure has been proved to have an impact on the local economy. The supply of goods and services contribute directly to the economy. The indirect benefits are many but hard to quantify [31]. By improving amenities, green infrastructure can increase surrounding property and land value also encourages investments, start-ups, and entrepreneurs which reduce unemployment [32]. The avoided capital and operational cost associated with gray infrastructure can reduce public expenditures on the stormwater system [28].

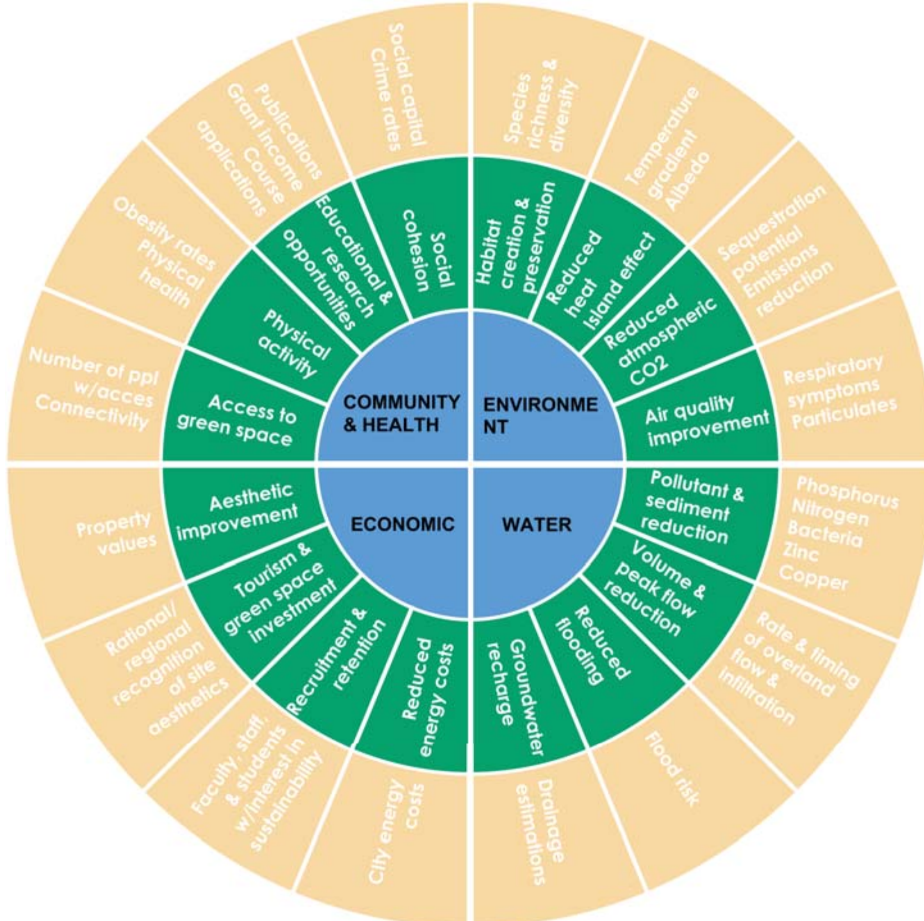


Figure.9: Benefits & potential metrics of green infrastructure

Source: Adapted from Green Infrastructure for Stormwater Management 2014 [27]

2.3 GREEN INFRASTRUCTURE APPLICATIONS

2.3.1 Stormwater Harvesting Systems

Rainwater harvesting is the core sustainability objective to conserve water and to reduce demand for potable water. The harvest system also helps to protect urban streams by reducing the rates and volumes of runoff for small, frequent events and use it as storage for productive use (Irrigation, drinking water) [32], [33]. Water harvesting techniques can be divided into two main types: in-situ and ex-situ. In situ (passive) system purpose is to increase the quantity of rainfall stored in the soil by directing and storing it in the desired landscape (to supply water for vegetation). Fundamentally, the method guaranty that distance between captured rainwater and usage landscape area is minimum [21]. This method also used for recharging shallow groundwater aquifers. Swales, bioretention and pervious surfaces are examples of in situ water harvesting.

Ex situ (Active) water harvesting is a system which captures and lead the rainwater to the point of water storage. The catchment areas of the system usually have low or little infiltration capacity like e.g., rooftops, roads or pavements. This water stored in natural or artificial reservoirs and, when needed, abstracted and distributed for irrigation. Examples include capturing and storing water in dams, wells, ponds, and Tanks [21].

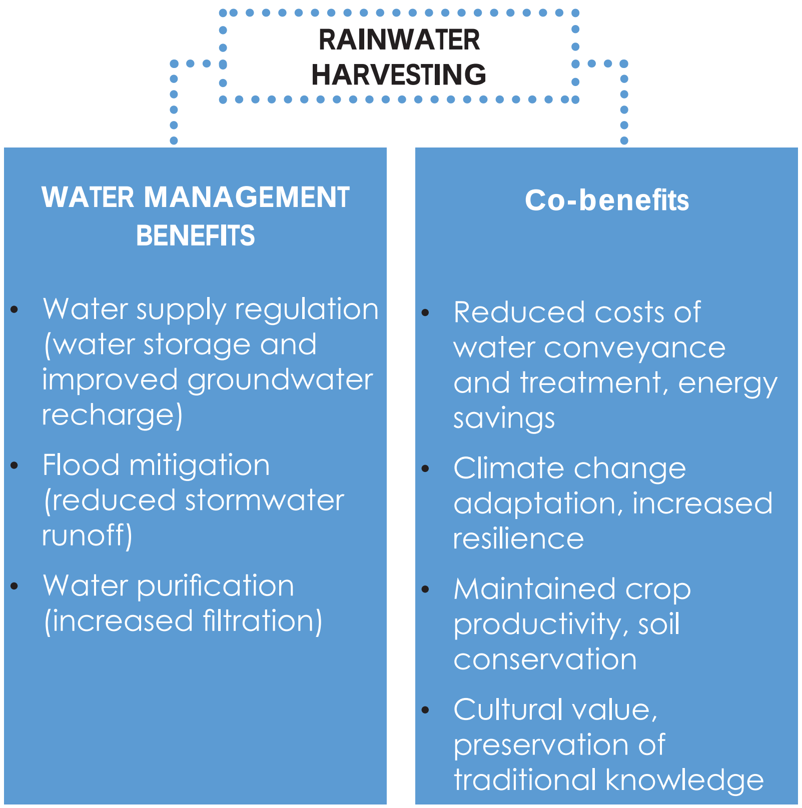


Figure.10: Water management benefits of rainwater harvesting

Source: Adapted from Green infrastructure: guide for water management 2014 [20]

The types and uses of ex and in situ water harvesting systems along with cost and maintenance analysis will be explained in this section as follow.

Rainwater Tanks

Rooftops considered one of the least deployed space in modern cities, which make up between 15 to 35 % of an urban footprint [34]. Rainwater from rooftops and hard surfaces can be stored and used potentially for a variety of non-potable purposes, but at most for irrigating urban green spaces. Considering the aesthetics of a development, rainwater tank can be incorporated into building designs like underground or into fence or wall elements or as part of a gutter system itself [33]. The size of the tank is determined according to the purpose they designed for. The desired level of reliability of the system can be achieved given a site's precipitation pattern and the accumulated area of roof or roofs drain to the tank [33]. The use of rainwater tanks has several considerations as follow:

Supply and demand – conditions such as in high-density development and low annual rainfall regions can cause an increase in rainwater tanks volumes to provide a reliable supplementary water supply.

Water quality – the quality of harvested water should be reconcilable with the quality of water required by end use.

Cost – the cost of rainwater tank system need to be compromised against alternative water management techniques.

Competing uses for stormwater runoff – there may be situations where a preferred beneficial use for stormwater (such as irrigation of a local public park or golf course) may provide a more cost-effective use of runoff from roofs than the use of rainwater tanks on individual allotments.

Maintenance – it is essential and required for most rainwater tanks to be maintained by the householder or a body corporate [33]water recycling, waste minimisation and environmental protection. The integration of urban water cycle management with urban planning and design is known as Water Sensitive Urban Design (WSUD.

Rainwater systems required regular maintenance. Thus, it should be designed to be temporarily discontinued. The system requires regular cleaning of tank, inlet, outlet, gutters and replace roof drain filters. Examination of the tank for accumulated sludge at least every two to three years. The system also requires inspection of any pumps on annual basis [33], [35]. However, the limited and seasonal rainfall in semi-arid regions leads to significant increase in rainwater tank size, which reduce the cost-effectiveness of the system [33].

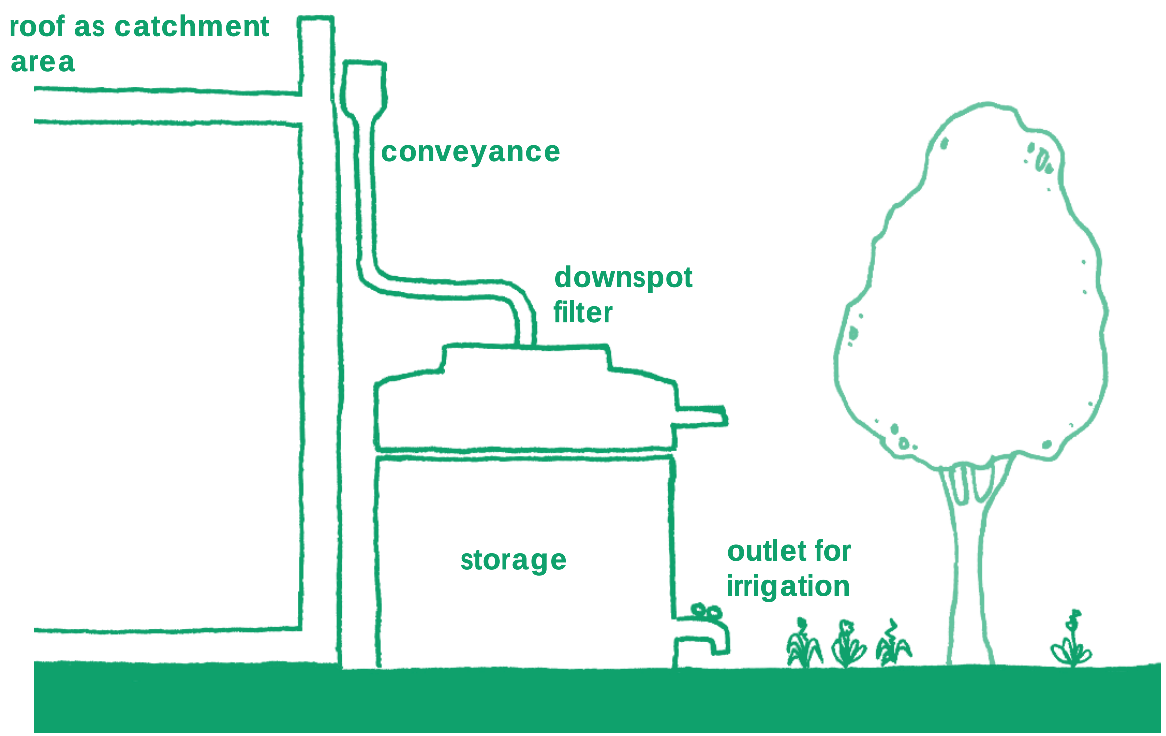


Figure.11: Main components of rooftop rainwater harvesting system

Source: Adapted from Susdrain [54]

Pervious Surfaces

Conventional pavements such as asphalt and concrete are impervious surfaces, which eliminate any runoff infiltration. Previous surface provides the alternative as it is suitable for pedestrian and vehicular traffic, whilst allowing rainwater to infiltrate into the soil and recharge the groundwater. Investing in permeable pavements can reduce stormwater runoff by 70 to 90 % [36]. In addition, the permeable system improves water quality and can eradicate the risk of contaminating groundwater. Studies showed that the amount of removed pollutants equals 85 to 95 % for suspended solids, 65 to 85 % for phosphorus, 80 to 85 % for nitrogen, and 30 % for nitrate and up to 98 % for metals [37].

Porous pavements allow for the water to infiltrate through the internal structure of the material itself to a subsurface collection system or to the soil [21], [38]. These materials such as porous asphalt and concrete can be used in parking lots, residential roads and driveways. Because the fast infiltration of these materials the groundwater quality should be considered. However, there is no official run-off coefficient of the porous pavement. The producers test the capacity of water absorption of the materials. It is measured in liters per time and hectare. For the porous pavement it is 100-400 l/(s*ha) [39]. In comparison, Permeable pavements are pavement stones and slabs which are laid in a grid system with a different size of spacing in between the stones, often filled with other highly permeable material such as gravel, sand or grass [35], [38], [40]. The actual pavement stone can be made of different materials such as concrete, natural stone or bricks. The width of the gap depends on the pavers, the grid pattern, the design and the intention of infiltration. The run-off coefficient varies based on the

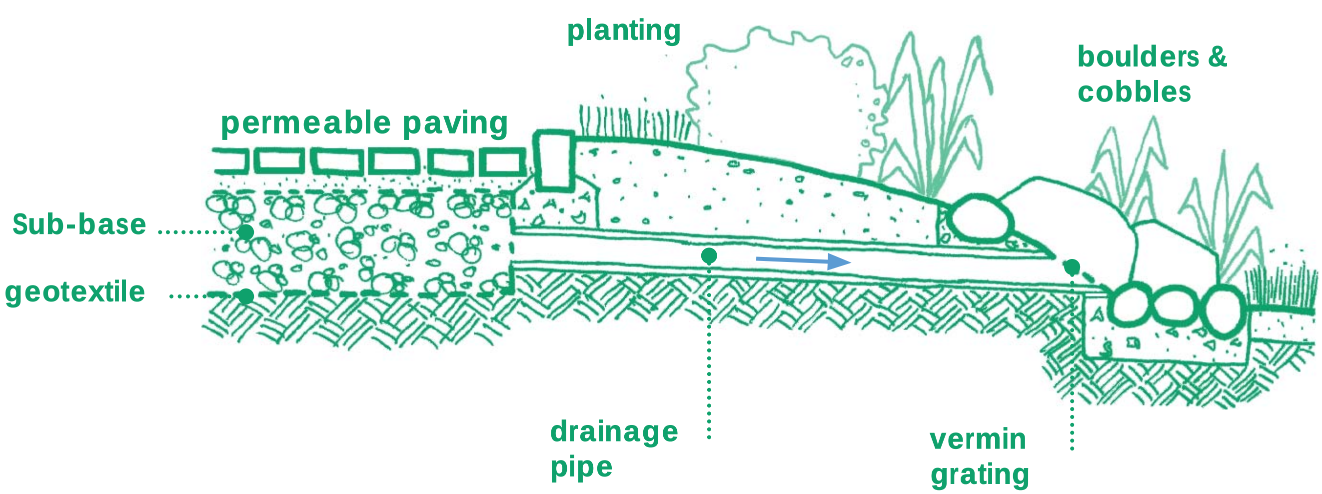


Figure.12: Surface water runoff collected through permeable surfaces

Source: Adapted from Susdrain [54]

size of the gaps. A grid system with small gaps from 2 to 5mm has a run-off coefficient of 0.75. For the gaps from 5 mm to 5 cm, it is 0.25 [39]. Pervious surfaces system, in general, has two underlying layers: the first consist of finer sediment that works as an initial filter and the second one consist of aggregate like gravel that conveys and store water and supports the system structurally as well. The infiltrated water can also be collected with perforated underdrain pipes, which are installed under the porous pavement and the base layer and lead into a natural green swale aside the pavement [21], [38].

Pervious pavements should be under regular inspection and maintenance for the effective operation of the system. Especially after heavy rainfall, it should be inspected for clogging, litter, weed and water ponding. A high-pressure hosing and vacuum sweeping can be used three to four times a year for maintenance [35]. Depending on the type of pavement and required maintenance, the estimated costs of the permeable pavement could vary from USD 30 to USD 150 per m^2 (in the USA), which is comparable to conventional pavers [36]. On the other hand, the installation cost of porous asphalt is 10-20 % higher than of standard asphalt. It requires more labor and experience for the installation and specific machines to achieve the properties of the porosity.

Swales

Swales are linear vegetated drainage features in which surface water can be stored or conveyed [41]. Swales can be designed for runoff infiltration or to provide an alternative to the concrete curb and channel for conveying runoff from roads and other impervious areas [35], [40]. Types of swales vary from standard conveyance swales, dry and wet swales. Dry swales are designed to include a filter bed of soil that overlays an under-drain system, which increases the treatment and conveyance capacity of the system. Wet swales enhance treatment process by encouraging wet and marshy conditions in the base. This can be used where the soil is poorly drained or water table is high [35].

Swales are typically placed next to roads and driveways but can also be placed adjacent to a car park, as a borderline feature in landscape design and in other open spaces. They are not well-suited for private gardens where the uninspected use of fertilizer and weed killer can result in runoff pollution [35]. Site slope, area and ground stability should be considered for using swales. They require significant land-take due to their shallow slope. The longitudinal slope should be flat as possible and not exceed 4% or 5% in other references (10% with check dams) as low runoff velocity ensures the optimum removal of pollutants and to prevent erosion as well [35], [38]. The maximum depth of swale is generally not greater than 45 cm at the outlet. Ground stability and

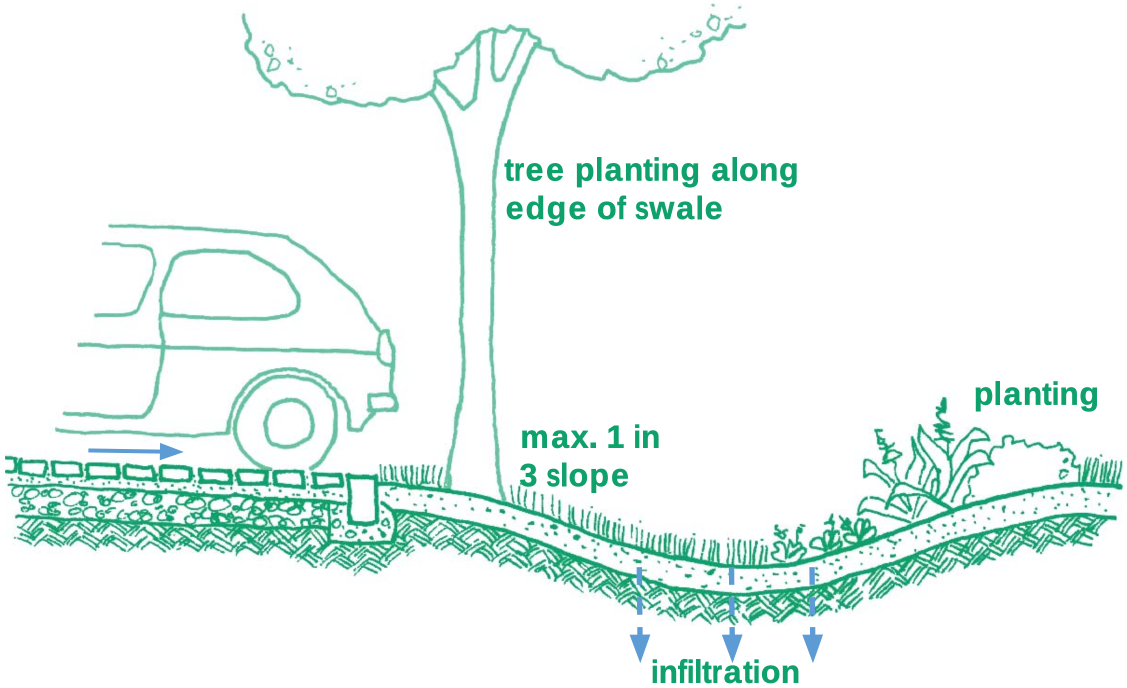


Figure.13: Shallow vegetated swale used to collect or move runoff

Source: Adapted from Susdrain [54]

groundwater condition should be verified by testing site soil before lining the system [35]. A vegetation cover needs to be selected based on local climate and precipitation pattern, also should be dense enough with dense rot structure to resist erosion. Native planting from local environment always serve the best for this purpose, considering the aesthetics aspect of landscape design [35], [38].

Vegetated swales have a relatively low construction cost compared to the conventional piped drainage system. However, high initial maintenance and periodic monitoring are required during establishing of the system [38]. Regular removal of sediment, trash, debris, leaf litter and dead or diseased plant material, in addition to routine mowing (to retain grass height within specific design range). Sediments dugout from swales in residential areas is not a hazardous material and can safely dispose of by landfill [35].

Bioretention

Also referred to as rain gardens, are shallow landscape areas which capture, treat and infiltrate the rainwater runoff with the same treatment process as swales, except that they are not linear (only convey excess runoff above design flow through overflow pits or bypass paths) [33], [38]. Bioretention areas can be incorporated in various landscape situations including carparks, along highways and roads, also in landscape islands and larger landscaped pervious areas [35]. An advantage of bioretention system is its scale flexibility which provides more solutions according to the site condition. It can take various forms, such as bioretention cells and rain gardens which capture runoff from gently sloping drainage area to a vegetated shallow depression and they are applicable for residential areas in urban and suburban locations. Another type is planter boxes which are typical for collecting rainwater from rooftops and small sidewalk areas as their capacity of runoff treatment is limited to small volumes [33], [42].

A bioretention system can work either to infiltrate rainwater into groundwater or to convey collected rainwater through underlying perforated pipe for reuse in irrigation system [33]. The typical area required for bioretention areas is 5 to 7 % of the overall site area. They should be integrated into the site planning and landscape design. Most ground conditions are suitable for bioretention areas. However, they should be designed with consideration of the adjacent infrastructure to avoid negative impacts on building foundations or from water ingress into surrounding pavement. The structural capacity of underlying soils should also be controlled in relation to the effect of water storage [38], [43]. Planting and vegetation consideration for bioretention are in general the same as for swales including the high density and use of native planting species.

Inspection and maintenance of the system are required regularly for litter and organic matters removal. Weeding is required after initial establishment of the vegetation then on annual bases. In case of system-clogging or contamination, both damaged vegetation and filter media layer should be replaced [38], [43].

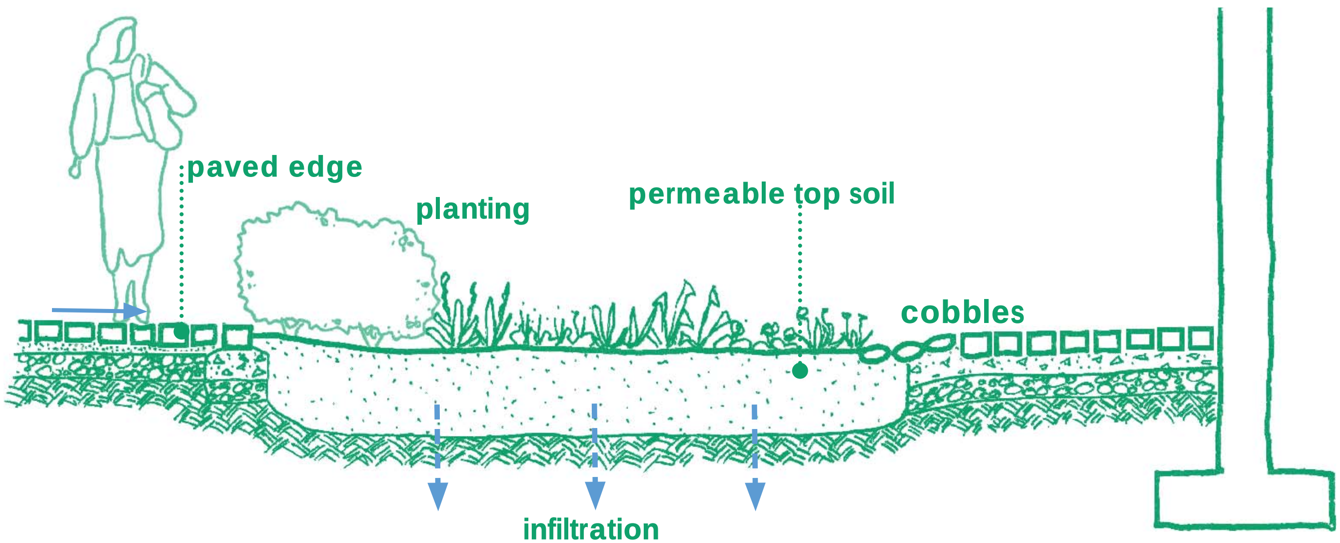


Figure.14: Vegetated bioretention with specially designed engineering soils

Source: Adapted from Susdrain [54]

Geocellular Systems

Geocellular systems are modular prefabricated plastic units used for stormwater infiltration or as a storage tank. [41], [43], [44]. Geocelleular systems come in a variety of sizes and can be adapted to meet the requirements of any site using cuboid structures with high void ratio and porosity. The individual plastic units can be installed together underground to form a larger tank which is wrapped in either impermeable geomembrane or a permeable geotextile [43], [44].

A geocelleular system can allow runoff to infiltrate into the soil at slow rate through its structure in order to recharge groundwater aquifers. In other cases where using the stored water for irrigation is required, the system is used as storage volumes [43], and should be located in the lowest level of the designed drainage area. However, the modular units should support earthworks materials and be designed as retaining structures according to geotechnical principles. Installing the system adjacent to existing infrastructure or building foundations can increase their vulnerability to damage during and after construction activities [44].

Monitoring and regular maintenance of the geocelleular system are required. This includes conducting a regular removal of debris from catchment surface and replace surface infiltration medium as necessary to avoid system clogging. Further, remove sediment from pre-treatment structures, also inlets, outlets, overflows, and vents should be restored especially after a strong stormwater event [43].

