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Possible Climate Change Effects and Mitigation Means for Plants in Al-Rehab's Public Spaces

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ABSTRACT

The urban settlement of Al-Rehab consumes approximately 30,000 m^3/day of irrigation water. This comprises of around 62% of all municipal water used by the settlement. Possible climate change effects could ultimately increase the plants' water demands by up to 20% in desert-located regions. Therefore, a theoretical scenario that assumes the same water availability and a 20% rise in plants' water demand is suggested in a region in Al-Rehab. Results showed that the green space within the study area could possibly suffer from a vegetation loss ranging from 12-16% of the total area. This is surely respective to efficient and facilitated irrigation practices. Due to the yielded results of vegetation loss, an alternative comprising of several plant substitutions with their native counterparts is proposed. Three different native grasses and 2 native tree species are suggested as alternatives to the current vegetation. After their establishment, and given the same variables of the suggested scenario, the vegetation loss is thought to substantially decrease to 2-2.5% when substituting grasses only. While those percentages could be further reduced to 1-1.6% of vegetation loss when both trees and grasses have been theoretically substituted. These results highlight the benefits of using native and drought tolerant species in our urban green spaces, along with discussing the role of facilitated irrigation in reducing the overuse of water. Moreover, the potential outcomes emphasize the importance of designing climate- and water-oriented landscapes.

KEYWORDS: Water demand, Climate Change, Vegetation loss, Plant substitutions.

تأثيرات التغير المناخي المحتملة ووسائل تخفيفها على النباتات في الفراغات العمرانية بمدينة الرحاب

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الملخص

التجمع العمراني لمدينة الرحاب يستهلك حوالي ٣٠,٠٠٠ م٣ في اليوم من مياه الري. هذا يعادل حوالي ٦٢% من إجمالي المياه المستخدمة في المدينة. تأثيرات التغير المناخي المحتملة قد يزيد من الاحتياج المائي للنباتات الى ما يقرب من ٢٠%. بالتالي، تم وضع سيناريو يفترض وجود نفس كمية المياه الحالية مع زيادة الاحتياج المائي للنباتات الى ٢٠% في منطقة ما بمدينة الرحاب. نتائج تلك الفرضية أظهرت ان المساحات الخضراء بتلك المنطقة قد تعاني من فقد في الغطاء النباتي يتراوح بين ١٢-١٦% من إجمالي المساحة الخضراء. وهذا بالطبع يعتمد على ان أنظمة وأساليب الري المتبعة تكون موجهة وذات كفاءة عالية. بسبب تلك النتائج، تم فرض بديل تصميمي عبارة عن تبديل عدة فصائل من النباتات بأخريات ذات طبيعة محلية. ٣ فصائل من العشب المحلي وكذلك ٢ من الأشجار المحلية تم فرضهم كبدائل من الممكن استخدامهم في المنطقة محل الدراسة. بعد تأسيسهم، وباعتبار اتاحة نفس كمية المياه المتواجدة حاليا، فإن فقد الغطاء النباتي قد يقل الى حوالي ٢-٢,٥% بعد تبديل فصائل العشب فقط. بينما تلك النسب قد تقل أكثر وتصل الى حوالي ١-١,٦% من فقد الغطاء

النباتي حينما يتم تبديل فصائل العشب والأشجار معا. تلك النتائج تسلط الضوء على منافع استخدام النباتات المحلية في فراغاتنا العمرانية الخضراء، مع مناقشة دور الري الموجه في تقليل الاستهلاك الزائد للمياه. بالإضافة الى ذلك، فان العواقب المحتملة تشدد على أهمية تصميم حدائق عمرانية تراعي المناخ ومورد المياه.

الكلمات الدالة: الاحتياج المائي، التغير المناخي، فقد الغطاء النباتي، بدائل النباتات

INTRODUCTION

The typical domestic indoor water consumption in Egypt is estimated to be $0.15m^3$/capita/day and $4.5m^3$/capita/month ٠. Egypt's per capita water share in 2018 was $112.1m^3$/day (CAPMASS, 2019). However, the per capita water share in Greater Cairo Region is approximately $151.3m^3$/day (NUCA, n.d.). Furthermore, several studies indicated that Cairo's per capita share is almost double or triple that in some regions in upper Egypt.