2.3.2 Wastewater & Greywater Reuse

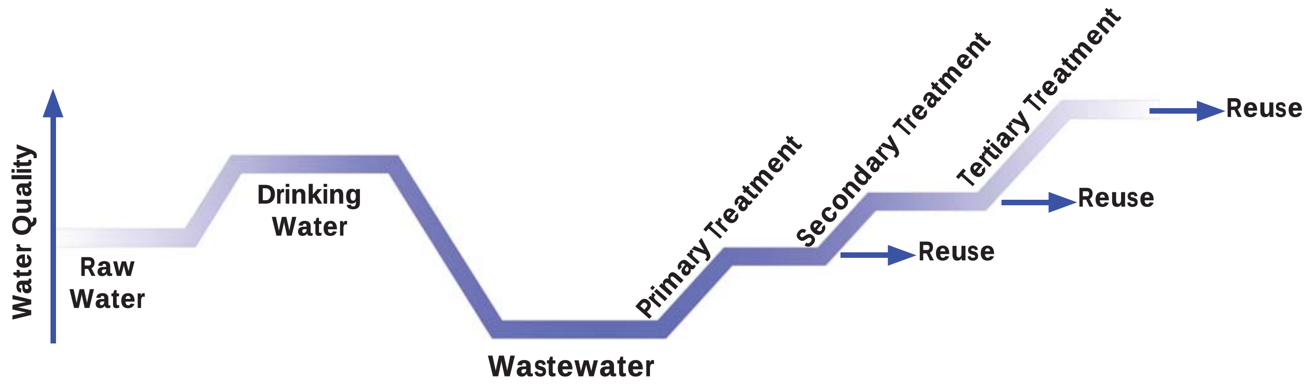
Wastewater reuse as a mean of supplementing water resource has gained considerable interest in arid and semi-arid regions due to water scarcity and water supply demand, considering its reliable low cost and technology methods [45], [46]. The benefits of reuse water are increasing the ability to acquire new water supply, conserve existing water sources and protect it from pollution [46]. Municipal wastewater and greywater can be seen as a source of both nutrient and water for plant growth, forestry, golf courses, parks and gardens [47]. Treatment options can control the achieved water quality depending upon the use of reclaimed water. These uses vary from groundwater recharge and crop production to the advanced treatment that produces potable water quality [46]. This section will shade the light on constructed wetland systems and afforestation as potential strategies in the context of this study.

Constructed Wetlands

Constructed wetlands are engineered systems composed of a shallow basin filled with water, a substrate material (mostly gravel or sand) and planted with vascular plants. The system allows Treated wastewater to feed into the system and discharge through inlet and outlet structures which control water level within the treatment cell [48]. Discharged water from the system can be stored and used for irrigation of parks and gardens during the dry season [47].

Figure.15: Treatment technologies available to achieve any desired level of water quality

Source: Adapted from Guide lines for water reuse [43].



Constructed wetlands incorporate two types of systems: free water surface (FWS) which imitate the appearance and function of natural wetlands. The system merges open-water areas (different depth) with emergent vegetation in a surface flow design. This design complexity of shape and size is an advantage to the aesthetics, enhances the landscape of the site and provide wildlife habitat. Also, it facilitates the operation and maintenance because the water surface is unconstrained [49], [50]. However, typical concerns to this type of constructed wetlands are the potential breeding sites for mosquitoes (could be tackled by maximizing macroinvertebrate predators in the system) [47]. In addition to the problem of high evapotranspiration rate from the water surface in hot climate regions [51].

Another type of constructed wetlands is vegetated submerged bed (VSB) which consist of sand or gravel beds planted with vegetation. The water level in the system remains below the surface of the substrate [49], [50]. Advantages of this system include that they have better nitrification due to the high oxygen transfer capacity of the system, the size is considerably smaller than free water system and concerns associated with insects and unpleasant odors are limited since the water is not exposed [48], [49]. However, the submerged system is less efficient in solid removal and can cause system clogging if the substrate media and vegetation were not well designed [48].

Due to the mentioned Advantages and disadvantages of both systems, a growing interest (especially in hot climate regions) is focusing on hybrid constructed wetlands systems that combine and complement them to achieve the maximum performance [48], [51]. Studies have proved the water losses in the hybrid system is only 30-53% of the total inlet in hottest summer. Further, the overall performance of mean removal rates are: COD 94%, BOD 95%, total suspended solids 84%, $NH4^+$ 86%, total nitrogen 60%, total phosphorus 94% [51].

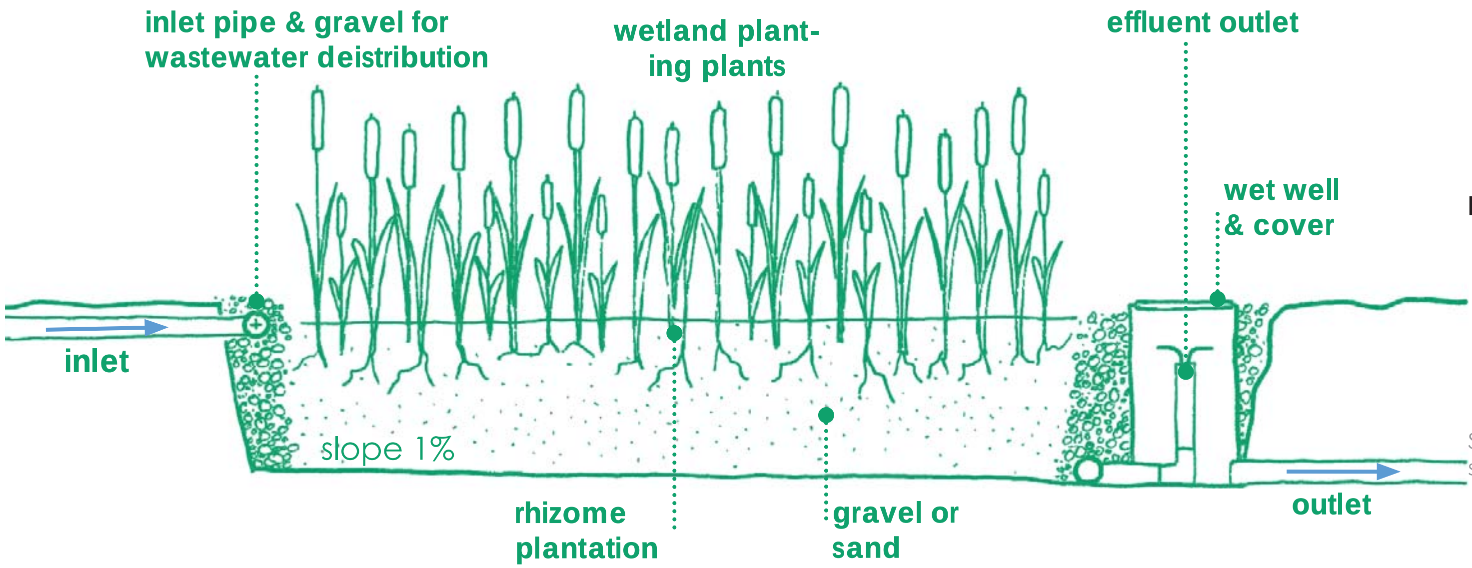


Figure.16: Vegetated constructed wetland that use sedimentation and filtration to provide treatment of wastewater

Source: Compendium of sanitation systems and technologies 2008 [119]

Operation and maintenance of constructed wetlands are mostly passive and involves less intervention in terms of start-up, routine and long-term [48], [50]. The main maintenance procedure is the adjustment of water level and flows control in the basin through inlet and outlet adjustment, which affect directly the performance of the system. In addition, conduct vegetation management in order to maintain the desired plant communities within the system and also conduct odor control procedures [48].

Afforestation in Arid Regions

Refer to the establishment of trees on lands that have no history of forest cover [21], [52]. In arid regions, where unutilized desert lands, sunlight and sewage water are considered to be potential resources, municipal wastewater can be treated and used to irrigate trees in woody crops forests. Treated sewage water in addition to sludge contains the primary nutrients that are essential for tree growth [53]. Afforestation provides plenty of ecological, economic and social benefits, which mainly can manage to use the scarce water resource efficiently. Trees increase infiltration, help the soil to store water and can protect the ground from soil erosion. Besides, Establishing forests improve water quality and protect water bodies from sediment by filtering pollutants. Simultaneously, Forests can offer a recreational aspect and enhance the local biodiversity in urban areas [21], [53].

The primary cost associated with forest establishment include the cost of land, purchasing seeds, planting and regular maintenance [36]. The time lag is a notable cost consideration in afforestation projects. Compared to grey infrastructure, trees take the time to fully grow and work as required which can increase the overall project costs [21]. Regular maintenance includes trees pruning and watering as well as conducting pest control [36].

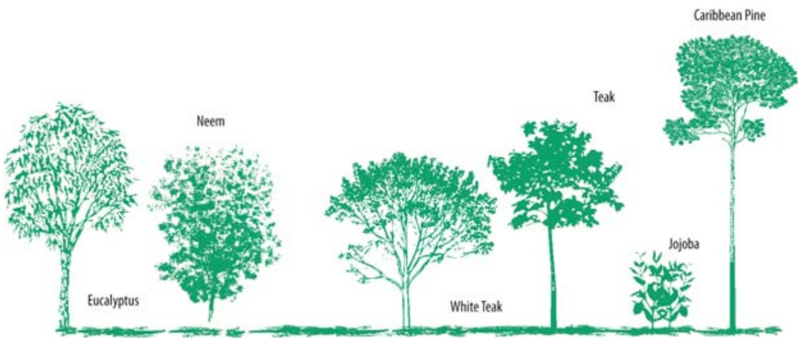


Figure.17: Example of mix of tree species for afforestation

Source: Adapted from Afforestation in Desert Lands of Egypt 2015 [53]

2.3.3 Landscape & Irrigation System

Vegetation and ground cover establishment in water-limited regions impose a serious challenge. Previously, green areas in deserts only existed in oases, but recent modern desert cities are generally dependent on technology to maintain their urban green areas and overcome the harsh environmental conditions [55]. Artificial imported landscape plants consume enormous quantities of water transported from far distances through pipes and channels [56]. In response to the urban and environmental challenges in arid regions, water-efficient landscape that integrates plant selection, adaptation, efficient irrigation and management practices is required to maintain water quality and reduce water consumption [57].

Water efficient landscape techniques can be based on seven water-wise principles:

Soil Analysis

Healthy soil preparation is the key to successful vegetation establishment. Soil with good aeration and drainage is essential to retain moister, treat stormwater runoff and provides nutrients. The Soil suitability for certain types of plants should be tested in order to have plants on existing soil without amendments. A topsoil contains organic matter (such as compost or shredded leaves) improves the ability of roots to penetrate deeper resulting in soil stabilization and strengthening plants against wash out during a heavy rain event [43], [59].

Planning & Design

Create a plan is an essential principle in the process of designing water-efficient landscape or renovating an existing one. First, mapping the area of intervention and identify the different qualities and characteristics e.g. existing shade (by structures or trees), wind direction, site slopes and site usage (public or private area). Then, group the zones that have different amounts of water

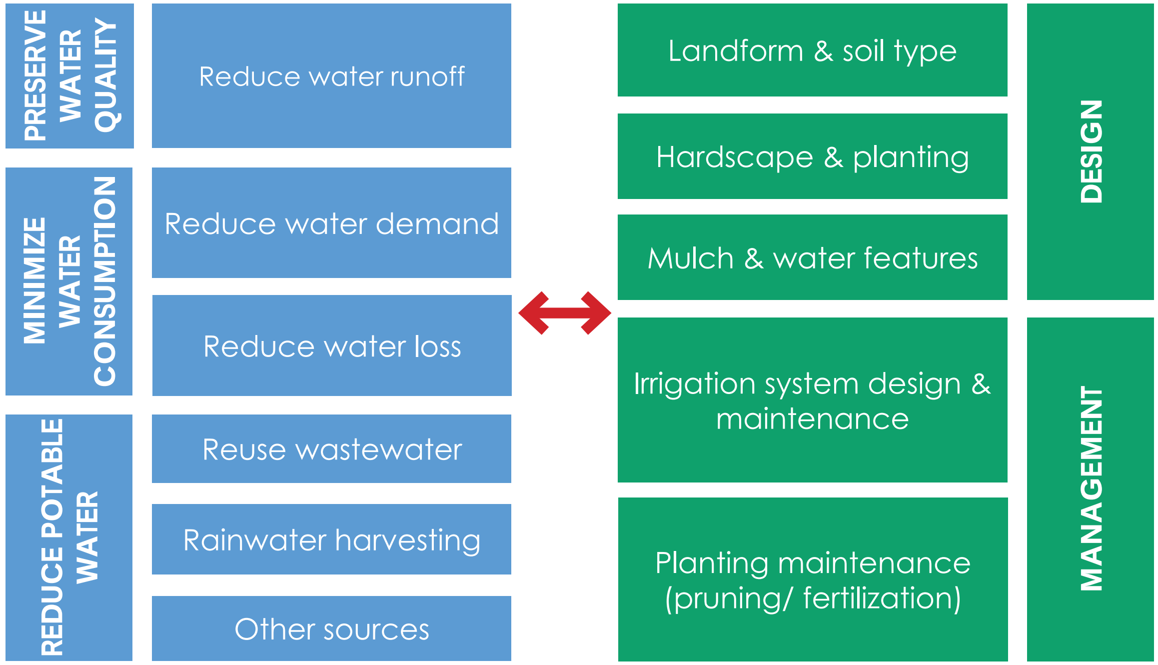


Figure.18: Water efficient landscape practices

Source: Adapted from Water Sensitive Landscape 2016 [58]

requirement. Plants selection should be based on zoning groups. Alongside that, an annual water budget, include annual precipitation, mature plant size, and annual plant water needs should be set to fulfill the water supply and demand balance [59], [60].

Efficient Irrigation

Irrigation practices can be most efficient if comprise two elements; setting a watering plan and proper selection of irrigation system. The watering plan is to identify the different water need of plants and then hydro zone or group plants together according to their water requirements. Irrigation system selection should be based on the determined watering plan and to ensure that each hydrozone is irrigated separately with a proper system that matches their water needs. Irrigation systems include various drip or sprinkler systems. For individual plants, trees and shrubs, a drip irrigation system are the most efficient to reduce evaporation and runoff. Sprinkler system is most proper for lawns and large grass areas. In hot arid climate, irrigation should take place only early morning or during the night to avoid evaporation [57], [59], [60].

Proper Plant Selection

Water conserving and drought tolerance is the main factors in the proper plant selection process. Water demand rate is the total amount of water required for plant's growth plus transpirated water from the leaf and evaporated water from the soil, and measured as (ET) in millimeters per day [61]. Generally, native plants are the best to fulfill these criteria besides that they provide habitat and prevent from invasive species. Trees and shrubs can serve as an aesthetic feature in the landscape design and most importantly, they provide shade over large areas which protect surfaces and soil from direct solar exposure thus reduce water evaporation and evapotranspiration. Appropriate planting can also protect young plants from being washed away by runoff in addition to minimize bank stability risks [43], [59].

Practical Grass Area

Unplanned lawns and large grass areas are against the principle of the sustainable landscape. In arid and semi-arid regions, frequent irrigation is required to maintain adequate growth and quality of the turfgrass. Lawn irrigation is considered a major cause of high freshwater consumption during summer months [62]. Thus, selecting lower water-use and drought resistance with lower ET turfgrass is essential for decreasing water needs. For instance, the warm season species such as buffalograss, bermudagrass, paspalum, and bahiagrass, have exhibited low and medium water use rates [61]. Furthermore, the turfgrass use is not recommended in non-recreational areas like road islands or roundabouts. Planning grass areas should be limited specifically to recreational areas such as in parks and public gardens, considering to integrate permeable hardscape and other soft scape elements in the design as well [63].

Mulching

Mulch can lower soil temperature by screening the direct radiation from landscape soil. That eventuating in roots protection, slow evaporation, and retain soil moisture. Mulch can be an organic or inorganic material such as pine straw or screened decomposing granite. However, studies have shown that organic mulch can be more effective in desert climate than inorganic mulch. Moreover, mulches may be used as an urban heat island mitigation strategy [59], [60], [63].

Proper Maintenance

A regular maintenance is required to keep vegetation grow strong as well as water-efficient landscape. Various maintenance practices include mowing, weed control, fertilizing and pruning. Mowing turfgrass during the summer should not be more than one-third of the height of grass, that the taller it is the cooler soil would be. Also, leaving grass clippings on the lawn helps nutrients to return to the soil. Weeds are undesirable plants purloins nutrients and water from other plants. Controlling weed mechanically is the best way to minimize their damage. Pruning stimulates the growth of trees and shrubs, should be during the winter season. Finally, adding fertilizer improves soil, increase root mass and surface area [57], [59], [60].

2.4 GREEN INFRASTRUCTURE PLANNING PRINCIPLES

Decentralized green infrastructure solutions for urban water management needs to be ecologically, economically and socially sustainable. The main challenges to achieve that goal are to consider green infrastructure solutions as an integral part of the overall urban design planning concept in terms of aesthetics, amenity of urban areas in addition to the cooperative multidisciplinary work of professional such as Planners, engineers, and architects. Also, the gap in professional's knowledge of the advantages and ideas of decentralized concepts. Secondly, the lack of public awareness and acceptance that the problems and advantages of water management are not properly demonstrated to the local inhabitants [38], [41].

In order to tackle these challenges, a set of specific principles have been constituted the concept of urban water management in combination with urban design as critical to the success of green infrastructure planning approach.

Aesthetics

Stormwater and wastewater management elements should provide an aesthetic value to the public and private open spaces; technical solution for securing water resources to be considered also as design problem [64]. Making green infrastructures visible as a design element, which counters to gray infrastructure, can capture the attention of city inhabitants through a noticeable daily and seasonal changes occur to the natural process of the water cycle. This flow of dynamic process invites residents to appreciate and understand the importance of water cycle and raise their awareness and sensitivity to the scarcity of water as a resource in urban areas. Decentralized solutions also contribute towards sustainable living and the improvement of quality of life science green spaces and water are essential components for city livability [41]. Moreover, green infrastructure elements should be integrated in surrounding area (buildings, urban structures, landscape) considering the adjacent built and natural context. The solutions are not limited to natural structures, but creative man-made designs can contribute to a positive urban design outcome engages the city and reacts to the environment [41].

Functionality & Context

As a main concept, it is inadequate to concentrate on the content alone (flora and fauna only within a single managed area). An analysis of the biological and physical components of the surrounding areas leads to a holistic understanding of the challenges to tackle and be adaptable to possible changes of basic conditions [22].

The local condition of the site such as topography, soil, and water table level and water quality should be fully considered while planning and design water management solutions. The variety of available technical measures give the flexibility to determine the optimum solutions. The selection of accurate measures based on the intended use of water; whether to be infiltrated, restored, or to be used, also the available space and the surrounding area [41]. In addition, solutions should be flexible against the future changing conditions. These conditions are either related to climate change such extreme weather events or the effects of demographic or economic changes such as population growth or economic crises [41]. An appropriate design of water management solutions adapted to the context of the site can afford benefits to the nature and people.

Linkage & Connectivity

Successful green infrastructure requires the creation of green space network that functions as an ecological system. Focusing on individual sites, a single green roof or random street trees cannot provide the required ecosystem services to post a sustainable city. Green infrastructure also requires linkage and communication between governmental programs, different agencies, non-governmental organizations and private sector in order to facilitate a collaborative conservation effort [22], [65]. This effort is occurring at multiple scales to create a connective network to serve the community. Scales of green infrastructure network varies from site-scale projects, city or community-wide to regional scale of protecting open and natural spaces [66]. Committing to this fundamental concept of connectivity provides a useful and satisfying framework for low impact development.

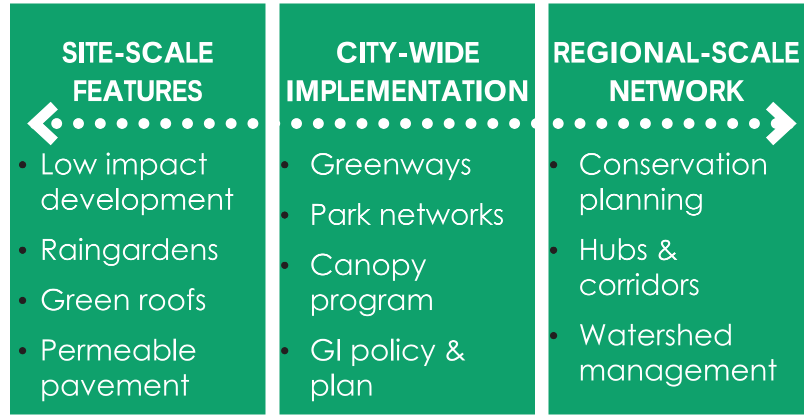


Figure.19: Nested scale of green infrastructure

Adapted from Greening the Grey 2013 [61]

Public Perception & Acceptance

Green infrastructure initiative requires the involvement of different stakeholders in the public, private, and non-profit sectors and incorporate the perspectives of residents, owners and users into the design process. The demands of local residents can be raised through community participation that allows to share plans with all related stakeholders, including those who are against a proposed development [22], [41], [65]. Benedict and McMahon stated that the landowners should "feel their voice are heard, their opinion is valued, and their rights are respected" [22]. As more the community gains awareness they understand the value of development and they will become active supporters of green infrastructure initiative.

On the other hand, the cost of implementing decentralized water management solutions should be comparable to the conventional counter ones. Expensive solutions, difficult to implement and technically complex should not be included in any development plan [41].

2.5 GREEN INFRASTRUCTURE PLANNING & DESIGN PROCESS

A successful green infrastructure approach must set overall objectives of the desired project before committing to a process that can be accomplished over time to achieve those goals. For instance, setting a yearly goal of stormwater runoff volume reduction or gradual increase of harvested rainwater for reuse over planned years. Comes after is selection of the potential area to be developed within site scale as small as residential area or it could be as large as the entire city or even expanding to include regional scale. An assessment of existing conditions of the project area provides a cohesive understanding of the circumstances posing the challenges. This includes gathering information related to the climate, water resources and consumption, green spaces and site condition. In addition, all maps and GIS data associated to the project area (e.g., Parcel Boundaries- Building Footprint Boundaries- Land Use- Water Quality Data- Flooding Data- Sewer Catchment Areas- Current Green Infrastructure Database- Tree Inventory or Canopy- Demographic Data- Pervious / Impervious Surface- Satellite Imagery). Using this basic analysis and data collection, a baseline estimation is needed as a measurement tool against the impact of proposed green infrastructure features, which will be identified in next step. Exploring the opportunity of applying these features on private and public lands including streetside or median strips, sidewalks or parking lots, besides parks and open spaces within the area. Volume retention, reduction or supply resulting from the implementation to be calculated once the features and projects of green infrastructure have been selected. The runoff retention or wastewater have been treated for reuse comparing to the previously estimated baseline are the subject of the calculations. Having these results in hand is leading to set annual goals considering what can be achieved by selected applications as a percentage of baseline in one year and the ability to maintain the performance of the system over the planned years. Monitoring the progress of installed green infrastructure applications is essential towards achieving the annual targets [67].

Figure.20: Flow of green infrastructure planning & design process

Source: Adapted from Green Infrastructure Portfolio Standard 2012 [67]

2.6 CONSTRAINTS AND OPPORTUNITIES TO GREEN INFRASTRUCTURE

Barriers to green infrastructure implementation can be sensed differently depending on the geography, community, and socio-economic context of specific urban area [68]. A study conducted in 2011 by the Clean Water America Alliance has found some common constraints and the most dominant were uncertainty about outcomes, standards, techniques, and procedures which impose the risk of implementing and funding green infrastructure projects [68]. The major barriers can be categories to technical, legal, financial and community barriers.

Community & Institutional

Since the gray infrastructure become the typical solution for waste and stormwater management, Public perception and education of builders and stakeholders might be an obstacle against shifting the social paradigm for integrating green with gray solutions [66], [68]. Thus, incorporating green infrastructure concepts into formal and informal education programs is necessary for institutions and communities to accommodate the values of green infrastructure. Education play main role in adjusting cultural values of political leaders, administrators, developers, professionals, and others in order to appreciate green infrastructure aesthetics and characteristics [68]. Additionally, cross-boundary coordination is required among agencies and community cooperation as well despite the difficulty of communicating across agency, politics and public, with different interests [68]. The opportunity of gaining public support for green infrastructure starts with education and sharing of information in parallel to training programs for municipal staff. Secondly, implementing demonstration project can promote the concept as a model for residents and facilitate the collaboration among city agencies, local organization, and the private sector [68].

Budgeting & Financing

The perception that green infrastructure implementations are costly and hard to maintain is widely spread among private developers and construction firms. Also, the risk-driven from the uncertainty of standards, techniques and the unclear life cycle and maintenance costs in some projects raise the financing challenge [66], [68]. A considered argument is that the cost of constructions and operation can be high if the population in a community or a city have not reached the critical mass for the use of green infrastructure [68]. Another constraint is the lack of economic incentives from state or local government such as reducing utility rates or provide tax reduction [19]. Making the case for green infrastructure requires an effort to quantify its many benefits and to conduct studies to identify the cost of service and revenue analysis. Besides, using both financial and non- financial incentives encourage green infrastructure [68].

Technical & Information

The technical barrier can be represented in the absence of the required skills to implement the project, in addition to insufficient knowledge related to the environment, design standards, best management practices, the investment and implementation plans. The lack of education and training programs are resulting in either non skilled calibers or a skeptic image of green infrastructure concept among stakeholders. Operation and maintenance are a dynamic and continuous process which is challengeable to many local cities or regional governments. Furthermore, the lack of design standards for the altering performance of green infrastructure systems could produce risk and reduce the accountability of the system among engineers. The availability of space might raise a conflict of interest between planners and investors since the green infrastructure features require mostly extra spaces, but the investors' financial interest lays in maximizing the buildup area for better profits [66], [68].

2.7 CASE STUDIES

Shading the light on existing successful experiences of green infrastructure implementation will be demonstrated in two different cities. Among the world similar desert climate regions similar to Egypt the choice was limited to Tucson city in Arizona, southwestern United States and Lima City, Peru in South America. The two cases are presenting both hyper-arid and semi-arid contexts with altering strategies focus.

Figure.21: Location of case studies

2.7.1 Tucson, AZ, USA

In the arid desert of Arizona State, Tucson city is located between the City of Phoenix and the U.S. Mexico border. Although Tucson has a desert climate, it has more precipitation than other surrounding areas with average 300 mm per year because of its elevation 806 m above sea level. The rainfall has a seasonal pattern that posing stormwater flooding and pollution threat. In addition, about 96% of this rainfall is lost by the effect of high evapotranspiration. The main water resource for the city's demand is groundwater. Due to the increasing water demand led by the population expansion, the source of groundwater started to deplete. Therefore, the city of Tucson has developed a sustainable approach using green infrastructure strategies to solve their stormwater pollution and water scarcity issue [69], [70].

The city has introduced General plan framed in main objectives; first to increase the efficiency of water use by implementing conservation program. Second, to acquire nonconventional water resources to supplement

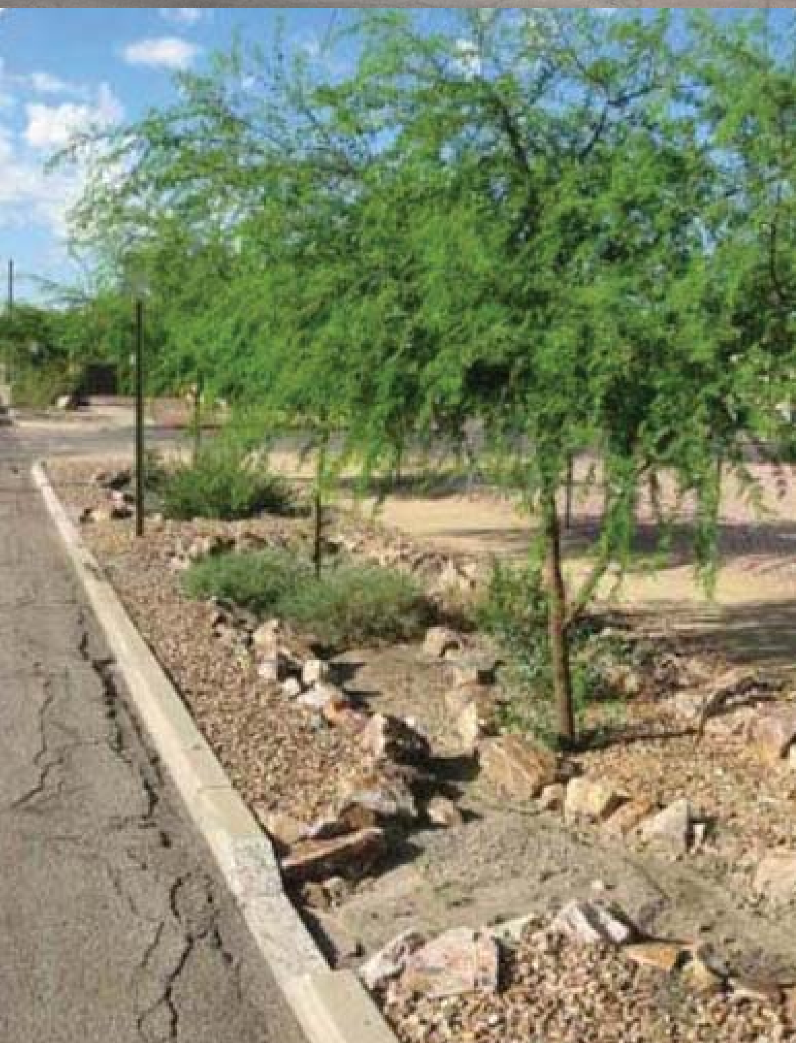
Figure.22: Active & pasive rainwater harvesting in Tucson,AZ

Source: City of Tucson 2009 [70]

the existing supplies and to sustain the future city's growth. Within these objectives, an urban landscape framework has been set to acknowledge the effect of landscape on the quality of life within the city in terms of reducing water demand, stormwater management and rainwater harvesting. The framework consists of a *Green Streets Policy* and *Green Streets Active Practice Guidelines* that incorporate green infrastructure features into Tucson roadways to harvest rainwater and use it for landscape irrigation. Reusing the rainfall in the adjacent green spaces of streets is reducing the losses occur by conveyance or evaporation [70], [71].

Project description

The city of Tucson has developed the green infrastructure guidance manual, which identifies a variety of techniques and practices for development and redevelopment projects. The manual provides guidance for site assessment, planning and design process. It presents technical guidance on how to design, install, and maintain structural green infrastructure practices. Planted green infrastructure basin was installed in order to retain at least 5 inches of rainfall within the public right of way, and to be infiltrated and drained in 24 hours span. Where infiltration is not possible, the stormwater to be directed to vegetated swales or bioretention systems for filtration before discharge in the sewer. This to ensure the maximum reduction of polluted runoff as well as supply green spaces with required irrigation. The city also outlined common green infrastructure components



(e.g., curb openings, check dams, berms and soil amendments. These on-site measures were to facilitate the reuse of rainwater for landscape irrigation, and also establishing mature tree canopies [72], [73].

Results

The implementation of green infrastructure applications in the city had positive impacts to public health by the reduction in stormwater flooding and pollution. According to a report for the city of Tucson, "the first half inch of rain liberates oil, grease, animal feces, brake dust, metals, and sediment." The water harvesting basin and vegetate swales improved the quality of runoff through filtration and infiltration. Other achievements associated with the green streets practices was to support water requirement in terms of irrigation for all vegetation and green spaces. Also, tree canopies and streetscape greening were essential to provide shade which leads to a reduction of heat island effect. The economic feasibility of implementing green infrastructure application has been approved to be positive as the benefit-cost analysis shows that per square foot of developed land the benefit is $ 48.35 to $23 for installation cost [72], [73].

Figure.23: Neighborhood pocket park captures onsite rainwater that previously flooded the street (top)

Figure.24: Green street captures onsite rainwater (bottom)

Source: City of Tucson 2009 [70]

2.7.2 Lima, Peru

Lima is the capital of Peru and the city lies on the coastal desert between the Andean Mountains and Pacific Ocean. The total population of metropolitan Lima was projected to be in 2015 almost 10 million inhabitants, which make it the second largest desert city in the world after Cairo. However, the city's water resources are much less than Cairo. Rainfall is only 9 mm per year comparing to 35 mm in Cairo, and its three rivers are fed from seasonal rainwater & melting glaciers flow from the mountains, which make average monthly flow of 39 m^3/s comparing to 2830 m^3/s for the Nile River. Due to this characteristic, the city of Lima is considered the most in the world affected by climate change [74].

Other threats than climate change make the city vulnerable. Among challenges such as rapid population growth, the lack of planning and basic urban services, the limited water resources and the inefficiency in its use is the main challenge facing the city. The planning of green areas has a decorative approach that lacks consideration of the local ecology. Using potable water and groundwater for irrigation is common. The greenery totally dependable on constant irrigation with frequent use of grass. This approach in addition to the inefficient irrigation methods results in high water demand of green areas in the city.

For the efforts of initiating a sustainable urban development process in the city of Lima, a new planning approach called "Lima Ecological Infrastructure Strategy" (LEIS) was developed. The development approach is adapting water and wastewater management with open space planning design in the city's desert context, suggesting that creating resilient city could be achieved by promoting the use of nonconventional water resources and building sustainable green areas. The concept of LEIS is to integrate and adopt green infrastructure and water sensitive design within the arid climatic conditions of metropolitan Lima. The methodology of this approach is elaborated in three main parts: LEIS principles that formulate a set of policy recommendations that promote water sensitive urban development and wastewater management with open space planning and design; LEIS tools develop (GIS)-based analysis for the entire city to map open spaces and water resources that can localize potentials and challenges; LEIS manual supports water saving, water and wastewater treatment and reuse within water sensitive urban design strategies. Based on this strategy, two projects were applied in the demonstration are in the Lower Chillon River Watershed. First, Chillon River Park as a flood control project. The other project, which is the concern of this study, is an ecological wastewater treatment system integrated into a children park [74], [75].

Ecological water treatment park 'Children's park' [75]

The rapid urban growth and the lack of basic services pose a threat to the water quality of the river's watershed

Figure.25: Irrigation ditch in Chuquitanta: solid waste & discharge of water contaminate soil & water

Figure.26: Irrigation ditch in Chuquitanta transformed into a concrete channel

Figure.27: Project site before construction

Source: Lima Ecological Infrastructure Strategy 2014 [75]

Figure.28: Ariel view of metropolitan Lima

Source: Lima Ecological Infrastructure Strategy 2014 [75]

area due to the regular discharge of wastewater and solid waste into the irrigation channels, which are used to irrigate both agricultural land and urban green areas. Therefore, an intervention integrates the open space design and water was implemented to restore and sustainably develop the waterways system. The project was implemented in a new urban settlement developed on former agricultural land. A small park next to irrigation channel was chosen for the development project.

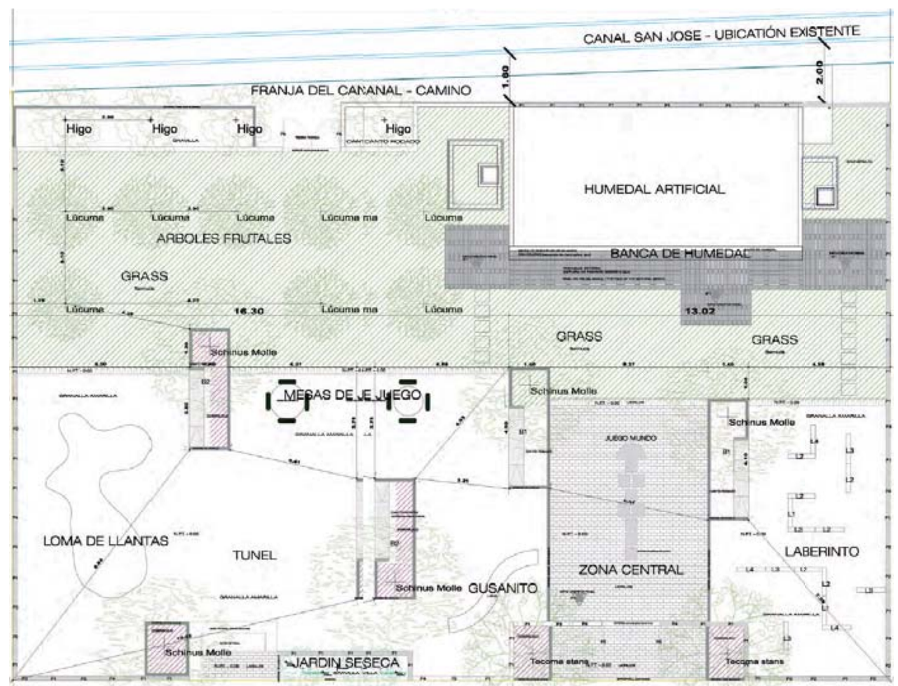
Objectives

The main objectives of the development project include the establishment of new and healthy green areas; improving the quality of water taken from the adjacent channel for irrigation of green areas; Integrating ecological water treatment technologies into the design of the park.

Project description

The park is 598.16 m^2, out of which is 50 m^2 of ecological wastewater treatment system that diverts polluted water from irrigation channel to a vertical flow, subsurface constructed wetland. The system treats and stores 20 m^3 of water in reservoir to be reused in irrigation for both Children's park and another nearby park. The treated water produced by the constructed wetland meets the standard quality criteria for green areas irrigation. The project also comprises educational panels for raising the awareness of water resources, treatment methods and reuse for irrigation; A communal play area with playground facilities made from recycled materials; trees to provide shading and low bamboo fence.

The water demand for irrigation was first calculated and given to a team of engineers to estimate the area required for the constructed wetland. The location of the system was taken into consideration to be on the highest point of the park and integrated into the natural slope of the elevated path along the irrigation channel. This to eliminate the use of pumps. Two plants species with good appearance were used in the constructed wetland to improve the atheistic features of the system within the park. The selection of both efficient irrigation



system and vegetation were essential to the overall water demand of the park. With only 1 m^3/day water the design was made up of 40% grass area planted with water-craving fruit trees, and the remaining area was mainly gravel and bricks surface with native trees and xerophytic plants that have low water demand. An efficient sprinklers system was used to irrigate the grass area with the fruit trees, and micro-tubes were used to irrigate the solitary trees and other plants.

Figure.29: Layout of the park project

Figure.30: Overview of the project site

Source: Lima Ecological Infrastructure Strategy 2014 [75]

Results

With all these components, the project demonstrates the potential of integrating treatment technology within the open space and green areas network. It proves the capability of ecological infrastructure network to improve water quality in the urban water cycle while introducing healthy, recreational green areas. The participative design approach with the educational panels has influenced the awareness of residents of the challenges and potentials of water and wastewater. Pollution threat was eliminated, water quality for irrigation was enhanced, healthy recreational areas were improved and the community's awareness was developed.

CHAPTER 3: **NEW BORG EL-ARAB CITY**

3. NEW BORG EL-ARAB CITY

The new Borg El-Arab City was one of the first generations of new towns to be announced and was inaugurated substantially in November 1988 with total area 47 thousand acres of which 30 thousand acres are built up urban area. The city lies 7 kilometers deep from the northwestern coast of Egypt, southern Lake Mariout, and some 60 kilometers southwest of Alexandria [76]. The current population presents a slow population growth rate of average 14.2% over the last 10 years. The population is concentrated in the most developed first district by 70 thousand inhabitants. With the current growth rate, the target of population planned for the city can hardly be achieved in a reasonable future time.

Table.2: Population according to the National Census of Population and Housing in various years

Source: Egypt's Desert Dream 2015 [1] & NUCA 2017 [76]

Population in New Borg El-Arab City	1986	1996	2006	2017	NUCA target
	0	7,051	41,351	100,000	750,000

Never the less, the city has very high development potentials since it is considered the natural extension of Alexandria and one of the main industrial zones in Egypt. A new strategic master plan for NBC has been approved in 2013 in order to promote a rapid development of the city and reach the population of 750 thousand inhabitants by 2032 [77]. This plan fits in the regional strategic development plan of the northwest coast of Egypt including the existing massive resorts development along the desert coastline, in addition to the newly established New El-Alamin town and a new nuclear power plant in Dabaa town [78]. The sufficient energy supply is expected to post the development in the region according to many public and official speculations. This context can create many challenges as well as opportunities to the ambitious goals of the city's sustainable development course.

The natural resources are very limited in the area, especially freshwater. The region receives relatively enough winter season rain to support basic cultivation activities. The groundwater reservoir is depleting due to the increasing and inefficient water extraction. The location of New Borg El-Arab City is the most distance from River Nile by almost 100 km, which puts high risks and cost on water supply lines to the city. Moreover, the relation of the city to Lake Mariout, as an ecosystem element in the region, and its environmental impact. These severe circumstances make the city most vulnerable to climate and environmental threats. On the other hand, the current status of the city's infrastructure of is fairly new and well maintained. There is so far only one district has been completely established, which gives much space for future sustainable development within the city considering the high potentials of rainwater harvesting and wastewater reuse. For all those reasons, New Borg El-Arab City has been seen the most suitable case for the purpose of this study

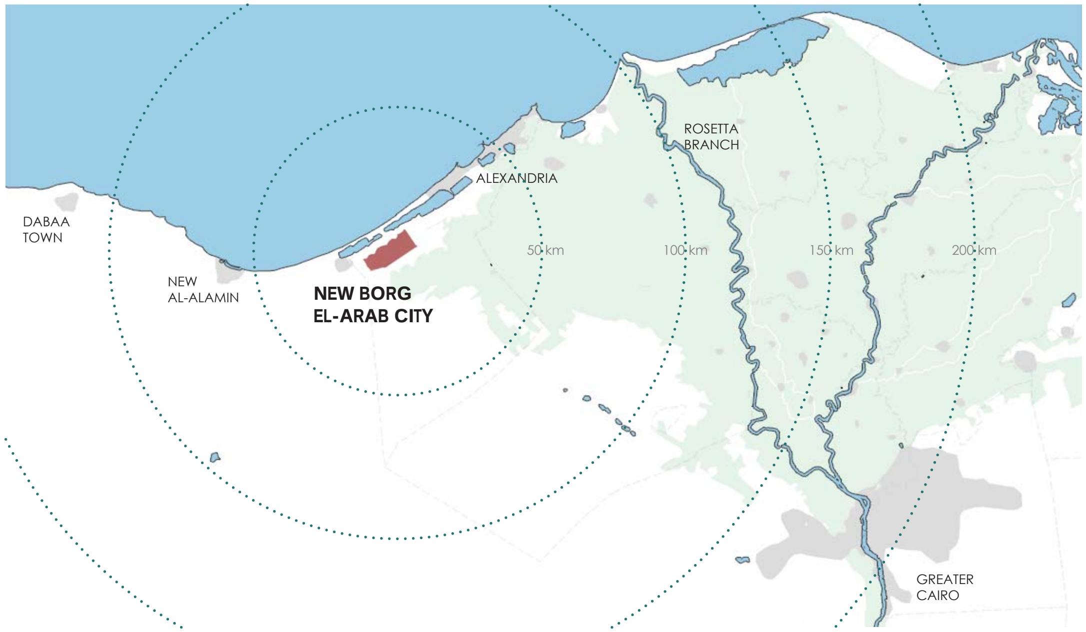


Figure.31: Location of New Borg El-Arab City with distances from other major cities

Source: Author

3.1 TOPOGRAPHY & CLIMATE

The New Borg El-Arab City is located northwestern Nile Delta on a tableland (Mariout Tableland) with not much difference in elevation that varies between 60 m and 110 m above sea level. The surrounding region of the city displays especial geomorphological features which can be categorized by 3 main elements [79]. First, the coastal plain located northern the tableland which starts from the Mediterranean shore and extends south. The plain characterized by a serious of ridges and shallow lagoonal depression. These lagoons are forming Mariout Lake with 1.5 m maximum depth [80]. Second, southern the tableland is an aggradational depression called Abu Mina Basin. The basin drains the tableland surface and it is now mostly reclaimed agricultural zone. The third is the

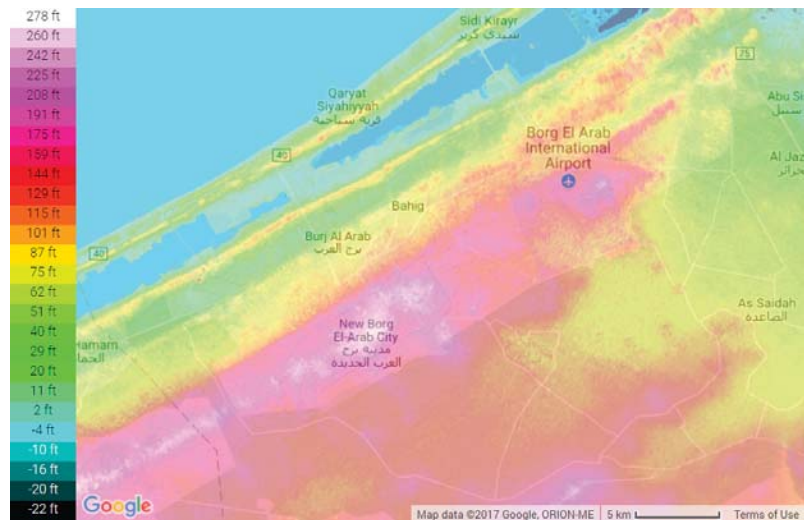


Figure.32: Elevation map of the city

Source: flood map 2017 [82]

deltaic plain which extends eastern Abu Mina Basin to the Rosetta Nile Branch [80], [81].

According to the Köppen-Geiger classification of climate, NBC belongs to the semi-arid Mediterranean climate with hot dry summer and mild winter with rainfall, High evaporation with moderately to high relative humidity. The annual average maximum temperature is 30.6 °C. The northwest Mediterranean coastal zone of Egypt receives noticeable annual rainfall which ranges from 180 to 200 mm, mostly during winter between November and March. The high temperature and sun radiation in summer increase the evaporation and evapotranspiration rates [83], [84].

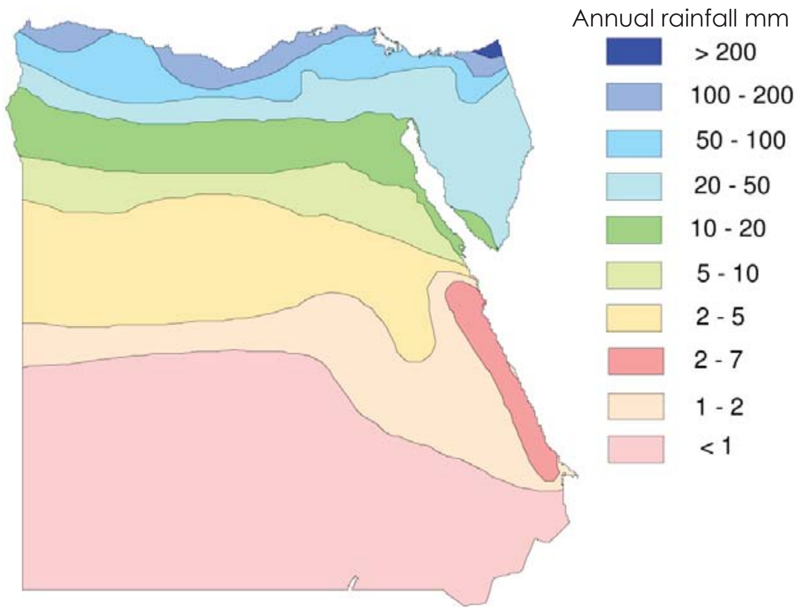


Figure.33: Annual rainfall zones in Egypt

Source: Rain Water Harvesting Using GIS 2015 [83]

3.2 HYDROLOGY

The hydrological characteristics of the NBC catchment area are related to the geographical and climatic context of the region. As the city is located on higher Tableland, force its surface to drain rainfall to the lower agriculture lands of Abu Mina Basin in the south, and to the coastal plain in the north. The site does not contain any surface flowing water or water bodies. High temperature and solar radiation increase the evaporation intensity with an annual average of 5 mm/day [9].

The urban water system in the city is represented in the water supply, treatment, and wastewater treatment. The drinking water company provides 166,000 m^3 fresh water to the city through water treatment plant at 40 Km Alexandria- Cairo road [76]. The intake of the treatment plant is from Mariout canal which branching out from Al-Nubareya canal and Rosetta branch of Nile. There are two secondary aerated basin wastewater treatment plants serving the city; one with capacity 36,000 m^3 and 115,000 m^3 for the other [76]. The plants discharge effluent to its surrounding area since there are no nearby water bodies to discharge to [85].

The natural water resources are limited to groundwater aquifers in addition to the water supply from the River Nile. The city lies on what so-called El-Ralat Aquifer which is low productive aquifer (less than 500 m^3/day), due to the past over pumping and the increasing salination of the water [81], [86]. The city is approximately 97 kilometers away from Rosetta branch of River Nile. The water is transported to the region by a network of irrigation canals and drains [85].

Figure.34: Satellite image showing the city and its boarders

Source: Google maps

3.3 LAYOUT AND LAND USE

New Borg El-Arab city layout is based on the similar planning norms of Egypt's most new cities that involve low gross densities and segregated land uses. The main element is a central grand scale spine with commercial, administrative, service and recreational uses. The residential districts are spreading along the city's spine in three main sectors, separated by regional service district. These include universities, sports clubs, medical and amusement park. The services of residential districts are concentrated in the center of each, all of which are connected to the main spine [87], [88]. Neighborhoods are grouped and distributed in each district ranging from upper to lower middle housing categories. In the recently approved new strategic master plan, the northern part along the city (formerly was perimeter buffer zone) is allocated for future regional services such as regional parks, exhibitions center, and residential gated communities [88]. On the eastern and southern limits of the city exist five industrial zones. Moreover, tracing the urban growth of the city since the time it has been established shows a huge gap between existing progress and planed masterplan of the city. Also, the changes have been added to this masterplan present the unstable circumstances and slow development of the city. This is due to many complicated aspects including manly the controversial policies, the economic and political situation of the country.

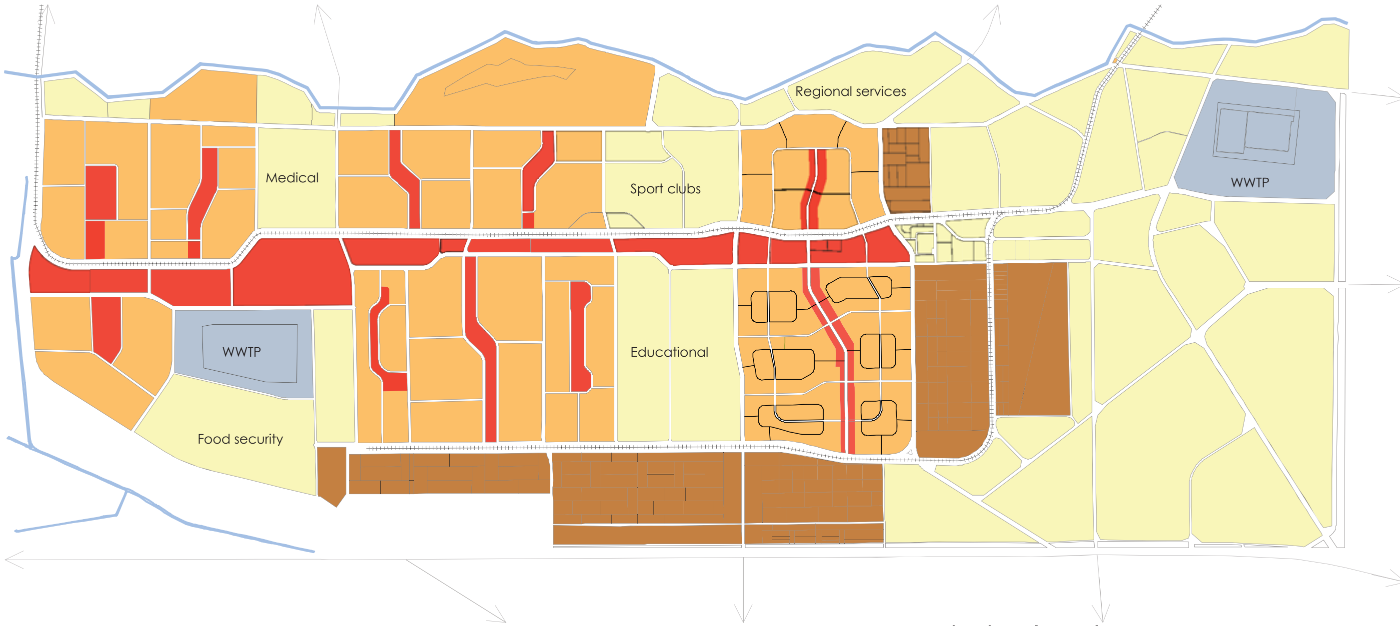


Figure.35: Basic landuse map showing the segregated urban form

Source: Author

3.4 MORPHOLOGY OF URBAN GREEN SPACES

The city's green space structure can be distinguished on both the city and districts levels. On the city level, central spine is dominating the most planed green spaces including recreational and theme parks in addition to the high percentage of greeneries associated with all civic buildings to be built there. Also, sports facilities and universities have considerable green spaces. There are two regional parks are planned in the northern limit area and luxury residential compounds with a golf course. Furthermore, perimeter buffer zone supposed to be a green belt for the city, in spite of the fact that these areas and the northern perimeter have been informally developed for agriculture.