These variations indicate an increase in water demand and consumption in Cairo, and especially in new settlements within the city. This is mainly because such settlements are heavily landscaped and require an abundance of water to be transported to them from the Nile. And during such water transfer, there is an approximate 30% leakage occurrence (MWRI, 2005). Which lead to an increased consumption in new settlements in Cairo.

This is yet another indicator to one of the major challenges of water in Egypt, which is the inequity of water distribution among the different governorates. Subsequently, this might suggest that the landscapes in new settlements are not designed and/or implemented adequately. According to research on new cities of Cairo, most of the settlements' green areas comprise of vast surface areas of groundcovers that are highly water demanding. It is estimated that each square meter of such groundcovers requires approximately $0.01m^3$/day of water to stay green (Zureikat & Husseini, 2011; Leinauer et al., 2012).

Municipal water in Egypt is highly vulnerable to external forces. The limited availability of water through the Nile leads to a limited quantity allocated to domestic use. This intensifies the importance of adequately managing such quantity even though the municipal water consuming sector is not the highest within the country. The expansion of highly water demanding green spaces in the new urban settlements in Egypt and Cairo continue to raise the water demand and consumption. Figure (1) shows the extent of development within the last 20 years in the same region of Al-Rehab settlement, revealing how green spaces expanded along the years in a desert-located region.

Given the possible climate projections and effects on Egypt's water supply, the quantity of what might be considered luxury-consumed water should be decreased. Especially since any water shortages affecting those landscapes could lead to possible losses in their vegetation and therefore decrease their functionality and aesthetic. Such possibilities are to be investigated in the urban settlement of Al-Rehab in this research paper.

Several studies show that climate change has become the single most pressing topic of global impact (Ouda & Zohry, 2016). Having a proper response to its possible impacts could enable an efficient use of current resources (Bohl et al., 2018). This might, consequently, sustain the populations' demands and requirements.

Since 1994, many studies were conducted regarding the impacts of climate change in Egypt (Gad, 2017). Many of which pointed to the potentially significant impact on Egypt's water resources. Most research indicate that several economic sectors in Egypt would suffer from the impacts of climate change. The agricultural sector would most likely suffer the most, mainly due to the high-water demand and consumption within the sector.