District level green spaces structure consist of a public garden in the district's service center and every neighborhood have a green core as well. Besides, the other private and semi-public green spaces associated with the public housing estates and individual housing blocks. According to national regulations, public gardens and pedestrian pathways should represent in 20-25% of the neighborhood's total area [9]. Samy Abdullah from Gardens and landscape department of NBC Authority stated that the total area of existing green spaces is 260 feddan (1.09 million m^2) including the 9 neighborhoods in district 1 (interviewee: Abdullah 2017).

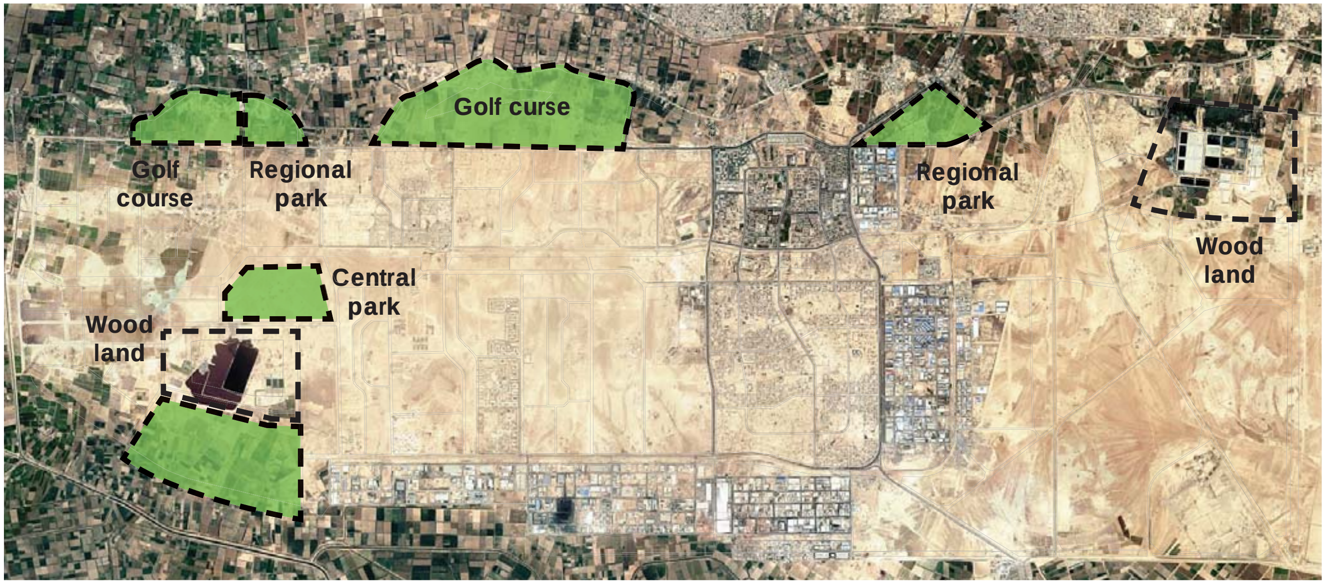
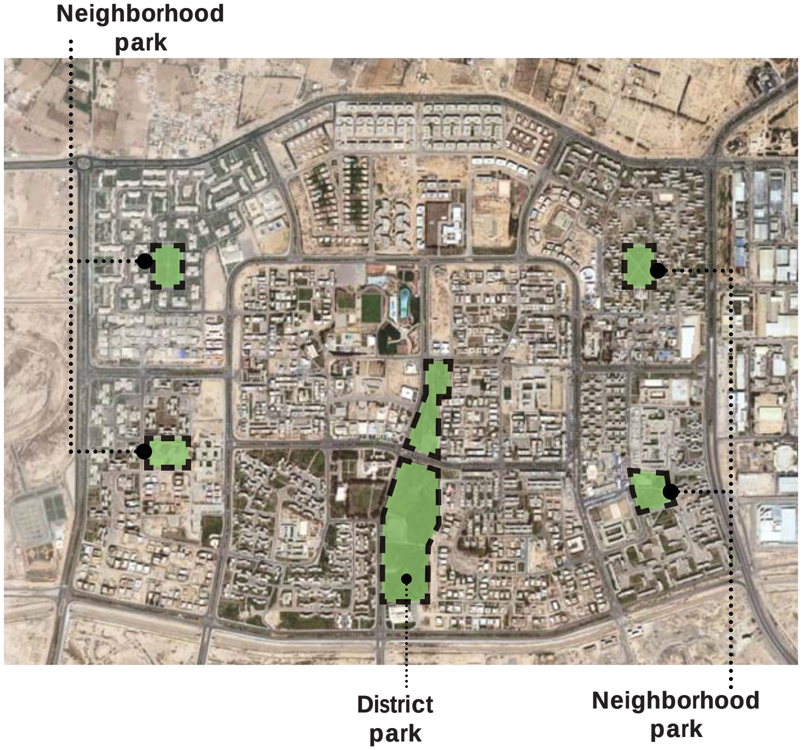


Figure.36: **Structure of green spaces on the city level**

Source: Author

Figure.37: **Structure of green spaces on the district level**

Source: Author



The World Health Organization suggest a minimum of 9 m^2/ Inhabitant of green space that a city should have. Green coverage ratio in NBC to the number of urban population of the first district provide almost 15.6 m^2 green space per person. This figure appears to be fulfilling the international recommended standard, yet can be considered as exceeding space over the resident›s needs [89], especially in such arid region, when compared to other cities around the world. For instance, the city of Berlin provides 6 m^2/ Inhabitant, Tokyo and Istanbul are providing 3 and 6.4 m^2/ Inhabitant respectively [90].

3.5 TYPOLOGY OF URBAN GREEN SPACES

The existing and planned urban green spaces of NBC is comprehensively surveyed and divided into eight types. This was based on the use of green space and more importantly, the way space is perceived by the public as distinct spaces which provide a range of services that enable different recreational activities [91]. The division can be concluded under three categories; Private, semi-public and public green spaces. As follows:

Public Parks and Gardens- are outdoor designed public space includes lawns, vegetation and is used for recreational purposes.

Public Squares & Street Islands- are green spaces associated with roads for managing traffic especially in arterial roads and expressways intersections, roundabouts and traffic islands.

Green Buffers- are enormous perimeter green belt zones, mainly to reduce the negative impact of noise and air pollution coming from the city, but not include recreational activities.

Wood Lands- are an establishment of trees on desert lands adjacent to a source of treated wastewater used for irrigation and sludge for nutrients.

Common Green Spaces- are common shared spaces dominated by lawns and small playgrounds. These spaces can exist as urban yards in individual housing subdivision or within the blocks of public housing estates.

Sports Field & Youth Centers- sports clubs have access to deferent green spaces that can offer sports activities, in addition to playgrounds for children.

Figure.38: Different green space typologies in the city

Source: Google maps 2017

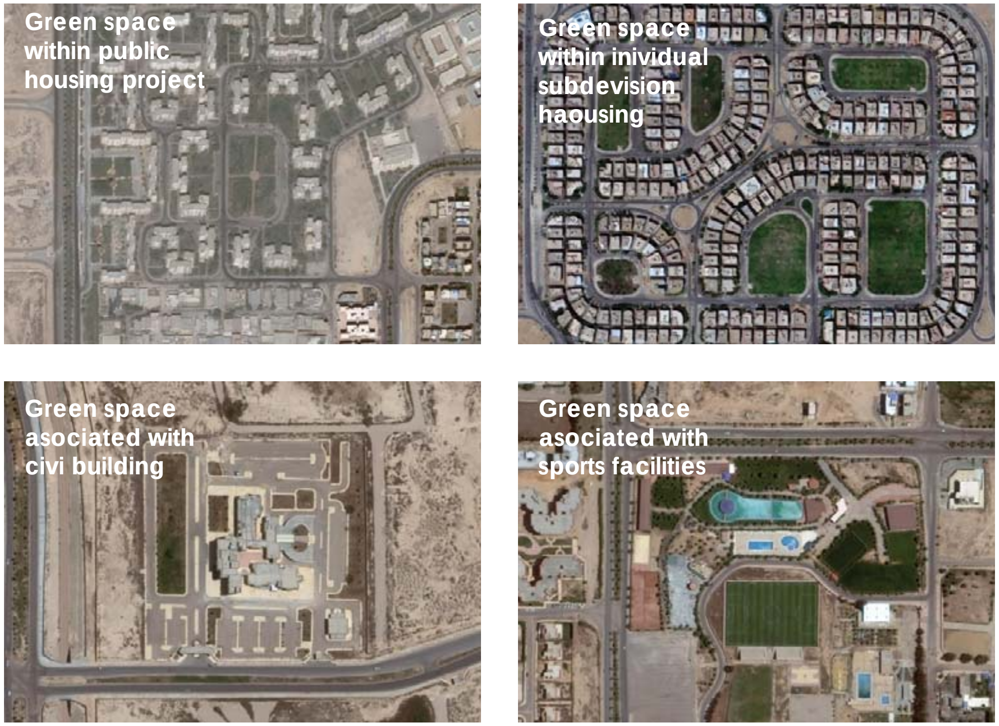
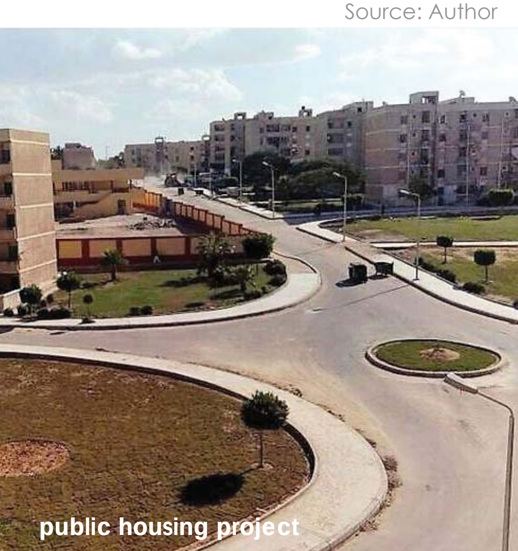


Figure.39: Images showing the different green space typologies in the city

Source: Author



Green Spaces associated with Civic Buildings- are vegetated outdoor spaces of public and administrative buildings, such as Educational Facilities, office buildings, religious buildings, and hospitals.

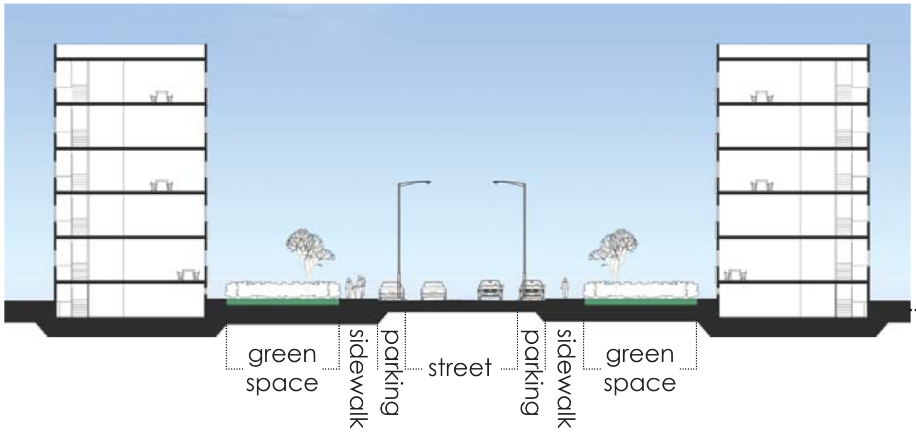
Private Gardens- are privately owned spaces, belongs to an individual property of house and villa, or in a gated community.

3.6 STREETSCAPE

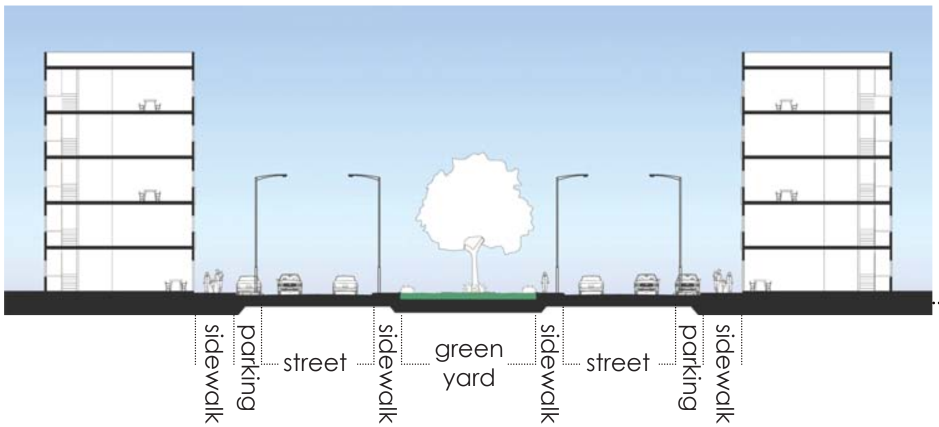
Street network and planning of its scene in New Borg El-Arab City are similar to those planed in most of the new towns in Egypt. Odd angles of 30- 60 degree were adapted in road intersections and the layout of public housing blocks, which creates unused pieces of land that is designated for more excess green space. The segregated land use patterns are formed to a standard hierarchical street network that is not referred to any traditional pattern of Egyptian cities. The arterial streets are separate residential neighborhoods and districts with an exceptional width of 24- 30 meters and green buffer strips. The local streets within neighborhoods are mostly 8 meters circulating in loops and bends [1], [87].

Arterial Streets

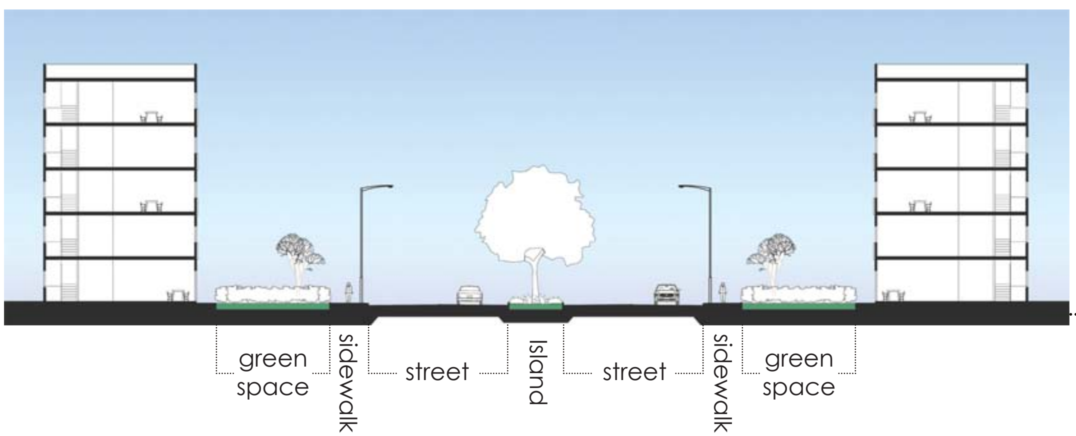
Arterial Streets are double sided streets separated by 4-6 meters grassed island, planted mostly with palm trees and short hedge trees on the edges. Every distance there is a paved strip for crossing. Strips of green space are laying on both sides along the street and work as a


green space
sidewalk
parking
street
parking
sidewalk
green space


LOCAL STREET OF PUBLIC HOUSING DEVELOPMENT


sidewalk
parking
street
sidewalk
green yard
sidewalk
street
parking
sidewalk


LOCAL STREET OF INDIVIDUAL HOUSING SUBDIVISION


green space
sidewalk
street
Island
street
sidewalk
green space


ARTEIAL STREET

green buffer to the different districts. The area has mostly grass cover with green hedges and scattered trees, with noticeable lack of seats and minor shading elements. A stamped concrete sidewalk is separating the driveway and buffer strips.

Local Streets

Local streets have different scenes according to the housing layout that the street run within. In public housing neighborhoods, the streets are two ways separating the residential buildings which clustered on tracts of extended open green space. Therefore, streets are always adjacent to green space on both sides with parallel car parking lots and sidewalks. In the individual housing subdivision, the streets are separating the residential blocks with parallel car parking lots on one side and the green yards on the other side. The green part of both streetscapes is dominated by grassland cover with minor shrubs and trees. Basic street and Landscape features such as furniture, shading or shops and restaurants are missing which does not generate any pedestrian activity within the neighborhoods. Thus, streets interaction with adjacent buildings is not represented with wide and unmanageable green spaces.

Figure.40: Streetscape profiles of different street types

Source: Author

Figure.41: Image from the site showing the types of streets

Source: Author

3.7 GREEN AREAS SUSTAINABILITY ANALYSIS

3.7.1 Water Supply and Demand of Green Areas

In the semi-arid climate of NBC city, the water demand required for irrigation of green areas is relatively high. The limited and uneven annual rainfall in addition to hot weather can vary the demand during the year from hottest summer to cooler winter months. Based on former studies and several engineers working in irrigation in Egypt [92], [93], the average water consumption for irrigation in Egypt is between 4.76 – 7.14 l/ m^2 · day (for public green areas) and 7.14 – 11.91 l/ m^2 · day (for private green areas). The current overall water required for irrigation of public and semipublic green spaces in NBC was calculated as between 1.9 – 2.85 million cubic meter per year. However, the ideal water demand of frequently used plants species in the city, which considered as moderate to high demand, can be categorized as follow [92]:

- High water demands (approx. 5.73 l/ m^2 · day)
- Moderate water demands (approx. 3.58 l/ m^2 · day)
- Water demand for turfgrass (approx. 4.29 l/ m^2 · day)
- Low water demands (approx. 1.42 l/ m^2 · day)

Since most trees are planted in turfgrass and according to Costello et al. that tree species planted in such case are generally met by the high water needs of turf [94]. Therefore, the ideal water demand of green areas of

NBC is calculated as 1.71 million cubic meters per year. This means that the current water consumption for irrigation in comparison to the ideal water demand for the same area is in average 28% more.

The main challenge to the sanitation sector in Egypt is the financial sustainability of services. Water and wastewater tariffs in Egypt are among the lowest in the world. The highly subsidized water prices are resulting in inadequate cost-covering of the sanitation services and subsequently, a high stress on the national budget. For instance, the water tariff for public services use was LE0.80 /m^3 and wastewater tariff could only cover a 20% of the total cost and 60% of operation and maintenance cost [95], [96]. Recently this year, a tariff's adjustment has been introduced and enforced to raise drinking water and sewage fees (see Appendix C). The new prices for public services and commercial use are fixed rates range from LE2 to LE6.95 per m^3 (about $0.11 - $0.40) depending on the sector consumes the water, whereas sewage fees are calculated as 92 % of water prices. Specifically, the total cost of water for public service use is LE3.84 /m^3 (LE2 water cost plus LE1.84 sewage cost) [97].

Table.3: Estimated annual water demand of green areas

Source: own

Water Demand L/m^2/ day	Green area total m^2	Water demand million m^3/year
4.76 - 7.14	1,092,000	1.9 - 2.85

3.7.2 Wastewater Treatment & Greywater Reuse

The reuse of municipal wastewater and greywater is essential to close the gap between supply and demand and sustain the NBC future. Many existing challenges are facing this potential and must be tackled. The Egyptian *Code* (501/2015) for the reuse of treated wastewater in agriculture is categorizing the quality of treatment to 4 grades; advanced (A&B), secondary (C) and primary (D). According to the code, the use of treated wastewater for irrigation of urban green spaces in new cities are limited to treated water grade(A), grade (C&D) effluents can be used for green belts, highways, industrial oil crops and woodlands. Advanced treatment should meet the treatment grade requirements sat in code by either using additional treatment process at the specific location of use or advancing treated wastewater grades (B&C) with fresh water mixture [98].

Figure.42: Treated wastewater effluents in 10th of Ramadan City (left) & 6th October City (right)

Source: Google maps 2017

The domestic water consumption per capita is 218 l/c/d [99]. The produced wastewater is estimated by 21,800 m^3/d, considering the population of the city along with losses in the distribution system. This estimate is apart from the industries' share of consumption which increases it dramatically to 180,000 m^3/d [100]. The sewage network is a combined network that also receives rainwater runoff. Greywater reuse is not practiced in any location of the city, and domestic drainage system in buildings is not separating black and grey waters. The city has an existing WWTP receives the sewage from the eastern residential districts and all industrial zones. Another plant has been recently built to serve the western part of the city. Both plants are adopting secondary treatment process (Aerated Lagoons) and discharge effluents to its surrounding. There is no existing infrastructure so far to utilized reclaimed water for any domestic reuse except an unsuccessful project of irrigating timber forest in the vicinity of the eastern WWTP. According to Dr.Tawfik from E-JUST (Interviewee: Tawfik 2017), the project was harmfully affected by the degrading quality of water due to the pollutant industrial effluents.

Industrial wastewater is one of the main challenges to reuse wastewater in NBC. The city has four industrial zones in which 266 running factories [101], a considerable number of factories are violating the law for the wastewater discharge into the sewage system. The factories lack adequate industrial effluent treatment systems, inspection, and monitoring of their waste. In addition, the absence of legal enforcement instruments or technical support from the government side [100], [102].

For the effort to tackle the wastewater problem in the city, a collaboration between E-JUST and Tohoku universities have resulted in establishing a pilot project of

Figure.43: Eastern & western wastewater treatment plants in New Borg El-Arab City

Source: Google maps 2017

down-flow hanging sponge sewage treatment reactor on the perimeters of one public housing neighborhoods. The project aims to develop an economically, low-tech and easily maintainable treatment system that provides safe and sustainable reuse of wastewater for irrigation purposes. The treated water from the reactor is used for growing Jojoba plants as industrial /non-food crop which has, of course, an economic benefits.

Figure.44: DHS reactor at NBC & the growing Jojoba plants

Source: Author

To sum up, the potential use of TWW for irrigating green spaces of the city might be limited due to the quality of treatment and the additional problem of polluting industrial wastewater. As an initial solution, the second WWTP was built in order to separate both industrial and domestic wastewater which considered in the future plans of the city (Interviewee: Hassan 2017).

3.7.3 Stormwater Management

Stormwater management in the city is a conventional system based on combined sewerage network. The system reduces infiltration and groundwater recharge, neglecting the value of stormwater runoff as a useful supplying resource for green spaces. The existing structure and planning of the city, in general, are not

Figure.45: Roof top pipes drain rainwater to the sewage, but not benefitting the adjacent green space

Source: Author

supporting the use of stormwater. The layout of housing in residential areas and other buildings are not facilitating the collection and use if stormwater. Public open spaces are located independently and not according to water sensitive considerations or focused on the water feature. Rainwater from rooftop surfaces is discharged into the sewerage system. Also, roads layout is lacking the design of crossovers, setbacks, and sidewalks that can maximize scope for retention of stormwater. Methods such as swales and rain gardens are not part of the streetscape.

3.7.4 Landscape design & Irrigation System

Landscape elements of the public green spaces are consisting of paved spaces and pathways (hardscape), in addition to the plant›s selection and arrangement (softscape). According to the personal observation of the city, pathways are stamped concrete surfaces with maximum runoff coefficient. Other hardscape elements like pergolas or benches are very limited.

Gardens and landscape department of NBC Authority are responsible for all maintenance and operation of public green spaces of the city. An interview with Eng. Samy Abdullah (interviewee: Abdullah 2017) had drawn the attention to the actual characteristics and plants typology of the city's landscape. The used plants are mostly planted in turfgrass, and apparently are non-native with moderate to high water demand. However, the water needs of the trees are generally met by the relatively high water needs of the dominating Turfgrass landscape. The mix of appropriate plants such as groundcover, shrubs, and trees are poorly represented in the city landscape scene. The grass is considered the first vegetation solution, by roughly 70%, regardless of the specific use of green space as road islands, yards or recreational areas. A study of dwellings in California has found that the turf-dominated landscapes used 54 percent more water than the mixed landscapes [103]. The used grass in the city has low to moderate water demand. In table 04 presenting the plants and grasses

Table.4: Types of used vegetation with water demand rate and percentage represented in the landscape

Source: Author- Water demand retrieved from Deister 2013 [92]

Botanical name	Local name	Type	Water demand rate (ET)	Percentage of green cover
Conocarpus lancifolius	Bazromia	Hedge	M	7%
Delonix regia	Poinciana	Tree	M	2.5%
Ficus nitida	Ficus	Tree	M	10%
Ficus elastica	Ficus Robusta	Tree	H	2.5%
Phoenix dactylifera	Date palm	Palm tree	M	3%
Washingtonia filifera	California palm	Palm tree	M	5%
Cynodon dactylon	Bermudagrass	Turfgrass	L	70%

been using in landscape of the city including water demand characteristic and an estimated percentage of representation of species in the city, water demand data were retrieved from Deister, 2013 [92] as data sheets, provided by the landscape architecture office in Cairo "Nature for landscape architecture and planning", Dr. Mohamed Refaat (see appendix G).

Other softscape elements like mulching, shrubs, and flowers are not efficiently considered in the landscape. Eng. Samy refers that due to an inevitable social behavior of the residents (vandalism). In spite of the extensive area of green space, the inhabitants seem not benefiting or considering any merits of such space. The deterioration of existing green areas and its total absence in many locations has been witnessed widely in the city, which caused by the lack of water resources that can cover the demand for landscape irrigation. In contrary, an observation of the site has shown some urban agriculture activities, residents cultivate food crops on their private gardens as well as undeveloped public common lands although it is against regulations of the city's Authority.

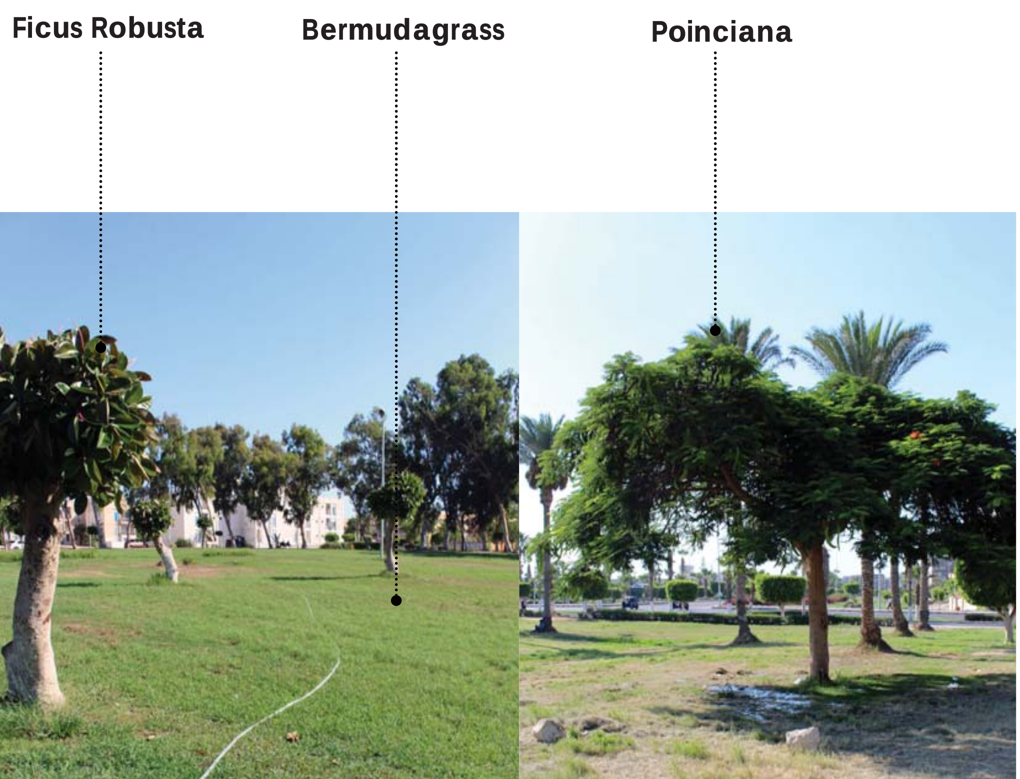
The commonly used irrigation method is hand watering by taps and hoses. A team of gardeners are responsible for connecting hoses to the water taps and use it for irrigation on scheduled times per day. Scattered water taps on different green spaces. According to Eng. Ahmed

Figure.46: Shows hand watering with hose as the main irrigation method

Source: Author

from Water & Wastewater Networks department, NBC Authority (interviewee: Hassan 2017), a pop-up sprinklers network were installed recently at the area of city's entrance, but not functioning so far due to technical issues. In addition, he mentioned that there are plans to construct irrigation network in the new developing districts and connect it with the newly constructed WWTP on the western edge of the city.

An essential aspect to be considered in general is the social behavior of resident and their awareness of the benefit and use of green space. From analysis and observation, the site lacks any provisions for leisure or recreational activities, which can fulfill the need of the residents to use the open space. Apparently, the residents and authority behaviors of neglecting the surrounding space could be an obstacle to limit solutions for the sustainable regeneration of green spaces. Specifically, in the operation and maintenance stage, along the lifetime of any project. This area of concern will not be directly tackled but will be considered as important criteria for the selection of any application for improvement.



3.8 THE REGENERATION

This section of the study draws a concluding framework and methodology of the proposed optimization. The different result and observation from the analysis of the city's context of green spaces will be reflected on the conceptual model, driven from chapter two of green infrastructure in arid and semi-arid regions. The goal is to present sustainable solutions that can contribute to establishing a water balance model for the city's green areas. Overall and specifically tailored models fit the different urban settings of NBC will be developed. The flexibility of the regeneration process is presented in terms of scenarios that offer different options that cover both site and city scales of green infrastructure, with more in depth focus on the site features comparing to the city or region. This direction was driven from the previously mentioned fact that the urban growth of the city is unpredictable, slow and influenced by different economic and political aspects, which can negatively affect any proposed solutions for the city-wide scale. Thus, decentralized or small features on a site scale can be adaptable to any current or future urban settings.

A project area will be considered for calculations and the demonstration of different features. This is an effort to evaluate the capability and efficiency of chosen strategies, in addition to illustrating the challenges and limitations of the regeneration process. The economic feasibility of the intervention is an additional aspect to be evaluated for any further progress and will be presented through cost analysis based on the different scenarios.

Figure.47: Nested scale of green infrastructure

Source: Adapted from Greening the Grey 2013 [61]

3.8.1 Green Infrastructure Strategy Framework and Methodology

The intervention framework of green infrastructure outlines the basic concepts and interlinked strategies that support the sustainable regeneration of urban green areas in NBC. Under the aim of creating a resilient green space in a water-scarce city, two main concepts were initiated for how to introduce nonconventional water supply in the urban context of NBC, while endeavoring to reduce the water demand of urban green spaces. Both concepts are realized in form of different strategies to be implemented. To control the fresh water supply and provide alternative sources, two strategies are being introduced; Adopting water sensitive urban design and treating wastewater within the design of open space. The applications of both strategies demonstrate the benefits can be gained by understanding the relation between green space design and the urban water cycle of the city. Harvesting rainwater from different surfaces according to the anticipated precipitation, in addition to facilitating the reuse of treated wastewater, are main tools in this direction. The design of landscape itself is a strategy to mitigate the increasing water demand for green space. Type of plants and irrigation regime affect noticeably the water demand of a green space. Turfgrass consumes water more than any plants species, native plants to the local environment consume less water than other imported species. In addition, using an effective irrigation technology that suitable to the plants can reduce the water demand of green space dramatically. Another important strategy is working on the improvement of public awareness towards the importance of open space as a median for social and cultural communication.

An overall summing up of the analysis can draw the attention to main points to be taken into consideration while planning or taking decisions for the regeneration process. The final conclusion of the adopted green infrastructure strategies was driven from all technical,

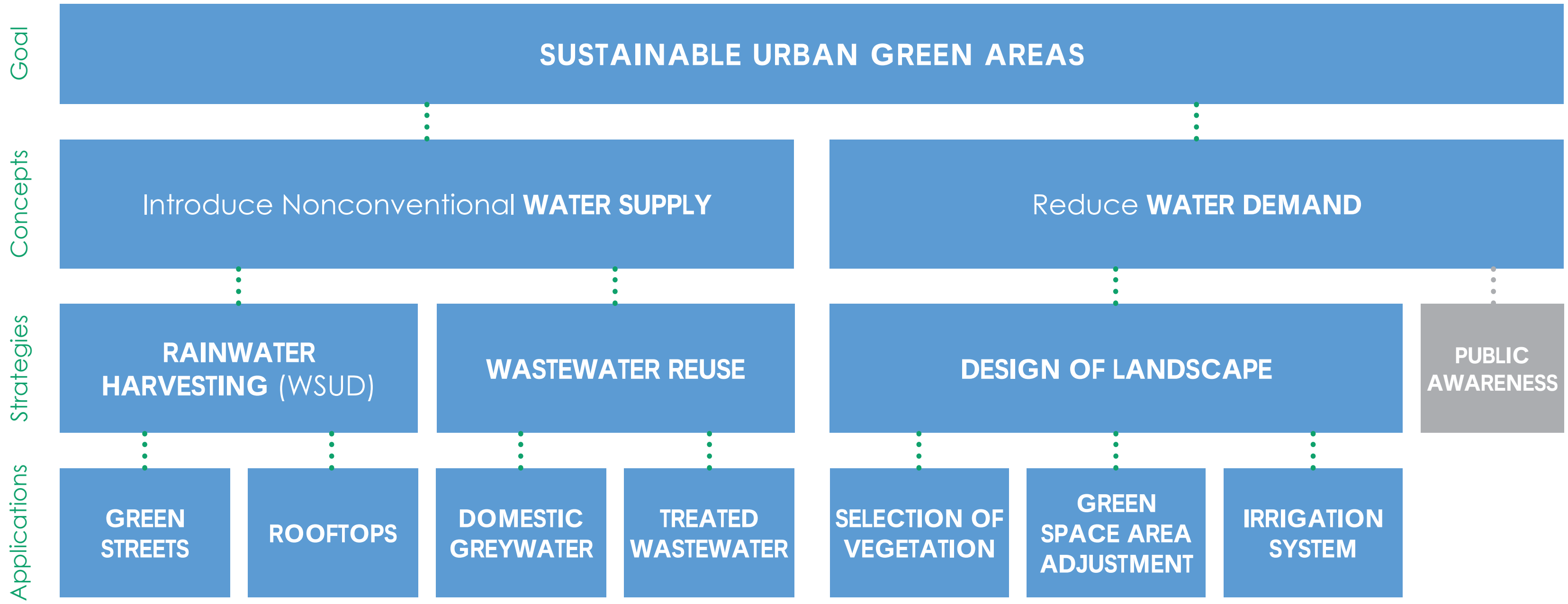


Figure.48: The intervention framework of green infrastructure outlines the basic concepts, interlinked strategies and applications

Source: Author

geoclimatic and social settings of New Borg El Arab City. The following points are an elaboration of these proposed strategies in accordance with the intervention framework:

Adopting Water Sensitive Urban Design Strategies

The NBC location and hydrological analysis present the lack of natural water resources and therefore impose the need for alternative non-conventional resources. The city and its relation to the surroundings as a higher table-land affect its character as a catchment area with the potential benefit of reusing rainwater from the annual precipitation fall on the region, especially in winter season. Stormwater conservation and SWUD strategies are currently not practiced. However, capturing rainwater solutions, in such circumstances, are considerably recommended rather than infiltration and groundwater recharge. There are possible active and passive strategies to be implemented on the site scale. The aridity of the region's climate to be respected while determining the applicable applications, and to avoid any exposed detention water bodies or water conveying open canals because the high temperature and solar radiation can increase the evaporation from exposed water bodies.

Developing green street strategies including Swales and Raingardens will increase the capacity of rainwater harvesting for nonpotable uses and reduce the demand for landscape irrigation on the fresh water supply. Linear swales can be created along street islands and roundabouts with the provision of water inlet as a curb opening, and in accordance with the street slope. Raingardens can be implemented within the space of urban yards in individual housing subdivision or as deducted areas from the generous green space in public housing estates, specifically adjacent to car parking areas which serve as catchment area along the internal streets of the neighborhoods. Raingardens can provide storage capacity as well, through subsurface perforated pipe collection system. The streetscape and segregated urban land use (residential - commercial – industrial) helps controlling pollution and quality of the harvested rainwater from different surfaces. For instance, road surfaces with average low traffic in residential neighborhoods are presenting less pollution threat. Other street surfaces in industrial zones, might need on site (passive) treatment prior to usage. The existing streetscape does not support the feature of rainwater storage, whereas the surfaces are mostly impermeable, but permeable surfaces and geocellular storage systems could be applicable for future development areas, although the skepticism regarding its economic feasibility in this specific urban setting.

Additionally, Rainwater from rooftops can be stored in cisterns and used potentially for irrigation of different green spaces. The collected water has the minimum risk associated with reuse, considering that the disinfection of water is not required. The cisterns can be incorporated into the design of different private or public constructions. For the sizable existing public housing development, rainwater from rooftops can be collected in central cisterns or to be integrated with decentralized constructed wetland system.

Integrating Wastewater Treatment in the Design of Open Space

Constraints such as the quality of treated wastewater and standards set by the Egyptian code would limit the potential use of TWW for irrigating green spaces of the city to few options. Other conditions like availability of open space (high density- low-density developments) or the location of the district in the city (existing- new development) can affect the decision for the possible solutions. An initial step is the separation of industrial and domestic wastewater. For the existing developed part of the city, reusing treated wastewater is not possible because the lack of available network and the very degrading quality of wastewater discharged from eastern WWTP. However, a decentralized community level constructed wetlands would be an accountable solution, considering the availability of unutilized open space within the existing public housing development. A horizontal flow constructed wetlands for greywater treatment can supply a substantial amount of treated water for irrigation of green spaces, benefit the pattern of high domestic water consumption per person in the city. The wetlands to be integrated within the landscape design of the area in an aesthetic manner. Separating black and grey water drainage systems is essential for any possible effective strategy of greywater reuse.

On the other hand, the western newly constructed WWTP can supply treated water for the irrigation of green spaces in the city's future development areas. The adjacent area of the WWTP can adjoin with Wastewater Treatment Park for further tertiary treatment of effluents from the WWTP as required by the Egyptian code. The treatment park will work as a centralized constructed wetland and be integrated with an adjacent planned city park. Also, to supply the planned regional parks and golf course within gated communities exists northern the city. The planned design of these connected green spaces will support the creation of a green corridor, which also provides sufficient habitat for urban biodiversity. Other solutions would be; the upscaling of decentralized community WWTP such as E-JUST project

Figure.49: Potential of creating green corridor supplied by treated wastewater in WWT park

Source: Author

previously mentioned, and facilitating the reuse of lower quality treated wastewater for irrigating the green belt in the perimeters of the city or woodlands projects.

Reduce Water Demand through Design of Landscape

The current landscape design shows many challenges. The imbalance of plants selection and dominating turfgrass increases the water demand and should be altered to be more varied in plants' species. The extensive green spaces area in the city, in general, and especially in the existing public housing areas, is raising the question how much green space does such developments in a city need?. Urban green area allocation to be adjusted and planning should adapt to climate and resident needs accordingly. This could be implanted in housing projects by dedicating existing green spaces for establishing decentralized constructed wetlands and redesign the area to accommodate more interactive surfaces that can create a cohesive and well connected green space.

Activity areas, active and passive recreational spaces, playgrounds, Trails, and Pathways are features to be introduced to the landscape planning in the city. The design should introduce a variety of surfaces that can vary between impermeable surfaces that contribute to rainwater collection like pathways and sports areas. Other permeable surfaces like sand or gravel for playgrounds for kids and landscape features. This will strengthen the aesthetic and functionality of open space, and increases the retention capacity of rainwater harvesting as well. An example of green space planning adjustment has been implemented by the city's authority in the year 2016, but unfortunately, without any consideration of stormwater management principles or grey water reuse (Figure 50). These space's use enhancements to combined with low flower beds and high trunks trees, that can increase the shading aspect as it is recommended landscape design in the hot humid climates [104].

Figure.50: Green space adjustment, implemented in 2016

Source: Google earth 2017

Applying hydrozone landscaping is an effective concept to conserve water for irrigation. Raingardens can clustering plants with low water requirements, mixed with Temporary ponding and areas do not require irrigation or receive only natural rainfall such as mulch, gravel, and naturally existing vegetation. Lawns hydrozone accompany plants with moderate to high water requirements such trees and shrubs. The overall water demand of the hydrozone will be met by the water needs of turfgrass. The third hydrozone is clustering the fencing vegetation (hedges) of shrubs or trees, which have moderate water requirements. The Irrigation method and efficiency are different for each hydrozone. The installation of an efficient irrigation system is essential instead of hand watering in order to control the water consumption. Sprinklers are the best irrigation technique for lawns with the efficiency of 85%. For fencing vegetation, drip irrigation is most efficient with 95% [75], [105]. Rain gardens have the minimum water requirements without any supplementary water supply.

The proposed strategies and associated applications to be integrated into a Water Balance Model for green spaces. The model to be used as a decision-support tool that can assess alternative management scenarios,

Table.5: Proposed hydrozones with water requirement

Hydrozone	Location	L/m²
01	Raingardens & swales	1.42
02	Turfgrass	4.29
03	Hedges	3.58

and simulate the dynamic balance of conventional and nonconventional water resources for freshwater, wastewater and stormwater.

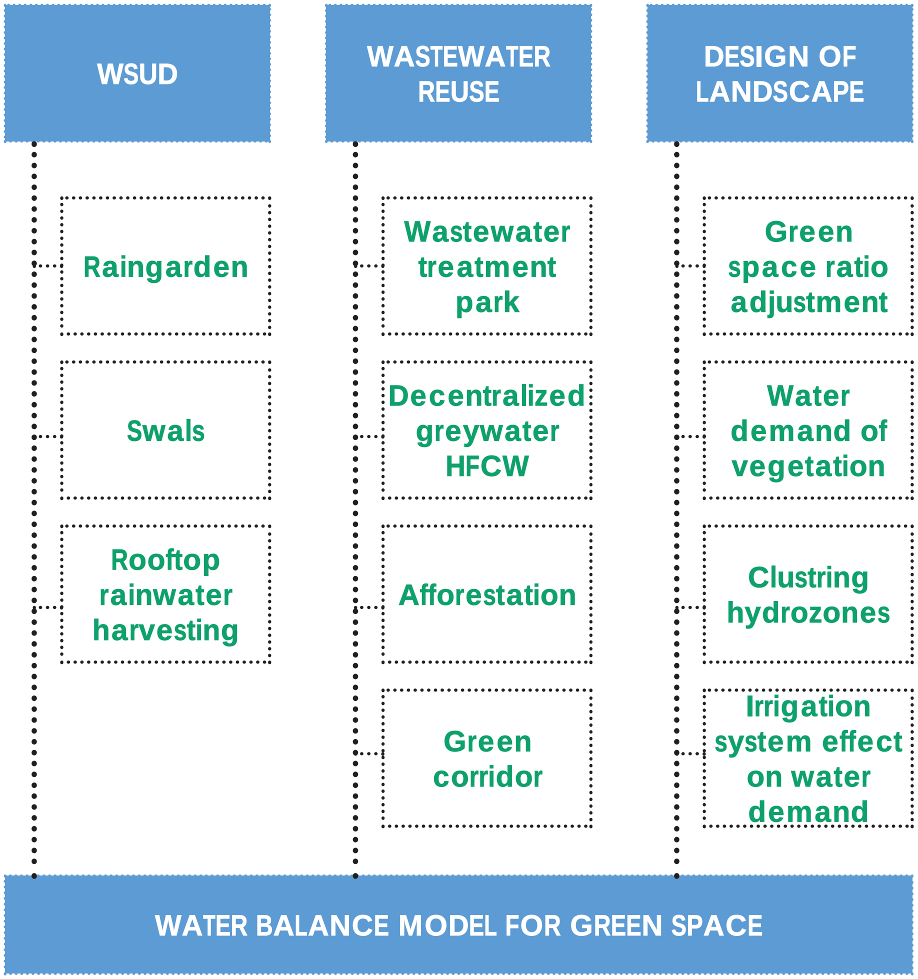


Figure.51: Site & city scale applications under three main strategies that contribute to a water balance model for green space

Source: Author

3.8.2 Project areas

A specific neighborhood area has been selected for a quantification assessment of the proposed Green infrastructure applications. The water budget required for green spaces in the site will be calculated as a baseline condition, considering the existing practices and the amount of rainwater running off currently surfaces. Then, the best fitting application for the site will be identified with basic design and dimensioning parameters in order to calculate the possible retention capacity of the intervention.

Selection criteria

In New Borg El-Arab City, there are only two developed districts out of the whole planned masterplan. The current population and green spaces mostly exist in the first district. Nein neighborhoods are forming the district, 5 of them are social housing states established by the government. The other four neighborhoods are either private housing, administrative or public buildings. In consonance with these facts, a social housing development, in the sixth neighborhood, were identified as potential project area for implementation and assessment of proposed applications. The selection is based on prioritizing important characteristics which can be concluded in points as follow:

- Public housing developments with common green spaces are major projects in the city and most of the similar new satellite cities in Egypt.
- The extensive green space area associated

with such housing projects raise the need for intervention for optimization.

- The aimed green spaces are under the direct charge of the city authority.
- Private Green spaces are private properties limited to the individual's preferences with the least obligatory authority.

Description

The project area is residential unmixed land use consist of apartment buildings formed in clusters on an extended layout of green spaces, with a total area of approximately 244 thousand square meters. The area is connected by a local street network that forms divided blocks. Fragmented linear parking lots exist along the side of streets. The buildings are linked with linear pathways through the landscape. The scale of project area includes different typologies of green space; a public garden, street islands, and common green spaces. The population of residents is estimated to 6,560 inhabitants, based on the average of 4 persons per household (according to Census Egypt 2017).

Surface materials and green spaces characteristics

By investigating the surfaces of project area during the site visit, the materials were categorized according to its properties and runoff coefficient. Data of runoff were retrieved from the book, Water quality: Diffuse pollution and watershed management [106].

The quality of water is always crucial when it comes to collect runoff from street surface. The base criteria for assessment are the volume of traffic in specific streets and the types of vehicles, which related to the land use of the area [107]. In the selected project area, there are no statistical figures of traffic capacity. However, the area is low-class residential with very low population density. According to the resident's numbers and their class, the estimated traffic would be lower than 500 private vehicles per day, which consider the least polluted streets for rainwater collection [108], [109].

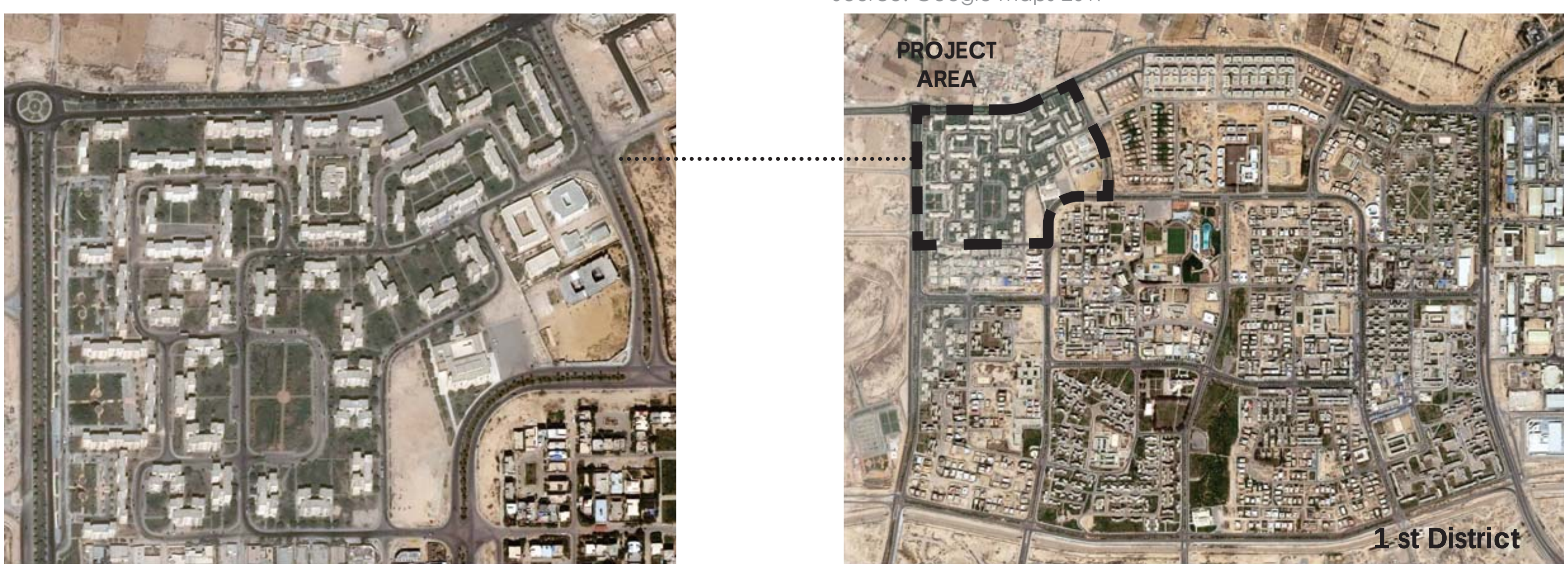


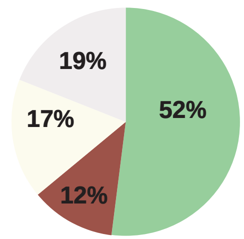
Figure.52: Satellite image of the selected project area

Source: Google maps 2017

Material	Location	Area m^2	Run-off coefficient
Asphalt	Streets & Parking areas	45,717	0.95
Stamped concrete	Pathways	27,368	0.95
	Sidewalks	15,654	
Roof tiles	Building rooftops	28,729	0.95
Vegetation	Green spaces	126,696	0.10

Figure.53: Project area layout showing surfaces material & areas ratio breakdown

Source: Author



The existing green coverage ratio to residents is 19.3 m^2 per person. Under this study area ratio should be adjusted. The turfgrass (Bermudagrass) is dominating the landscape as it is the case in the whole city, in addition to unorganized scattered trees planted in the grass, and very few hedges (Bezromia). Trees are mostly one species (Ficus nitida) with exception of few Royal Poinciana trees in limited locations. In general, all analysis and observations previously mentioned in this chapter are applying on this project area. The proposed intervention will cover all typologies with different applications.

Figure.54: Satellite image of the selected project area

Source Google maps 2017

3.8.3 Baseline Conditions

Calculating the baseline of the existing condition of the site can provide a reference measurement to assess the impact of introduced green infrastructure applications on the water budget of the green spaces in the site. The calculation includes annual and monthly estimation of water consumption for irrigation, rainwater harvesting capacity, and wastewater (black and grey) produced within the site household. Other essential aspects are the breakdown of surfaces' area which presented in this section along with additional main figures.

Table.6: Main Figures required for calculation

Precipitation mm/year	199.4
Population	6,560
Green cover ratio m^2/person	19.3
Domestic water consumption per capita l/c/d	218

According to the current pattern of irrigation practices and water consumption for square meter per day (mentioned in analysis section), the annual water consumption for irrigation of total green space is estimated by max. 330,182 m^3/year and min. 220,122 m^3/year. An average consumption would be 275,152 m^3/year. Yet, with optimization of water consumption according to the turfgrass water demand, the total water consumption per year would be 198,387 m^3/year.

The amount of rainwater runoff from impermeable surfaces and that falls directly on green spaces can be calculated using the formula:

$$Q = C * I * A$$

Where **Q** is the runoff volume in cubic meter; **C** is the runoff coefficient of different surfaces; **I** is the rainfall intensity in millimeter; **A** is the area of each surface in a square meter. Other variables such as duration of the rain event and time of concentration are not included in the calculation. The scale of the analysis is best served with such relatively simple calculation that can weigh up with the retention capacity of the proposed intervention. The further detailed calculation can be made for more specific projects, where data are available as well.