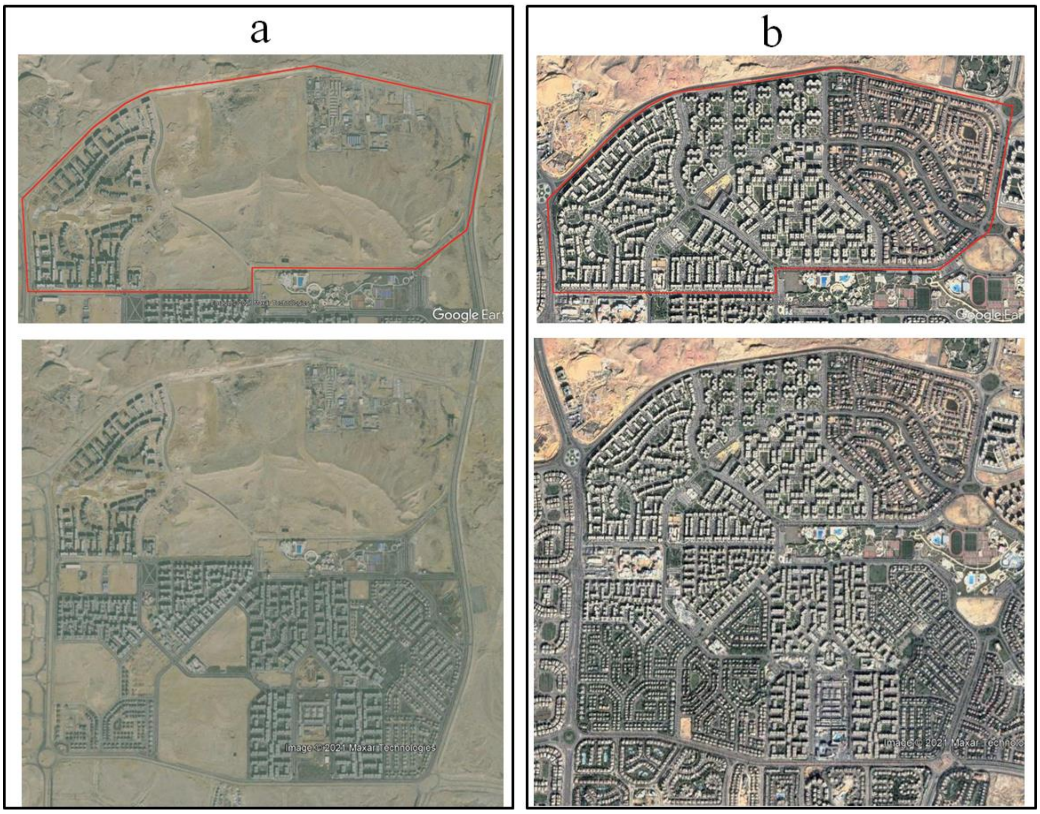

Figure (1). Extent of development in phase 1 of Al-Rehab showing the occurrence of green expansion in a desert land. a. December 2002. b. January 2021.
Source: Google Maps Imagery, 2021.

It is stated that Egypt's vulnerability to climate change stems from The River Nile's high susceptivity to it (Elsaeed, 2012). The variations in temperatures and inconsistent quantities of annual rainfall are the main factors affecting The Nile. Subsequently, rise in temperature increases evaporation and evapotranspiration (ET), which eventually reduces the water-flow levels in the Nile sub-basins by double or triple the percentage of ET. A 4^{o}C increase in temperature with a 20% decrease in precipitation could substantially decrease the Nile's flow (Elsaeed, 2012). Such a theory suggests a potentially dramatic effect on the Nile flows and subsequently on the water resources of Egypt.

Floods and drought events are also potential occurrences in Egypt due to climate change. The sea level at the northern third of the delta is lowering at the rate of 4-8mm per year due to the increase in temperatures leading to evaporation (Pink, 2018). While the Nile's water level is becoming lower at the coastal delta margin, the sea level is rising at a rate of about 3mm per year (Pink, 2018). It is estimated that, since the population in Egypt is expected to double by the year 2100 causing more land stress and water insecurity, the per capita water share will decrease by 50% by 2050 (Pink, 2018).

The expected rise in sea levels could drown the Nile Delta and potentially lead to the evacuation of nearly 12 million Egyptians to safer locations (Tolba & Saab, 2009). In a scenario of a 0.5m rise in sea level, more than 50% of the Nile Delta would experience devastating effects. In addition, ten major cities (including Alexandria and Port Said) would be threatened (Tolba & Saab, 2009). Another study considered the impact of a 1m sea-level rise for 84 developing countries. In it, Egypt was ranked the second-highest country for the most affected coastal population and fifth highest for the proportion of affected urban areas (Pink, 2018). It is safe to say that sea-level rise might substantially affect all sectors and the country will be burdened with the costs of mitigating and restoring infrastructure damages.

Additionally, climate change could have a pronounced impact on temperature and drought conditions. Scenarios for North Africa and Egypt indicate "[…] an average rise in annual temperatures, higher than the average expected for the planet" (Pink, 2018). Heatwaves are, consequently, expected to increase in intensity and duration leading to more frequent drought events. Projections of increased evaporation, saltier coastal aquifers, and reduction in annual rainfall by 4-27% could lead to a worsened water deficit status in Egypt. Furthermore, sea level could rise by 23-47 cm by the end of the 21st century (Pink, 2018). As this water stress intensifies, the irrigation of precious agricultural lands will become strained leading to increased food insecurity. This would dramatically increase food prices and affect Egypt's livelihood. Moreover, with the expected population growth by 2030; drought, water insecurity, and climate change adversity would most probably be intensified.

Climate change could also have indirect effects on water in Egypt. They include the projected rise in temperatures, CO_2 concentrations in the air, etc. The climate change knowledge portal of the World Bank Group shows projections of climatic factors in all parts of the world. According to it, temperatures will average at 32.8^{o}C in summer months (May to October) and 21^{o}C in winter months (November to April) during the years 2080 to 2099 in Cairo's Eastern region (World Bank Group, 2021), as shown in Figure (2). This would be referred to again in the methods section.

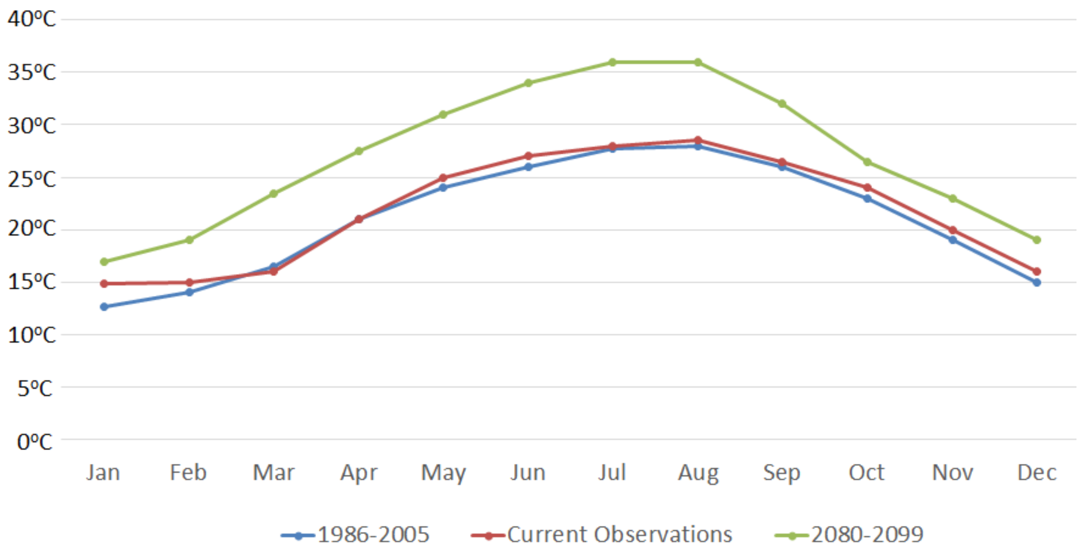

Figure (2). Historical, current, and future projections of temperatures in East Cairo.
Source: (World Bank Group, 2021).

Several research concluded that increases in temperatures and CO_2 concentrations might lead to higher water demands for plants due to longer and warmer growing seasons. Not to mention that the elongated growing seasons due to the rise in temperatures means that plants will have more time to grow and to consume water.

This might also affect the plants' appearance and quality since their metabolism conditions could become inconsistent. Such factors might make plants thirstier. Consequently, this paper would primarily aim to investigate the potential impact of climate change on re-considering and re-evaluating the design and implementation of green areas in desert-located residential settlements.

In that regard, the water consumption of newly implemented green spaces in Egypt needed to be analyzed. The efficiency of such use and its correlation with the country's current and projected water status are evaluated. The landscape consumption of a specific public space in the urban settlement of Al-Rehab is thoroughly mapped and analyzed, followed by a suggestive scenario that is used to test the occurrence of vegetation loss(es) in the same study area. Accordingly, Figure (3) briefly outlines the research methodology.