The wastewater estimation is driven by the number of population and their water consumption rate. According to data from Alexandria water company (AWCO), which retrieved from a study by SWITCH and CEDARE in 2010 [99], the domestic water consumption per person is 218 l/c/d. This result in total annual water consumption of 553,106 m^3/year for all households. Domestic wastewater is estimated 60% of water consumption at 313,188 m^3/year, of which 70% of is grey water and 30% is blackwater. Thus, the total greywater is estimated by 121,683 m^3/year. To verify the calculation results, another method is considered to verify the calculations is based on a breakdown of household end-use survey and workshop held by AWCO and CEDARE [110]. The calculation of greywater includes water from shower, laundry and bathroom tap. The result is very close to the previous calculation (detailed calculation in appendix H). The total production of domestic wastewater can cover at least 95% of current water requirement.

Table.7: Results of baseline calculation according to the ranges of green space water demands

Source Author

			Max. 7.14 l/m²/day	Ave. 5.95 l/m²/day	Min. 4.76 l/m²/day	Opt. 4.29 L/m²/day
Annual water demand	m³/year		330,182	275,152	220,122	198,387
Rainwater harvesting	m³/year	47,515	14%	17%	22%	24%
Wastewater reuse	m³/year	313,188	95%	114%	142%	158%
	Greywater	219,231	66%	80%	100%	111%
	Blackwater	93,956	28%	34%	43%	47%

The results of calculation show that total rainwater can be harvested on site is 47,515 m³/year. This amount can supplement the existing water requirement by 14% to 22% of the total current water budget, and up to 24% for an optimized one. The green space benefits directly from rainwater fall on it, while small amount can be collected actively and stored from rooftops surface. Due to the seasonal rainfall characteristics, the supply fluctuates throughout the twelve months of the year.

The monthly analysis of current situation illustrates that only 5 months, from November to March, can cover above 20% of the monthly water requirement, at maximum in December and January by almost 80%. During the summer months, rainwater has no contribution to the water budget. In addition, the active storage capacity of rainwater during rainy months is very low in comparison to the monthly water requirement during the same months, almost 3% of the annual water budget.

To sum up, the rainwater harvesting strategy cannot

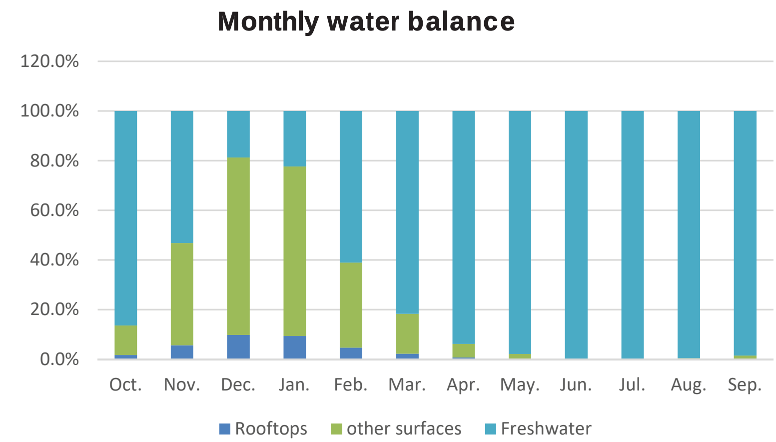
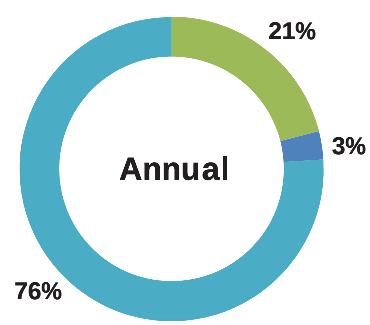


Figure.55: Annual and monthly breakdown of green space water balnce

Source: Author



support a constant supply of water for irrigation throughout the year. This is due to the relatively low precipitation and the limited built-up surfaces that can actively store rainwater runoff. The high water consumption per capita results in a high amount of wastewater that can be used effectively to supplement the water required for irrigating green spaces. The Green cover ratio to the site residents population is relatively high for such urban setting, the green space is presenting almost 70% of the total site area, which can explain the reason of the very high water demand for irrigation. Thus, an adjustment of the site layout will enhance the usage of unutilized space in a way that can sustain the supply and demand of green space within the project site.

3.8.4 Identifying Green Infrastructure Applications

Based on the existing conditions assessment of the city, in general, and specifically the project area, and according to the intervention framework, five green infrastructure applications are selected to address the green area regeneration project. The focus of this project is the use of raingardens, swales, interactive landscape surfaces and rooftops for rainwater harvesting and storage; decentralized constructed wetlands for greywater treatment and reuse, and finally landscape design and irrigation for water demand reduction. This section of study will present a detailed overview of each selected application with rough dimensioning of the systems' design parameters along with design example of each application.

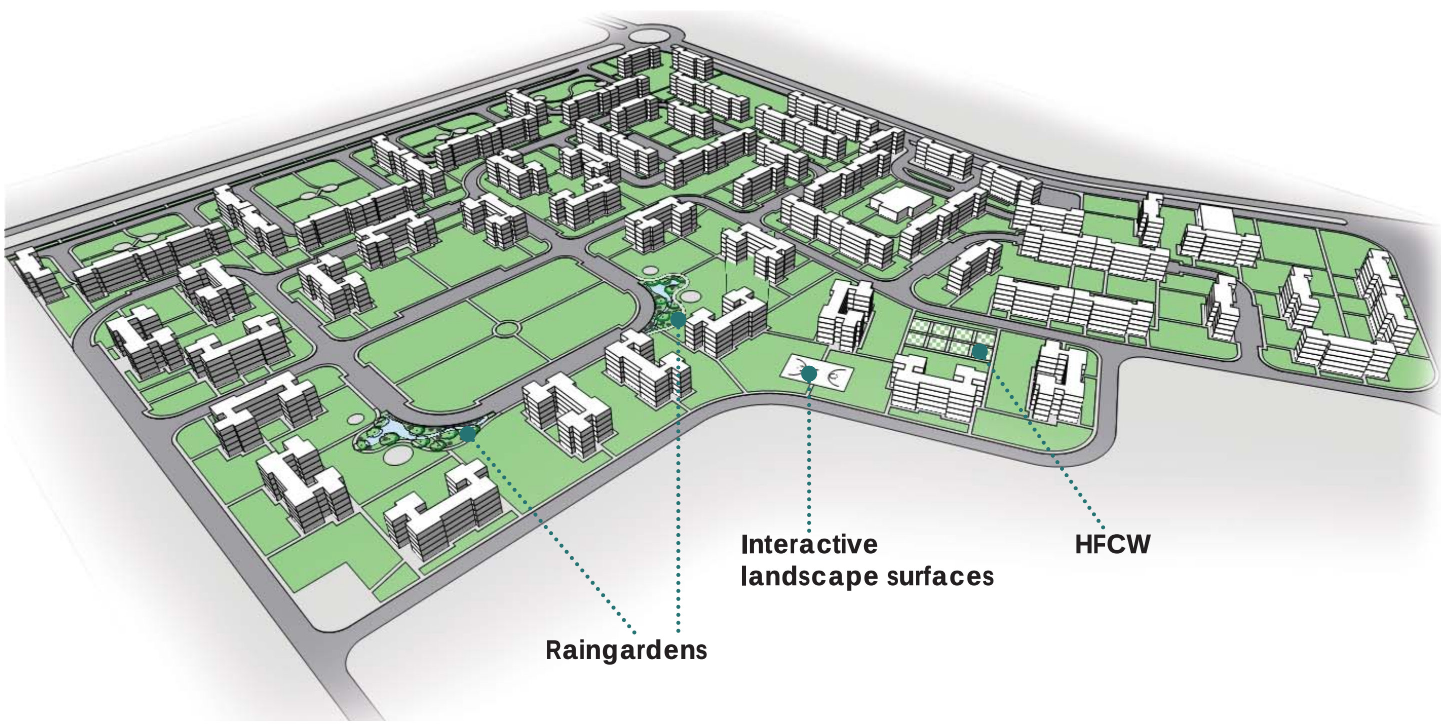


Figure.56: Location Examples of proposed regenration applications

Source: Author

Raingardens & Swales

The determined system for the purpose of this project area is intended to be filtration and collection system rather than an infiltration one. In this sense, a raingardens combined with rain harvesting tank is a better conjunctive onsite system that can be used to filter the collected rainwater and improve its quality, before reusing in landscape irrigation [111].the system should not retain the collected rainwater more than 48 hours. This to optimize the performance of removing pollutants and prevent mosquitoes spread since they cannot breed during this time [43], [111].

The surface area required for the system can be calculated by different methods. A basic method is the relation of the raingarden system to the impervious catchment area, which is estimated 7% for best performance, according to CIRIA SuDS manual [43]. This means that the required surface area of raingardens for the project area, according to the street surface area, mentioned in table 00000, is approximately 3500 m² to be distributed and incorporated into the site landscape. A criterion of water balance for the system should targeting not more than 50% for plants uptake and evapotranspiration and the rest 50% for filtration and collection [112], [113].

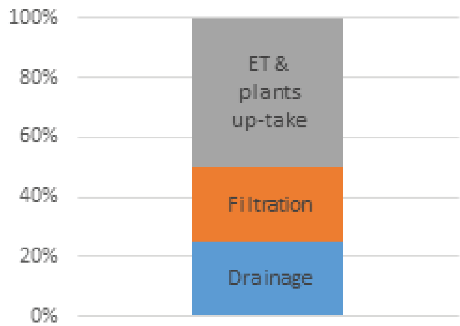


Figure.58: Water balance criteria of the raingarden system

Source: Adapted from Water Balance of Soil Mixes for Rain Gardens 2016 [112]

The parking areas on the side of streets are suitable

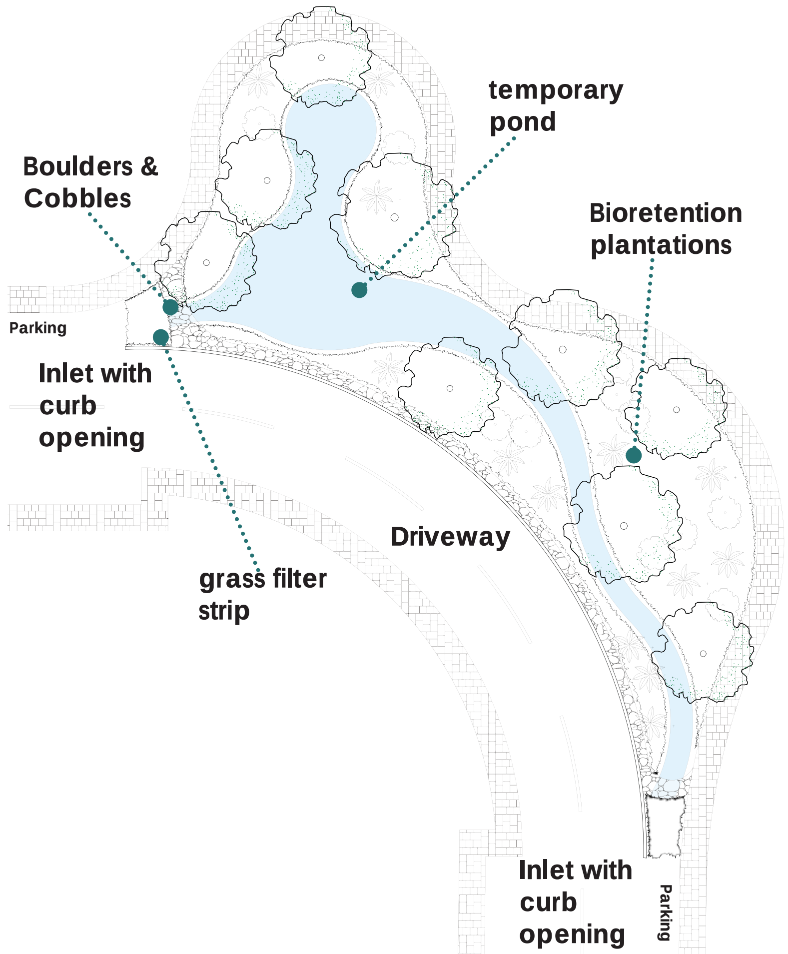


Figure.57: Proposed raingarden design

Source: Author

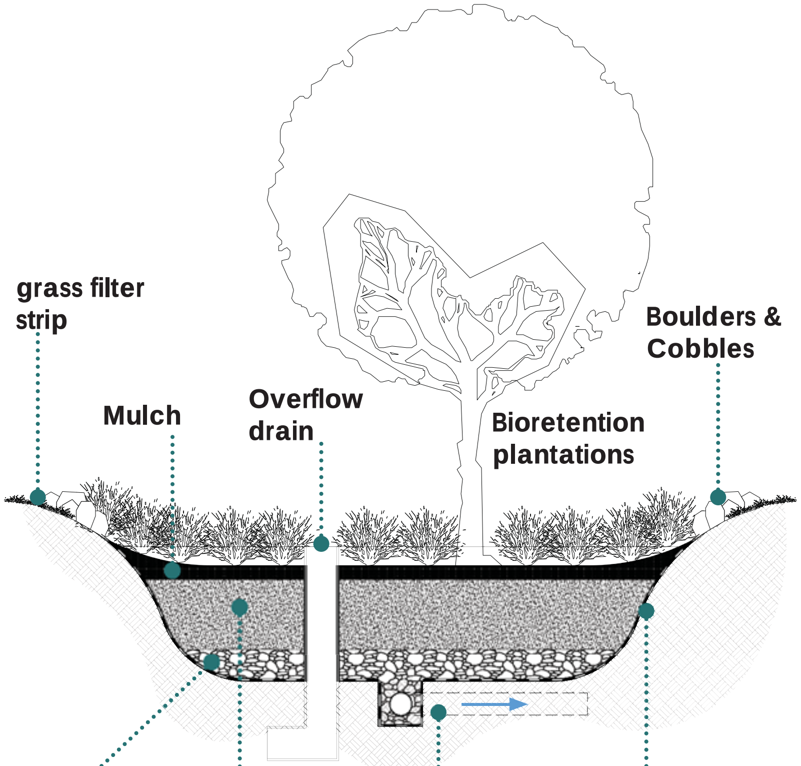


Figure.59: Profile of the raingarden system

Source: Adapted from Susdrain 2017 [54]

catchment zones for directing runoff to the raingardens. The slope of parking surface to be adjusted according to each location's conditions. The design of the raingarden consist of different components that have purpose in the overall performance of the system; An inlet system with curb opening and grass filter strip is a pretreatment stage and reduce the velocity of incoming runoff; A ponding area for the temporary storage of collected rainwater; mulch area for filtration, and to stimulate the growth of micro-organisms; planting medium for plantation growing; woody and herbaceous vegetation; bedding is a gravel and sand layers work as a final polishing treatment and drainage layer; An outlet of the system to convey the collected water by perforated underdrain pipe to the storage tank. Furthermore, an overflow drain has to be considered to pass exceeding flows from

Figure.60: Rain garden at the VA Central Western Massachusetts

Source: EPA 2017

storms to the common drainage system [33], [43].

Landscaping and vegetation in the raingarden should provide dense cover to resist erosion. Selected plants should be Native with low to medium water requirement (hydrozone 01) that can withstand drought and fluctuating water levels for long periods. A variety of trees and shrubs can provide flow control, in addition to shade from solar exposure, which can reduce evaporation [43].

Swales to be used in the linear vegetated strips of street islands as a conveyance structure along the strips, not for storage, but for infiltration. Both swales and rain gardens have the same other consideration of plants selection, soil, and design components.

Rooftops rainwater harvesting

Main considerations like supply and demand, water quality and cost are essential points to determine the right choice when using rainwater tank system. In such low-density residential site, a limited use of rainwater tank arises due to the low roof surface area to the total site area. The reliability of supply of the system for the green space water demand is very low in this case (3% as mentioned in baseline calculation section).also, with relatively low and seasonal rainfall in the region, the cost-effectiveness of the system is reduced because the increase of rainwater tank size plus the cost of connections. According to Australian WSUD guide, recommend that the reliability should be at least 50% for a viable system [33]. Thus, a supplementary source of water supply (raingardens or treated greywater) should be taken into consideration in order to maintain the given reliability of supply and increase the cost-effectiveness of the system.

The surface of rooftops is tiled with high runoff coefficient material. The use of rainwater for green spaces irrigation is most suitable since the water does not require any additional treatment. A flush diverter is required to prevent the first contaminated flush of water from ingress the tank. The availability of space can allow having above ground decentralized tanks. However, centralized larger underground tanks are a better choice in case of applying a conjunctive system that supports other supplementary water supply from raingardens or greywater constructed wetlands.

Horizontal flow constructed wetland system for greywater reuse

In this study, it has been found that the reuse of treated household greywater through Constructed wetlands (CWs) is a viable solution for the effort to provide a nonconventional water supply for irrigation. The availability of space and the high water consumption rate of residents lead to the choice of horizontal flow constructed wetland system (HFCW). Among the water flow regimes of CWs, a subsurface flow (SSF) or at least a hybrid system would fit the best in such residential setting. That will reduce the concerns associated with insects, odors and water loss due to high evaporation rate.

The required area for the system is affected mainly by the climate of the region and type of CW. A basic method for sizing the HFCW system is based on specific area requirement per population equivalent (PE). According to a report published by GIZ in 2011, an example of CW for treating greywater in Dubai has a specific area of 1.9 m^2/p.e [114]. thus, the total required area of the systems in accordance with the given population is estimated by 12,464 m^2.

The decentralized HFCW systems to be planned and distributed within the site layout. The main components of the system consist of gravel, sand, lining and piping system for inflow and outflow. A pre-treatment of grey water is required before subsurface flow CW treatment to avoid clogging of the system. This can be provided by septic tank system, to receive direct effluents from buildings.

Cisterns and storage systems required for rainwater harvesting and treated greywater can be afforded by the infrastructure of the city which has available underground and high cistern allover the city.

Figure.61: Decentralized greywater treatment in urban areas - Klosterenga, OSLO, Norway

Source: Technology review of constructed wetlands 2011 [114]

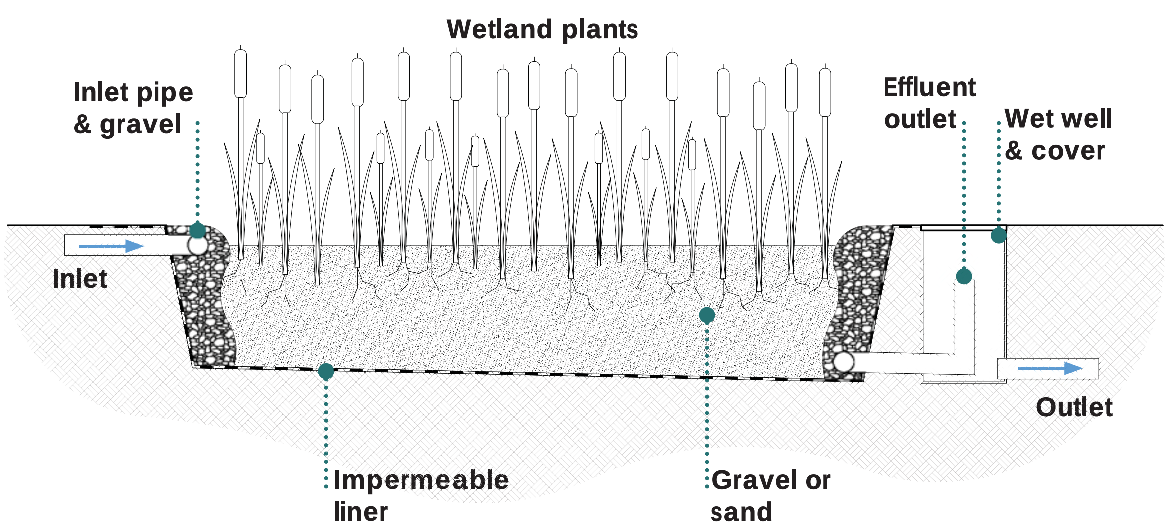


Figure.62: Profile of Subsurface HFCW system

Source: Compendium of sanitation systems and technologies 2008 [119]

Interactive landscape surfaces

The quality of open space is important for any residential development. Therefore, the existing green space of the site needs to be adjusted to the principles of recreational and open space planning, in terms of layout and planning. Introducing spaces such as sitting-out areas, paved areas for informal games, children's playgrounds, jogging and fitness circuits etc. The creation of such active spaces within the site will significantly increase the potentials to utilize the unused vast space for the development of the community alongside with harvested rainwater from these surfaces, and better control of water demand by green space [115], [116]. The new spaces will be deducted from the existing green area. The introduced surfaces would vary between permeable and impermeable. For instance, a playground for children have a permeable sand surface that promotes infiltration, surfaces like paved sitting areas would contribute to the supply of water demand by green space. The balance goal is to plan for 70% of surfaces with high runoff coefficient and 30% permeable surfaces to promote infiltration.

Those proposed green infrastructure application must be implemented along with water demand reduction strategies as mentioned before in this section. Applying

Figure.63: Different landscape surfaces combine sitting area, pathways, playgrounds and sport pitch

Source: Image on top Royce E. Pollard Japanese Friendship Garden hydrozones vegetation areas with the installation of efficient irrigation systems (drip or sprinkler irrigation) that suite each zone. Besides, the adjustment of the excessive area of green space in accordance with the standard requirement for green cover ratio per person in residential developments.

In general, all methods used to determine the design parameters of the mentioned systems are only used as a first indication tool for basic assessment of the systems. A further detailed study should be conducted for each green infrastructure application.

3.8.5 Retention Capacity of Green Infrastructure Applications

As the green infrastructure applications have been identified for intervention, the retention capacity of each system to be calculated. The results will be presented in this section within two proposed scenarios supported by water balance model for each. Fundamental applications are forming the structure of scenario 01, which include the adjustment of the total green area by introducing the interactive landscape surfaces, in addition to dividing the existing green cover to two hydrozones; raingardens and irrigation optimized turfgrass. Scenario 02 will incorporate an additional application that facilitates the reuse of waste greywater as in HFCW. An additional scenario is to cover both city-wide implementation and regional network scale.

Scenario 01

In this scenario, the adjusted area of green space is reduced to be 34% of the site's total area. For each resident is almost 13 m^2 of green cover. The deduction is in favor of raingardens (2%) and interactive landscape surface (16%). Adjusting green space area along with using an efficient irrigation sprinkler system will result in optimized water requirement by 131,231 m^3 per year, which is approximately half (52%) of the initially calculated existing water consumption baseline. The proposed green infrastructure applications are expected to support this requirement by 32%, which gathered directly from the surface to green spaces or stored in tanks from rooftops and raingardens.

One-third of the overall water budget can be reclaimed annually by applying rainwater harvesting strategy.

Surfaces	Area m^2
Green space	83,808
Raingarden	3,500
Pathways	27,368
ILS	39,388
Sidewalks	15,654
Street	45,717
Roof tiles	28,729
Total	244,165

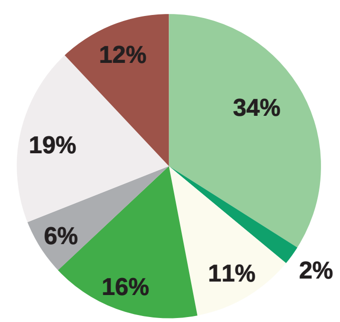


Figure.64: Surface areas breakdown of scenario 01

Source: Author

However, an analysis based on the mean total rainfall throughout the year shows the monthly fluctuation of rainwater supply, due to its seasonal intensity. The harvested rainwater can exceed slightly the water demand of green space only in December and January.

Table.8: Calculated retention capacity of rainwater harvesting in first scenario

Scenario 01			Hydrozone 02 (Turfgrass)
Annual water demand	m³/year		131,231
Rainwater harvesting	m³/year	41,423	**32** %

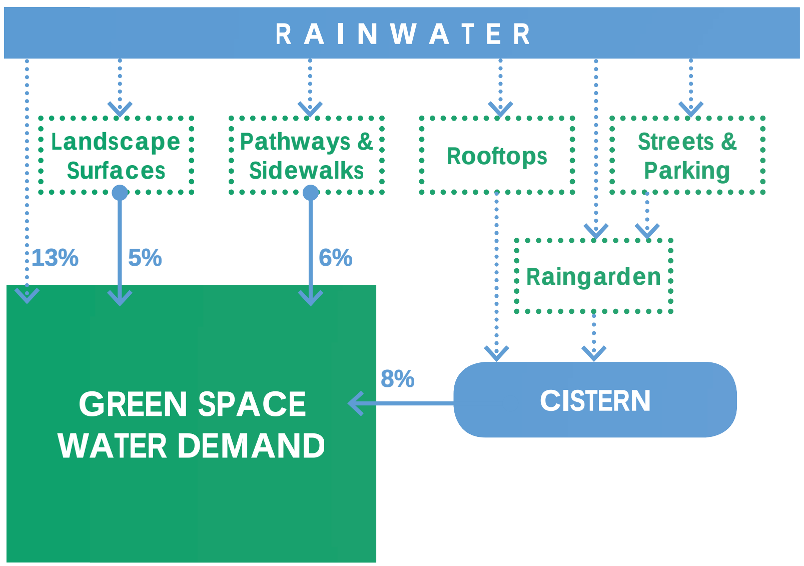


Figure.66: Water balance model for green space in scenario 01

Source: Author

Freshwater is to supplement the total water supply budget of green space with different percentage during the winter, and almost 100% during the summer months. The analysis shows as well that the storage capacity of collected rainwater (8% of total water budget) cannot provide a reliable supply source throughout the year.

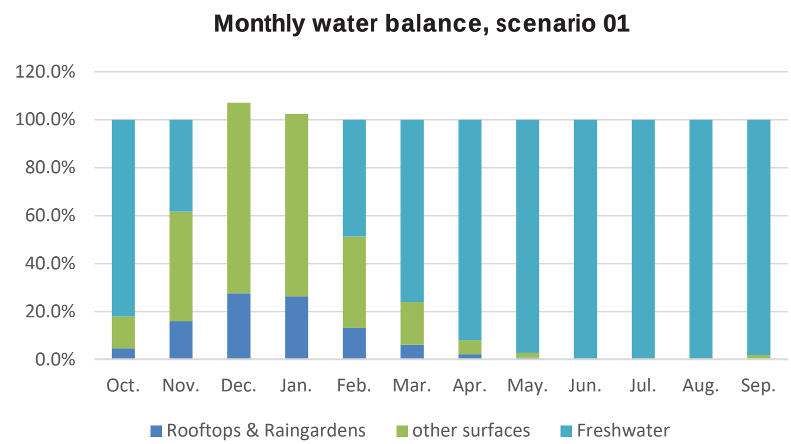
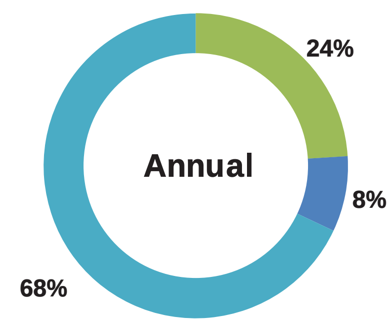


Figure.65: Annual and monthly breakdown of green space water balnce

Source: Author



Scenario 02

The reuse of domestic greywater is introduced in this scenario as an additional nonconventional water supply strategy. A storage system will receive treated water from HFCW, in addition to rooftops and raingardens before it is pumped into sprinkler irrigation system. The adjusted area of green space is reduced to be 30% of the site's total area. For each resident is 11 m^2 of green cover, still within the international slandered. The total annual water budget will be reduced consequently to 112,992 m^3 per year, which is 60% less than the initially calculated existing water consumption baseline. The retained rainwater capacity will be increased to 37% of the same water budget. On the other hand, the total produced treated water from HFCW in a year 219,231 m^3 is nearly as twice as the total water demand of green spaces within the project area, only 33% of which 71,190 m^3 are required for the project's site to complement the water budget. The extra treated water can be a valuable use in the irrigation of other green spaces in the adjacent neighborhoods, especially with higher density and less available open spaces, or another beneficiary nonpotable uses.

Table.9: Calculated retention capacity of rainwater harvesting in second scenario

Scenario 02		Hydrozone 02 (Turfgrass)
Annual water demand m^3/year		112,991
Rainwater harvesting m^3/year	41,423	**37** %
Greywater reuse m^3/year	219,231	**194** %

Surfaces	**Area** m^2
Green space	72,160
Raingarden	3,500
HFCW	12,464
Pathways	27,368
ILS	38,572
Sidewalks	15,654
Street	45,717
Roof tiles	28,729
Total	244,165

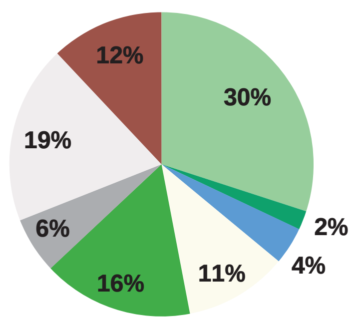


Figure.67: Surface areas breakdown of scenario 02

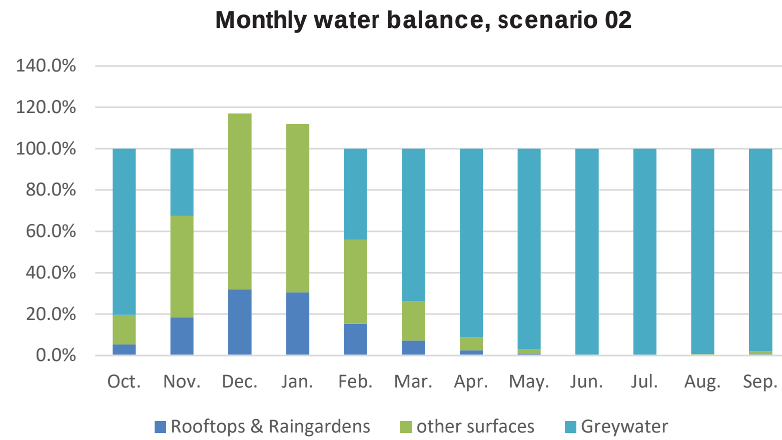
Source: Author

The monthly profile of scenario 02 illustrates an enhancement in the overall retention capacity of rainwater harvesting. The most important is that the constant supply of treated greywater throughout the whole year is providing a reliable non-conventional water resource for green space irrigation.

Since the current domestic water consumption of residents is relatively high and considering that this is targeted to be sustainably reduced to the international averages, a sensitivity assessment of the proposed scenario is required for the possible future changes in water consumption behavior. The production capacity of the HFCW system is recalculated based on reduced domestic water consumption of 121 l/c/d, which is the average domestic water consumption in Germany) [117]. The result shows that the system nevertheless can supply almost 100% of the total water budget of green space within the project area.

Table.10: Calculated retention capacity of rainwater harvesting for future reduced domestic water consumption

Scenario 02 'Future'		Hydrozone 02 (Turfgrass)
Annual water demand m³/year		112,991
Rainwater harvesting m³/year	41,423	**37** %
Greywater reuse m³/year	121,683	**108** %



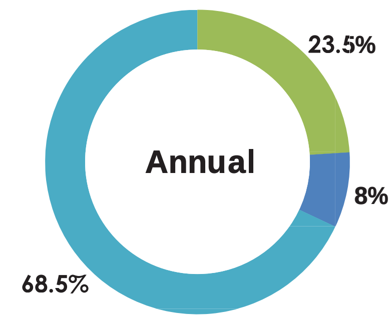


Figure.68: **Annual and monthly breakdown of green space water balnce**

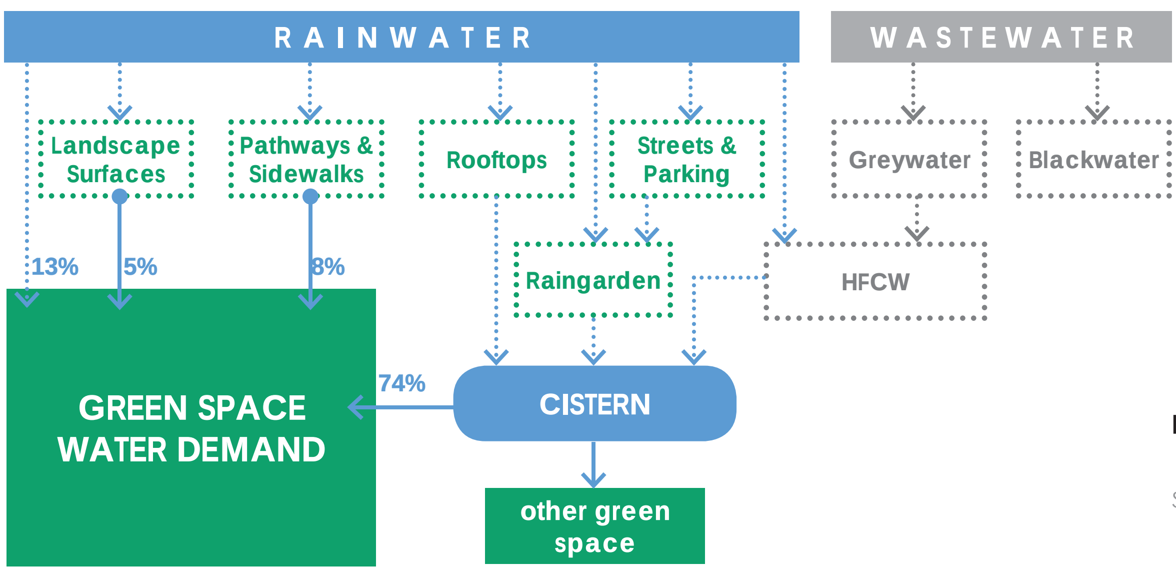


Figure.69: Water balance model for green space in scenario 02

Source: Author

Table.11: A sum-up of calculation results for all scenarios

	Average Existing	Optimal Existing	Scenario 01	Scenario 02	Scenario 02 (Future)
Annual water demand m^3/year	275,152	198,387	131,231	112,992	112,992
Annual water demand reduction	-	28 %	52 %	59 %	59 %
Rainwater harvesting	17 %	24 %	**32 %**	**37 %**	37 %
Greywater reuse	80 %	111 %		**194 %**	108 %

City-scale Model

On the city-scale level, the water balance model is developed to include a centralized wastewater treatment park that provides a tertiary treatment of effluents from the western wastewater treatment plant and supplying water for irrigation of the green spaces in the central and regional parks, in addition to areas lack space for decentralized solutions.

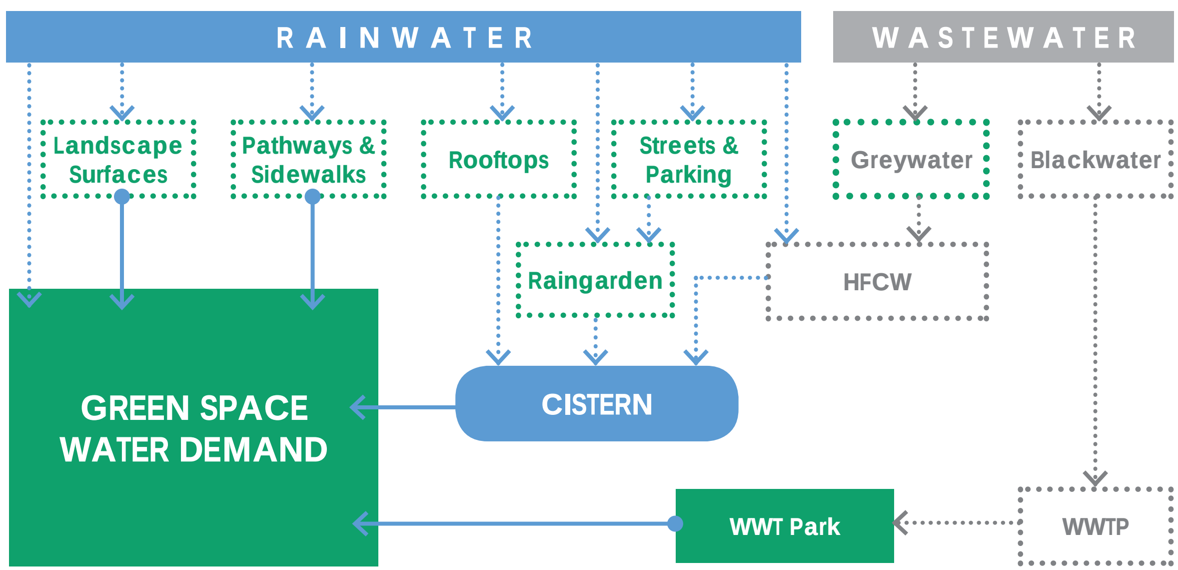


Figure.70: Water balance model for green space of the whole city

Source: Author

3.8.6 SWOT Analysis

S

- Green infrastructure strategies maintain the balance of urban water cycle by using natural process of rainwater harvesting, wastewater treatment and groundwater recharging.
- GI maintain the quality of water
- The availability of space for strategies implantation & the high potential for development.
- The urgent need for efficient and safe discharge of treated wastewater effluents enforces the chances of adopting GI strategies
- The good condition of existing infrastructure reduces the risk & cost of regeneration.
- Working staff capacity of planning, construction and O&M are already available within the authority system in the city.

W

- Reusing treated wastewater is associated with environmental & health concerns in the public perception.
- The lack of challenges awareness among the private & government sectors limits the funds & leadership to adopt GI development concepts.
- The absence of community involvement & participation in decision making.
- The negative social behavior of residents bounds the implementation of some GI solutions.
- Shortage of technical & management engineering skills for GI implantation.
- Insufficient research in the discipline of green area management & stormwater management.

O

- Enhancing the ecological effects of biodiversity & habitat, in addition to introducing ecosystem services in the city and the region.
- Improving the connectivity of local community, foster their sense of belonging and raise the overall quality of life of people in the city.
- Actively promote the multiple benefits of GI among officials and public community.
- Adding value to the city's image to attract population and investments that can stimulate the local economy.
- The opportunity of establishing Green Infrastructure Partnership (GIP) network in Egypt that can deliver green solutions via education, technical assistance, and incentive programs.

T

- The health & environmental hazards associated with insufficient maintenance and improper handling of GI systems.
- Possible contradictions with complying Egyptian laws and codes.
- The uncertainty of government & city's authority leadership adopting the GI development concepts.
- Community ignorance of GI importance.
- Political instability and speculative decision making.

3.8.7 Feasibility Analysis

Implementation of green infrastructure applications provides a range of benefits to communities. These benefits combine direct and indirect economic values, which have a market value that benefits investors, community and local government such as direct utility cost or maintenance cost reduction. Indirect economic values can only be estimated through related costs savings for the society such as energy cost reduction of groundwater pumping due to the water conservation practices. These values could conclude as follow:

Direct economic values

- Water conservation and water cost saving
- Energy savings
- Increase of properties value
- Reduced maintenance and operation cost

Indirect economic values

- Social and community development
- Stormwater flood and pollution reduction
- Green gas emissions reduction
- Urban heat island effect reduction
- Energy reduction of pumping potable water and groundwater

For the purpose of this study, only the direct economic values will be considered for calculation. The benefits of indirect economic values would require additional research for identification and quantification of its values. The calculation analysis will consider costs as the estimated investment cost of the applied green infrastructure applications, such as Constructed wetland, Raingarden, Green streets, landscape surface and irrigation network, in addition to the annual operation and maintenance for the life cycle of the project. The possible high cost of the project's land will not be included since the land is state-owned property. The benefits will be considered as the annual cost savings from the achieved water consumption reduction. Regarding the different scenarios and as mentioned previously in this chapter, the first scenario is initially not cost effective due to the low reliability of supply of the system. The cost-benefit analysis therefore, will address the case described in the second scenario.

Scenario 02

The cost-benefit analysis (CBA) approach in this study will adopt a Rough Order of Magnitude Estimate method (ROM) as an estimation of a project's level of effort and cost to complete.

According to a study in Egypt held by Water Resource Management Program and CEDAR in 2014 [118], the approximate estimated investment cost of additional tertiary treatment for wastewater including the cost of conveyance pipes and pumping is 0.1 Euro/m^3 (LE 2.16 /m^3). The annual operation & maintenance cost is estimated at 0.025 Euro/m^3 (LE 0.54 /m^3). The treatment annual capacity of HFCWs system is 219,231 m^3, which would cost approximately LE 475,000. O&M would have annual cost at LE 118,000.

The average construction cost of raingardens and other landscape surfaces would be considered having the rate of landscape works including hard and softscape at 0.82 Euro/m^2 (LE 17.7 /m^2). The total area of proposed modifications (raingardens and interactive landscape surfaces) is 3,500+ 38,572 = 42,072 m^2. This will result in a total cost of approximate 745,000. The O&M coat will not be added since it already occurs for the existing landscape. The irrigation network has an approximate estimated investment cost of 276 Euro/feddan (LE 6000 /feddan). The available green space area is 72,160 m^2 (17.2 feddan), which would cost approximately LE 100,000. The O&M cost to be estimated as 10% of investment cost at 10,000 per year.

The new potable water prices for public service use for each cubic meter is LE2 water cost plus LE1.84 sewage cost, which make the total cost of LE3.84 /m^3. The existing average water consumption for irrigation is 275,152 m^3/year. This would have an annual cost of LE 1,056,583.

The new potable water prices for public service use for each cubic meter is LE2 water cost plus LE1.84 sewage

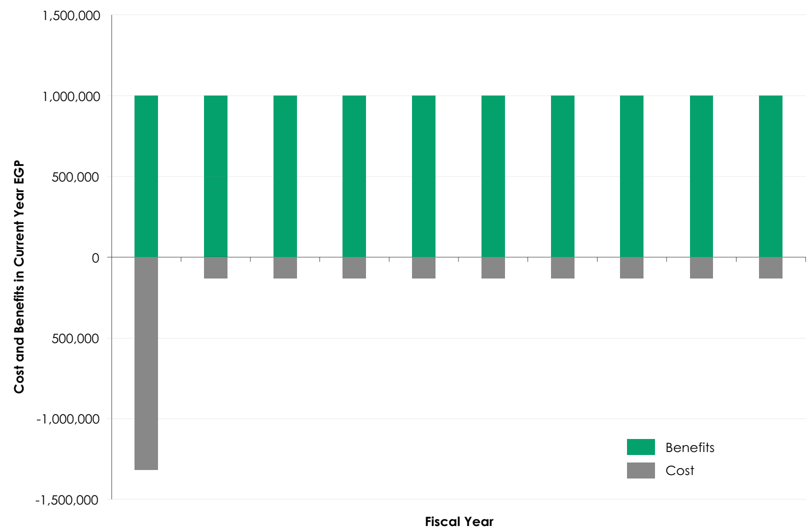


Figure.71: Cash flows of costs & benefits

Source: Author

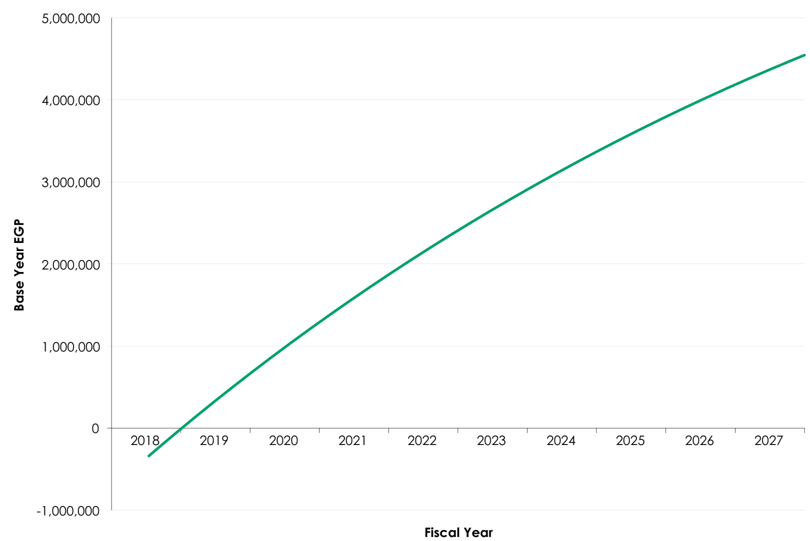


Figure.72: Discounted payback period

Source: Author

cost, which make the total cost of LE3.84 /m^3. The existing average water consumption for irrigation is 275,152 m^3/ year. This would have an annual cost of LE 1,056,583.

The result of analysis over the period of ten years shows a positive Net Present Value of approximate 4.7 million, and pay pack period of only one year.

3.9 BARRIERS AND LIMITATIONS

The lack of community's awareness and understanding of the value of development is definitely limiting the plans for regeneration. Green infrastructure solutions are confined to the social behavior of residents. Also, the absence of public, private, and non-profit sectors involvement in the current design and decision-making process could create a distrust atmosphere to any solutions, while putting most economic and technical burden on the government to solve alone. The cost of constructions and operation can be relatively higher if the local residents have not reached the critical mass for the use of green infrastructure applications.

The current government employed vision of reusing treated wastewater and stormwater management is only considered outside the urban areas. The lack of technical experiences and academic research in applying green strategies in the multidisciplinary context of urban areas could impose struggles and risks to the implementation and durability of the regeneration project. Improper operation and maintenance procedures of proposed systems could cause health and environmental hazards.

The lack of coordination and conflict between the Egyptian wastewater reuse code, the Irrigation & Drainage Egyptian law and Environmental & health regulations & laws are raising constraints to the implementation of green strategies. A sustainable infrastructure framework that combines green policies and practice guidelines with consideration of the related laws and codes is not presented at the moment to tackle the challenges.

CHAPTER 4 : **CONCLUSION & OUTLOOK**

4. CONCLUSION AND OUTLOOK

Urban green areas are an essential element in any new settlement as they provide the quality of built environment and improve the living conditions of residents. However, the deficient planning and management practices along many years in the establishment of new towns in Egypt have resulted in making the urban green areas a burden on the built environment, waste natural resources with high cost and deprive society of the minimum standards of well-being. The regeneration of the existing urban green areas and better planning for future ones was the main objective of this study by paving a knowledge base roadmap to apply sustainable measures in the management and planning of green areas in Egypt's new desert towns. This was driven by the hypothesis that the deterioration of green areas can be inverted efficiently and feasibly by adopting green infrastructure strategies.

The method of research has been used in this study towards this objective was to understand and analyze the context of urban green areas in New Borg El-Arab City, besides identifying the challenges and obstacles to its development. Then, confronting the findings against a conceptual model which was drawn from the review of related literature of green infrastructure discipline, in order to propose solutions for the sustainable regeneration of those green areas.

The analysis of the case study of NBC proves that the urban green areas in desert cities were planned and still managed with ignorance to all evidence of climate change raised from the risks of sea-level rise and storm surges, Also ignoring the emerging water crisis which resulted in the degradation of green areas and the inability to support the new expansions of existing desert cities. On the contrary, these facts have not deterred the government policies to support building more luxury extensive greenery gated communities and golf courses in the middle of the desert which exploit the water resources on the back of Struggling valley of Nile.

The key findings conclude that applying green infrastructure strategies in the urban setting of new towns are essential to the endurance of green spaces. This sustainable approach could make the city better resilient to the environmental threats in such harsh climate and the scarcity of water resources while providing quality of life, ecosystem services and boost the economy. However, this distinctive context of a city in the desert found to require applying consideration measures to the adoption and selection of green infrastructure solutions. The stormwater management practices that were originally developed for humid regions cannot be plainly imported without sort of adjustment. Another aspect to be considered is the altering urban forms and land use segregation, which involve substantial flexibility in applying different solutions. Thus, both the city-wide and small-scale planning approaches have advantages in this effort.

The results from proposed project show that the area offers the potential of employing water sensitive solutions in the regeneration of green areas process, combining treatment and storage measures could have a positive impact on reducing runoff volume while supplying the green space water requirements for irrigation and reducing the cost of the construction and maintenance of grey infrastructure. Yet, applying rainwater harvesting applications, alone, in such low-density development would not be the most effective solution due to the low reliability of the system, caused by the reduced rainfall and the higher seasonality effect. However, other high-density urban settings in the city would be much suitable for effective and feasible systems.

The proposed greywater treatment and reuse system could offer a drastic solution by providing a constant nonconventional water supply for landscape irrigation. With the current water consumption rate by residents the treatment system can even provide additional green areas than the project area has. As the future consumption should aim to be reduced, still the system can supply safe and sufficient amount of treated water for irrigation.

Although that the indirect social and environmental values of the proposed intervention might not be measurable, but the cost analysis proves the feasibility of the combined systems in the second scenario with positive net worth present value. Applying Green infrastructure strategies in the project area could save the annual cost of fresh water. However, alleviating subsidies on water tariffs could encourage communities and government to save water and opting for a sustainable solution.

Adopting green infrastructure strategies could better utilize the open space as a key asset within the project area with greater recreational amenity and more visually attractive that can bring the community together. The residents will have room for social and cultural interaction. However, the social aspect needs to be furtherly investigated in order to cover this gab which affects any potential development. In addition, future studies could explore the opportunity to integrate the community in organized urban agriculture practices by reusing treated wastewater, which can offer economic support and as a food security aspect, in addition, promote green infrastructure partnerships concept.

Generalizing the case of NBC to other new desert cities might take different shapes. Since the rainfall rate in other cities is relatively less, local rainwater harvesting applications would have limited effect, but collecting seasonal rainwater streams flow from areas out of the cities is essential. On the other hand, centralized and decentralized wastewater treatment and reuse projects could be most effective as the problem of discharging treated wastewater effluents exist. Urban form planning and policies practices should be changed to fit the environment and the people's needs.

Further studies need to investigate the cost/environment/social-competitiveness of green infrastructure against the potential commonly discussed solutions of seawater solar or nuclear desalination, especially in the coastal desert cities.

The effort has been conducted in this study needs to be furtherly continued with deeper research for the development and optimization of the specific solutions, in order to produce concrete practice guidelines for green infrastructure that can make a paradigm shift in the planning, design and management of urban green areas in Egypt's desert cities.

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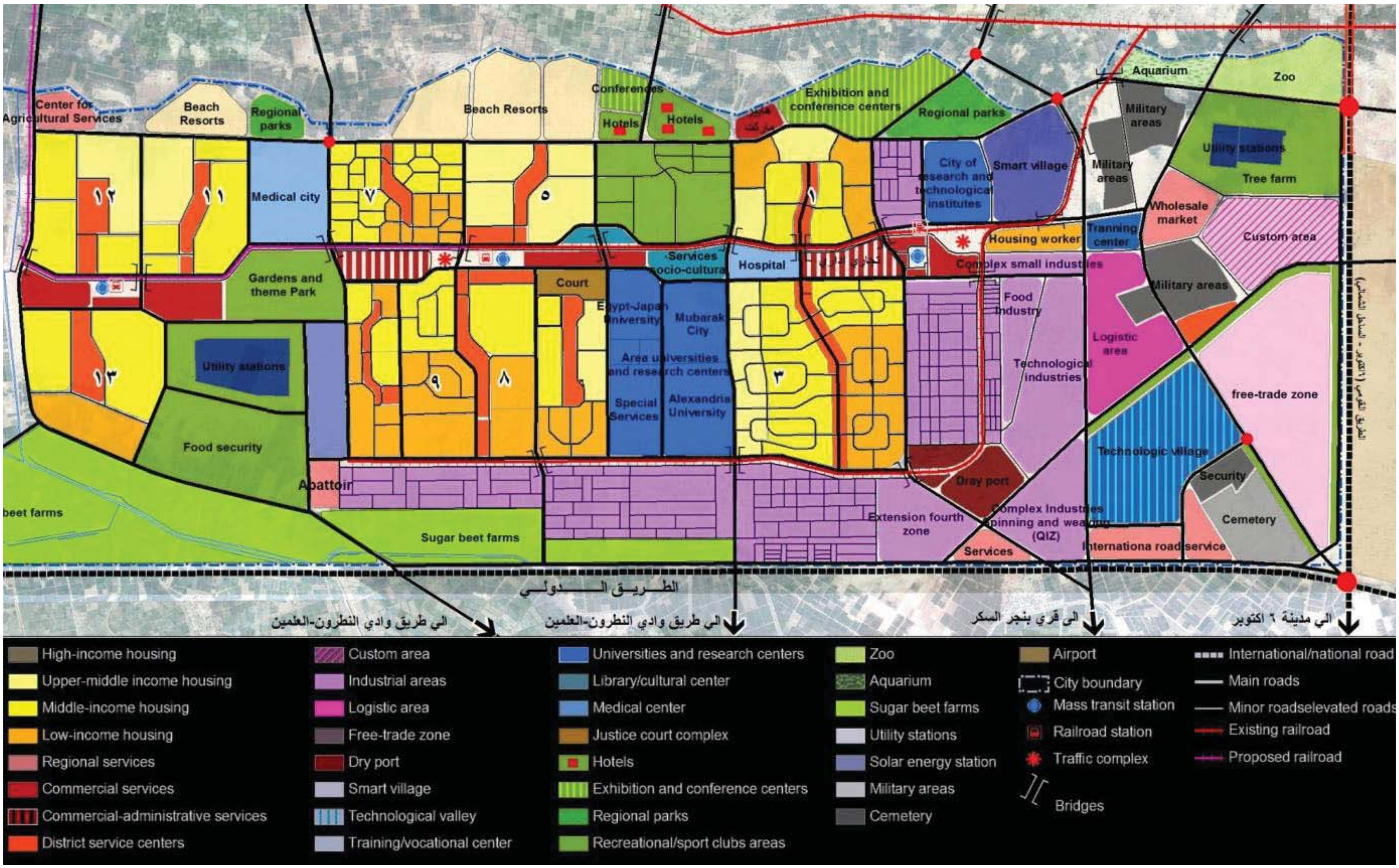
6. APPENDICES

Appendix (A): Detailed landuse map of New Borg El-Arab City [88]



Appendix (B): Monthely rainfall and mean daily temperature [88]

Month	Mean Daily Minimum Temperature (°C)	Mean Daily Maximum Temperature (°C)	Mean Total Rainfall (mm)	Mean Number of Rain Days
Jan	9.1	18.4	54.9	9.5
Feb	9.3	19.3	26.6	8.9
Mar	10.8	21.3	12.9	6.0
Apr	13.1	23.5	4.2	1.9
May	16.4	26.6	1.5	1.0
Jun	20.2	28.6	0.0	0.0
Jul	22.0	29.7	0.0	0.0
Aug	22.7	30.6	0.3	0.0
Sep	21.1	29.6	1.0	0.2
Oct	17.6	27.6	9.3	2.9
Nov	14.4	24.2	33.1	5.4
Dec	10.8	20.3	55.6	11

Appendix (C): Water Sanitation Tariff [97]

Usage	Categories	Price EGP
Residential	00 - 10 m3	0.45
	11 - 20 m3	1.20
	21 - 30 m3	1.65
	31 - 40 m3	2.00
	> 40 m3	2.15
Cost of wastewater	% of water tariff	63%
	Services	2.00
	Governmental	2.20
	Commercial	2.40
	Industrial	3.35
	tourism	3.40
	Other	6.95
Cost of wastewater	%of water tariff	92%

Appendix (D): Water consumption breackdown in the city of Alexandria[99]

Year 2010		
Total Water Produced	947343750	
Total Water Sold	606300000	
Population	4670000	
Category	**Consumption**	
	%	l/c/d
Domestic	61.16	**218**
Industrial	11.2	40
Commercial	11.71	42
Investment	6.51	23
Govermental	6.73	24
Harbour	0.03	0
Discounted Units	0.86	3
Exported (Behira)	1.8	6
Sum W/O losses	100	356
UFW, %	36	
UFW		200
Sum ALL INCL UFW		556

Appendix (E): Treatment grade requirements and Agricultural groups according to Egyptian Code (501/2015) for the reuse of treated wastewater in agriculture [98]

Grade	Agricultural Group
Advanced Treatment	G1-1: Plants and trees grown for greenery at touristic villages and hotels.
	G1-2: Plants and trees grown for greenery inside residential areas at the new cities.
Secondary Treatment	G2-1: Fodder/ Feed Crops
	G2-2: Trees producing fruits with epicarp for processing.
	G2-3: Trees used for green belts around cities and afforestation of high ways or roads
	G2-4: Nursery Plants
	G2-5: Roses & Cut Flowers
	G2-6: Fiber Crops
	G2-7: Mulberry for the production of silk
Primary Treatment	G3-1: Industrial Oil Crops
	G3-2: Wood Trees

		Treatment Grade Requirements			
		A	**B**	**C**	**D**
limit values for BOD and Suspended Solids (SS)	BODs	15	30	80	350
	TSS	15	30	50	300
	Turbidity NTU	5	Unspecified	Unspecified	Unspecified
limit value for fecal coliform and nematode eggs	E.coli per 100mm	20	100	1000	Unspecified
	Intestinal nematodes per liter	1	Unspecified	Unspecified	Unspecified

Appendix (F): Runoff coeffecients in urban areas

Source: Novotny, V. (2003). Water quality: Diffuse pollution and watershed management. John Wiley & Sons.

Urban Area	Runoff Coefficient
Business	
Downtown	0.7-0.95
Neighborhood	0.5-0.7
Residential	
Single family	0.3-0.5
Multiunits, detached	0.4-0.6
Multiunits, attached	0.6-0.75
Residential-suburban	0.25-0.4
Apartments	0.5-0.7
Industrial	
Light	0.5-0.8
Heavy	0.6-0.9
Pavements	
Asphalt and concrete	0.7-0.95
Brick	0.5-0.8
Roofs	0.6-0.9
Lawns	
Sandy soils	
Flat, slope 2% or less	0.05-0.10
Average, slope 2%-7%	0.10-0.15
Steep, greater than 7%	0.15-0.20
Tight soils	
Flat, slope 2% or less	0.15-0.17
Average, 2%-7%	0.18-0.22
Steep, greater than 7%	0.25-0.33

Runoff Coefficients for the Rational Formula
Source: Novotny, Vladimir, Water Quality, second edition, New Jersey, John Wiley & Sons, 2003

Appendix (G): Water demands of plants frequently used in landscape design in Egypt [92]

Plant types:

T Trees
P Palm trees
S Shrubs
G Ground cover
Su Succulents

water demands

H High
M Moderate
L Low

Botanical name	Type	Water demand
Acacia farnesiana	T	M
Acacia saligna	T	H
Acalypha	S	L
Acasia nilotica	T	L
Acer palmatum	S	M
Achillea millefolium	G	M
Agapanthus headbourne hybrids	G	H
Agave marginata	Su	M
Ageratum houstonianum	G	M
Albizzia lebbeck	T	M
Aloe vera	Su	M
Alternathera versicolor	G	M
Althaea rosea	G	H
Antirrhinum majus	G	H

Botanical name	Type	Water demand
Aptenia cordifolia	G/ Su	M
Araucaria araucana	T	H
Archontophonix	P	M
Arctotis breviscapa	G	M
Arctotis hybrida	G	M
Bougainville aspectabillis	S	M
Brachychiton acerifolius	T	M
Caesalpinia pulcherrima	S	M
Calendula officinalis	G	M
Calendula officinalis geisha girl	G	M
Callistemon viminalis	T	H
Canna indica	S	H
Carica papaya	P	H
Carpobrotus edulis	Su	L
Caryota mitis	P	H
Cassia alata	S	H
Cassia fistula	T	M
Cassia glauca	T	M
Cassia javanica	T	H
Cassia nodosa	T	M
Cassia senna	S	M
Celosia argentea	G	H
Ceratonia sisliqua	T	M
Chamaerops humilis	P	M
Chlorophytum comosum	G	M
Botanical name	Type	Water demand

Botanical name	Type	Water demand
Chorisia speciosa (Ceiba speciosa)	T	M
Chrysalidocarpus cabadae	P	M
Chrysalidocarpus lutescens	P	M
Chrysanthemum morifolium	G	H
Citrus limon ponderosa	T	H
Citrus reticulata	T	H
Citrus sinensis	T	H
Cocos nucifera	P	M
Coleus	G	H
Companula medium caycanthem	G	H
Conocarpus erectus	T	L
Conocarpus species	T	M
Cordia myxa	T	M
Cotula barbata	G	M
Cupressus arizonica	T	M
Cycas revoluta	P	M
Delonix regia	T	M
Dodonaea viscosa	S	L
Duranta repens	S	M
Echinocactus grusoni	Su	L
Entrolobium cyclocarpum	T	M
Erythrina caffra	T	M
Euphorbia lactea	Su	L
Euphorbia milii	Su	L
Ficus altissima	T	M
Ficus benghalensi	T	M

Botanical name	Type	Water demand
Ficus carica	T	M
Ficus elastica	T	H
Ficus infectoria	T	M
Ficus lyrata	T	H
Ficus microcarpa (nitida)	T	M
Ficus religiosa	T	M
Ficus retusa	T	H
Ficus salicifolia	T	M
Ficus virens	T	M
Gazania uniflora	G	M
Gerbera	G	H
Helianthus annuus	G	M
Hibiscus rosa-sinensis	S	H
Hibiscus tiliaceus	T	M
Hymenocallis narcissiflora	G	H
Hyphaene thebaica	P	M
Iresine	G	M
Jacaranda acutifolia	T	M
Jacaranda ovalifolia	T	M
Jatropha integerrima	S	M
Kalanchoe blossfeldinana	Su	L
Koelreuteria paniculata	T	M
Lagerstroemia indica	T	M
Lampranthus spectabilis	G	M
Lampranthus roseus	Su	L
Lantana	G	H

Botanical name	Type	Water demand
Lantana camara	G	M
Lantana montevidensis	G	H
Lavandula dentata	G	M
Lawsonia inermis	T	M
Livistona chilensis	P	M
Magnolia grandiflora	T	H
Mammillaria seitziana	Su	L
Mangifera indica	T	H
Melia azedarach	T	L
Mesembryanthemum crystalinum	Su	L
Morus alba	T	M
Myoporum parvifolium	G	M
Myrtus communis	S	M
Nerium oleander	S	L
Ocimum basilicum	G	M
Ocimum basilicum	S	H
Olea europaea	T	M
Opuntia dillenii	Su	L
Opuntia ficus indica	Su	L
Oreodoxa	P	M
Pandanus utilis bory	Su	M
Pandanus veitchii	Su	L
Parkinsonia aculeata	T	L
Pedilanthus tithymaloides	Su	L
Pelargonium peltatum	G	M
Peltophorum africanum	T	M

Botanical name	Type	Water demand
Pennisetum setaceum	G	M
Petunia	G	H
Petunia hybrida	G	H
Petunia hybrida pink satin	G	H
Phoenix canariensis	P	M
Phoenix dactylifera	P	M
Pinus halepensis	T	M
Plumbago capensis	S	H
Portulaca grandiflora	Su	L
Portulaca oleraceae	Su	L
Portulacaria afra	Su	L
Prosopis juliflora	T	M
Prunus domestica	T	M
Prunus persica	T	M
Psidium guajava	T	L-M
Pyrus communis	T	M
Quercus robur	S	M
Ravenala madagascariensis	P	M
Rhapis excelsa	P	M
Rhoeo discolor	G	M
Roystonia regia	P	M
Ruellia tuberosa	G	H
Russelia juncea	S	H
Sabal palmetto	P	M
Salvia	S	M
Sansevieria trifasciata	Su	M

Botanical name	Type	Water demand
Schinus molle	T	H
Schinus terebinthifolius	T	H
Selaginella biformis	G	H
Senecio cineraria	G	L
Setcreasea purpurea	G	M
Spathodia	T	M
Sterculia diversifolia	T	H
Strelitzia reginae	G	L
Suaeda fruticosa	Su	L
Suaeda monoica	Su	L
Syagrus romanzoffiana	P	M
Tabernaemontana coronaria	S	M
Tamarix aphylla	T	L
Tecoma capensis	T	H
Tecoma stans	T/ S	M
Tecomaria	S	M
Terminalia catappa	T	M
Thespesia populnea	T	M
Thevetia nerifolia	T	M
Verbena	G	M
Verbena hybrida	G	M
Vinca minor	G	M
Vinca rosea	G	H
Vitex agnus castus	S	M
Washingtonia filifera	P	M
Washingtonia robusta	P	L

Botanical name	Type	Water demand
Wedelia trilobata	G	M
Wodyetia bifurcata	P	M
Yucca aloifolia	Su	L
Zephyranthes	G	M
Zizyphus spina christi	T	L
Zygophyllum species	Su	L

taken from data sheets provided by the landscape architecture office "Nature for landscape architecture and planning", Cairo (Dr. Mohamed Refaat, landscape architect)

Appendix (H): Elaborated calculation sheets of baseline condition and different scenarios

Surfaces	**Area m²**
Rooftops	28,729.00
Green areas	126,696.00
Pathways	43,023.00
Streets	45,717.00
total	**244,165.00**

Annual precipitatior	199.4
population	6560
GA ratio m²/Inh	19.3

			Max. 7.14 L/m²	**Ave.** 5.95 L/m²	**Min.** 4.76 L/m²	**Opti.** 4.29 L/m²
Existing water demand	water demand L/m² day		7.14	5.95	4.76	4.29
	Daily water demand L/day		904,609	753,841	603,073	543,526
	Annual water demand L/year		330,182,446	275,152,038	220,121,630	198,386,931.60
	Annual water demand m³/year		**330,182**	**275,152**	**220,122**	**198,387**
Rainwater harvesting m³/year	Green area	25,263	8%	9%	11%	13%
	Pathways	8,150	3%	5%	13%	4%
	Rooftops	5,442	2%	2%	2%	3%
	Streets	8,660	3%	3%	4%	4%
	Total	**47,515**	**14%**	**17%**	**22%**	**24%**
Wastewater reuse m³/year	Greywater	219,231	66%	80%	100%	111%
	Blackwater	93,956	28%	34%	43%	47%
	Total	**313,188**	**95%**	**114%**	**142%**	**158%**

Monthely calculation for the current status

Months	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	
Mean Total Rainfall (mm)	9.3	33.1	55.6	54.9	26.6	12.9	4.2	1.5	0	0	0.3	1	199.4
Rainwater harvesting m³	2,216.11	7,887.45	13,249.01	13,082.21	6,338.56	3,073.96	1,000.82	357.44	-	-	71.49	238.29	47,515
Water demands m³	16,305.78	16,849.30	16,305.78	16,849.30	16,305.78	16,849.30	16,305.78	16,849.30	16,305.78	16,849.30	16,305.78	16,305.78	198,387
Rainwater harvedting %	14%	47%	81%	78%	39%	18%	6%	2%	0%	0%	0%	1%	24%
Rooftops	1.6%	5.6%	9.8%	9.4%	4.7%	2.2%	0.7%	0.3%	0.0%	0.0%	0.1%	0.2%	2.9%
other surfaces	12.0%	41.2%	71.5%	68.3%	34.2%	16.0%	5.4%	1.9%	0.0%	0.0%	0.4%	1.3%	21.1%
Freshwater	86.4%	53.2%	18.7%	22.4%	61.1%	81.8%	93.9%	97.9%	100.0%	100.0%	99.6%	98.5%	76.0%

Surfaces	Area m²
Rooftops	28,729.00
Green areas	72,160.00
Raingarden	3,500.00
HFCW	12,464.00
Pathways	27,368.93
ILS	38,572.00
Sidewalks	15,654.07
Streets	45,717.00
total	**244,165.00**

Annual precipitation	199.4
population	6,560
Green Cover m²/Inh	11

			Hydrozone 01 (Raingarden)	Hydrozone 02 (Turfgrass)
Adjusted water demand	water demand L/m² day		1.42	4.29
	Daily water demand L/day		4,970	309,566
	Annual water demand L/year		1,814,050	112,991,736.00
	Annual water demand m³/year		**1,814**	**112,992**
Rainwater harvedting m³/year	Rooftops	5,729		5%
	Green area	14,389		13%
	Raingarden (50%)	4,907	100%	4%
	HFCW	2,485		2%
	Pathways	5,457		5%
	ILS	5,384		5%
	Sidewalks	3,121		3%
	Total	**41,472**	**100%**	**37%**
Wastewater reuse m³/year	Greywate	219,231		194%
	Blackwater	93,956		83%
	Total	**313,188**		**277%**
Wastewater reuse m³/year	Greywate	121,683	Future scenario	108%
	Blackwater	52,150		46%
	Total	**173,833**		**154%**

Monthely calculation forScenario 01

Months	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	
Mean Total Rainfall (mm)	9.3	33.1	55.6	54.9	26.6	12.9	4.2	1.5	0	0	0.3	1	199.4
Rainwater harvesting m³													
Rooftops	267	951	1,597	1,577	764	371	121	43	-	-	9	29	5,729
Green area	779	2,774	4,660	4,601	2,229	1,081	352	126	-	-	25	84	16,711
Raingarden (50%)	229	815	1,368	1,351	655	317	103	37	-	-	7	25	4,907
Pathways	255	906	1,522	1,503	728	353	115	41	-	-	8	27	5,457
ILS (70%)	256	913	1,533	1,514	733	356	116	41	-	-	8	28	5,498
Sidewalks	146	518	870	859	416	202	66	23	-	-	5	16	3,121
Total	**1,932**	**6,876**	**11,550**	**11,405**	**5,526**	**2,680**	**873**	**312**	**-**	**-**	**62**	**208**	**41,423**
Water demands m³	10,786.09	11,145.63	10,786.09	11,145.63	10,786.09	11,145.63	10,786.09	11,145.63	10,786.09	11,145.63	10,786.09	10,786.09	131,231
Rainwater harvesting %	18%	62%	107%	102%	51%	24%	8%	3%	0%	0%	1%	2%	32%
Rooftops & Raingardens	4.6%	15.8%	27.5%	26.3%	13.2%	6.2%	2.1%	0.7%	0.0%	0.0%	0.1%	0.5%	8.1%
other surfaces	13.3%	45.9%	79.6%	76.1%	38.1%	17.9%	6.0%	2.1%	0.0%	0.0%	0.4%	1.4%	23.5%
Freshwater	82.1%	38.3%	0.0%	0.0%	48.8%	76.0%	91.9%	97.2%	100.0%	100.0%	99.4%	98.1%	68.4%

Monthely calculation forScenario 02

Months	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	
Mean Total Rainfall (mm)	9.3	33.1	55.6	54.9	26.6	12.9	4.2	1.5	0	0	0.3	1	199.4
Rainwater harvesting m³													
Rooftops	267	951	1,597	1,577	764	371	121	43	-	-	9	29	5,729
Green area	671	2,388	4,012	3,962	1,919	931	303	108	-	-	22	72	14,389
Raingarden (50%)	229	815	1,368	1,351	655	317	103	37	-	-	7	25	4,907
HFCW	116	413	693	684	332	161	52	19	-	-	4	12	2,485
Pathways	255	906	1,522	1,503	728	353	115	41	-	-	8	27	5,457
ILS (70%)	251	894	1,501	1,482	718	348	113	41	-	-	8	27	5,384
Sidewalks	146	518	870	859	416	202	66	23	-	-	5	16	3,121
Total	**1,934**	**6,884**	**11,564**	**11,418**	**5,532**	**2,683**	**874**	**312**	**-**	**-**	**62**	**208**	**41,472**
Water demands m³	9,286.99	9,596.56	9,286.99	9,596.56	9,286.99	9,596.56	9,286.99	9,596.56	9,286.99	9,596.56	9,286.99	9,286.99	112,992
Rainwater harvesting %	21%	72%	125%	119%	60%	28%	9%	3%	0%	0%	1%	2%	37%
Rooftops & Raingardens	5.3%	18.4%	31.9%	30.5%	15.3%	7.2%	2.4%	0.8%	0.0%	0.0%	0.2%	0.6%	9.4%
other surfaces	14.2%	49.0%	85.1%	81.3%	40.7%	19.1%	6.4%	2.2%	0.0%	0.0%	0.5%	1.5%	25.1%
Greywater	80.4%	32.6%	0.0%	0.0%	44.0%	73.7%	91.2%	96.9%	100.0%	100.0%	99.4%	97.9%	65.5%

Appendix (I): Wastewater calculations

Population	6,560				*350 l/c/d including industries
water consumption per capita per dy	0.35	m^3			
total water consumption per day	2,296	m^3			
Unaccounted for Water (UFW) Losses	780.64	34%			
net total water consumption per day	1,515	m^3			
net total water consumption per year	553,106	m^3			
wastewater per year (0.6%)	331,864	m^3	**232,304.69**	99,559.15	
			70% grey	30% black	

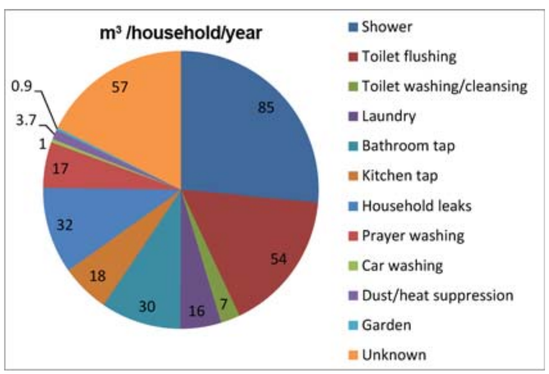
* Source: African Green City Index: Assessing the environmental performance of Africa's major cities. (2011). Siemens AG.

Population	6,560				*Domestic 218 l/c/d
water consumption per capita per dy	0.218	m^3			
total water consumption per day	1,430	m^3			
net total water consumption per year	521,979.20	m^3			
wastewater per year (0.6%)	313,188	m^3	**219,231.26**	93,956.26	
			70% grey	30% black	

*Source: Abu-Zeid, K., Yasseen, A., Van Der Steen, P., Sharp, P., & Elrawady, M. (2011). Alexandria 2030 Integrated urban water management (IUWM) strategic plan. SWITCH, Sixth Framework Programme & CEDARE.

Population	6,560				*Future domestic 121 l/c/d
water consumption per capita per dy	0.121	m^3			
total water consumption per day	794	m^3			
net total water consumption per year	289,722.40	m^3			
wastewater per year (0.6%)	173,833	m^3	**121,683.41**	52,150.03	
			70% grey	30% black	

*Source: German Federal Statistical Office



Shower	85	m^3	*Domestic 321.6 m3 /household/year	Domestic 220 l/c/d
Laundry	16	m^3		
Bathroom tap	30	m^3		
Grey water consumption per husehold per year	131	m^3		
Housholds	1640			
Grey water per year	**214,840.00**	m^3		

*Source: AbuZeid, K.M., Smout, I., Taha, H., Sabry, N., Elrawady, M. 2010b, Alexandria Water Demand Management Study, CEDARE and Alexandria Water Company (AWCO), March 2010.

Appendix (J): Cost- Benefit Analysis calculation sheet

	Fiscal Year									
	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Undiscounted Flows in EGP										
Costs	-1,320,000	-128,000	-128,000	-128,000	-128,000	-128,000	-128,000	-128,000	-128,000	-128,000
Benefits	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000
Net Cash Flow	-320,000	872,000	872,000	872,000	872,000	872,000	872,000	872,000	872,000	872,000
Discount Factors										
Discount Rate	10.0%									
Base Year	2018									
Year Index	0	1	2	3	4	5	6	7	8	9
Discount Factor	1.0000	0.9091	0.8264	0.7513	0.6830	0.6209	0.5645	0.5132	0.4665	0.4241
Discounted Flows in EGP										
Costs	-1,320,000	-116,364	-105,785	-96,168	-87,426	-79,478	-72,253	-65,684	-59,713	-54,284
Benefits	1,000,000	909,091	826,446	751,315	683,013	620,921	564,474	513,158	466,507	424,098
Net	-320,000	792,727	720,661	655,147	595,588	541,443	492,221	447,474	406,794	369,813
Cumulative	-LE320,000	472,727	1,193,388	1,848,535	2,444,123	2,985,566	3,477,787	3,925,261	4,332,056	4,701,869

Net Present Value	LE4,701,869
Internal Rate of Return	272%

Appendix (K): annotated list of interviews

Water Resource Research Institute

Dr. Islam Al Zayed,

He was my first contact in the institute. We had discussed over several phone calls a rainwater harvesting project conducted by the institute in Alexandria. He introduced me and arranged a meeting with prof. Karima Attia, the director of the institute.

Prof. Karima Attia, Director of WRRI

Prof. Karima gave a comprehensive overview of the on-ground work and studies being conducted in many regions of Egypt. The projects include rainwater harvesting either to supply fresh water in rural areas or to tackle the urban flooding of the rainy season in cities. Also, mapping and the management of dray rainwater streams in Egypt. She gave me more information about a project in Alexandria to harvest rainwater.

Projects Development & Scientific Research Technology center

Prof. Wael Abdelmoez,

Grey water recycling options and technologies in Egypt was the main topic of discussion with prof. Wael. He explained the potential of sustainable utilization of domestic greywater treatment according to his practical experience on many pilot projects in Egypt. He introduced some of his books and publications on the topic.

Egypt-Japan University of Science and Technology (E-JUST)

Prof. Mona Gamal Eldin, Dean of the Department of Environmental Engineering

By presenting my topic of research related to the case of NBC, Prof. Mona gave an overview of the research works and programs in the department and introduced me to both Dr. Ahmed and Dr. Wael.

Dr. Ahmed Tawfik

Dr. Ahmed’s area of interest is the Innovative waste and wastewater treatment technologies. We discussed the potential reuse of treated wastewater in the city and he explained the current challenges and obstacles including the uncontrolled industrial waste discharges and its effect on previous afforestation project. In addition, he gave an overview of decentralized DHS Sewage Treatment plant project for agriculture reuse, already implanted in cooperation with TOHOKU University in one of the neighborhoods.

Dr. Wael Elham

Since his current research projects related to Groundwater and Surface Water Hydrology, Dr. Wael presented the current situation of groundwater availability and use. We discussed the potential use of non-conventional water resources within the city.

New Borg El Arab City Authority

Eng. Samy Abdullah, Gardens and Landscape department

Eng. Samy guided me through one of the residential areas while inspecting recent development works of open green spaces. He gave me a valuable information about the management of green areas in the city including irrigation methods, plant types, and water consumption. Also, the obstacles developing these practices.

Eng. Ahmed Hassan, Water & Wastewater Networks department

Eng. Ahmed gave an overview of the water and wastewater network in the city and planned project for efficient irrigation network to be implemented. He provided me with networks map of the city and information about the location and capacity of exciting and future treatment plants.

GIZ Egypt

Mr. Khalil Shaat, Policy Advisor at GIZ & Cairo governorate

The interview was about the legal aspects related to water and urbanization in new cities and to explore the government and NGOs perspective about the issue in Egypt.

Hafencity University, Hamburg 2018
Resource Efficiency in Architecture and Planning
Master Thesis

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