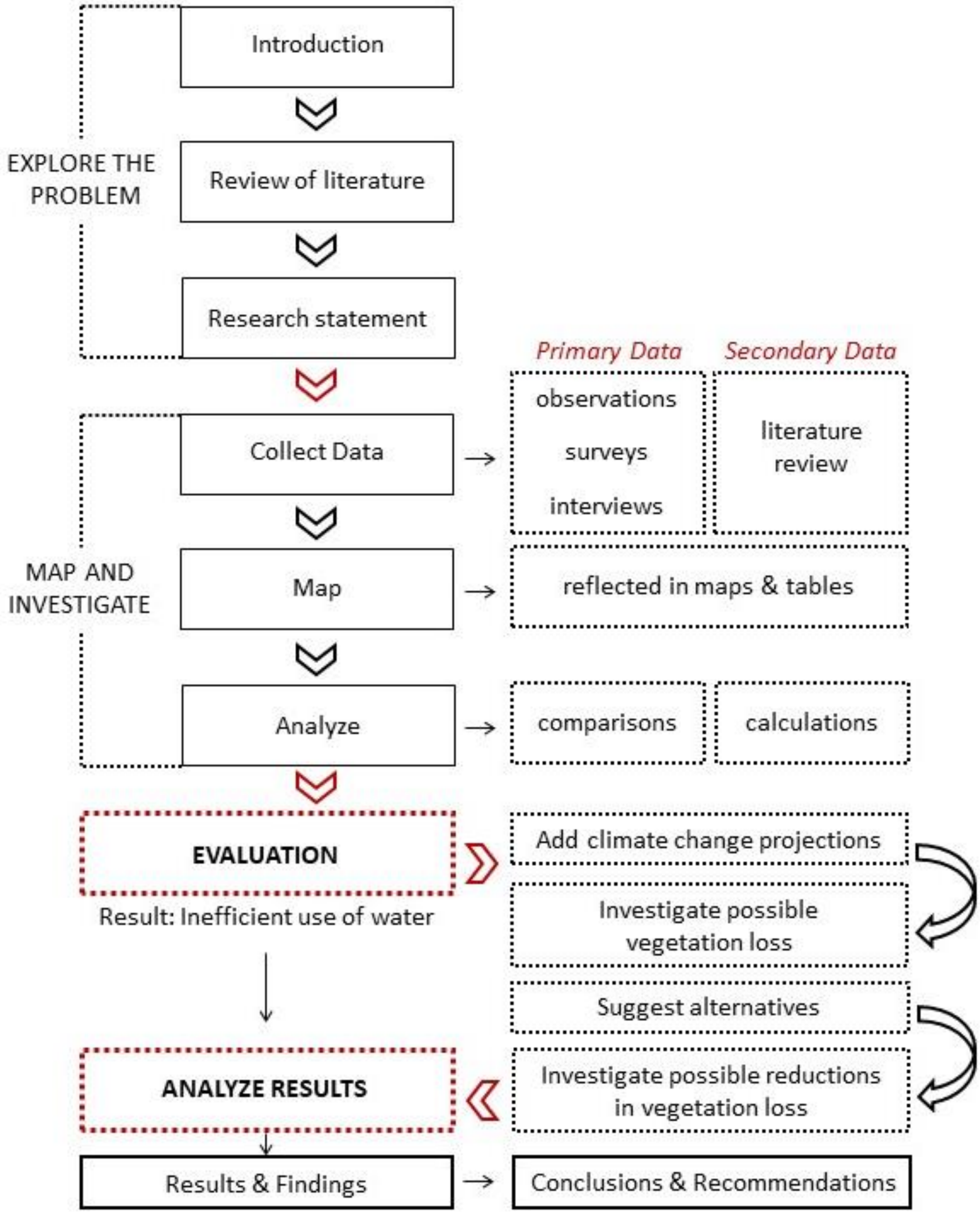

Figure (3). Research Methodology.

1. METHODS

1.1 Al-Rehab City

Al-Rehab is one of the first fully integrated gated settlements in Egypt and the Greater Cairo region. Its early establishment and development through the years made it possible to investigate how water consumption and management strategies evolved with the on-going water crisis in Egypt. Additionally, the design of green spaces in the settlement is considered a pioneer prototype that has been followed and implemented in several new settlements in Cairo.

The settlement has a total surface area of 10 million m². It is divided into 10 districts that are targeted to inhabit 200,000 people (Alrehabcity, n.d.). Within Al-Rehab, low-rise residential buildings and villas are distributed all over the settlement and surrounded by green spaces that comprise 30% of the settlement.

A selected study area within Al-Rehab, namely study area 1, is a 0.10km^2 residential area. Based on interviews with city council personnel, along with previous research conducted in the region (Deister, 2013), it is found that study area 1 comprises of 20.2% residential buildings, 29.7% streets, 14.5% pedestrian pathways, and 35.6% green spaces, as shown in Figure (4).

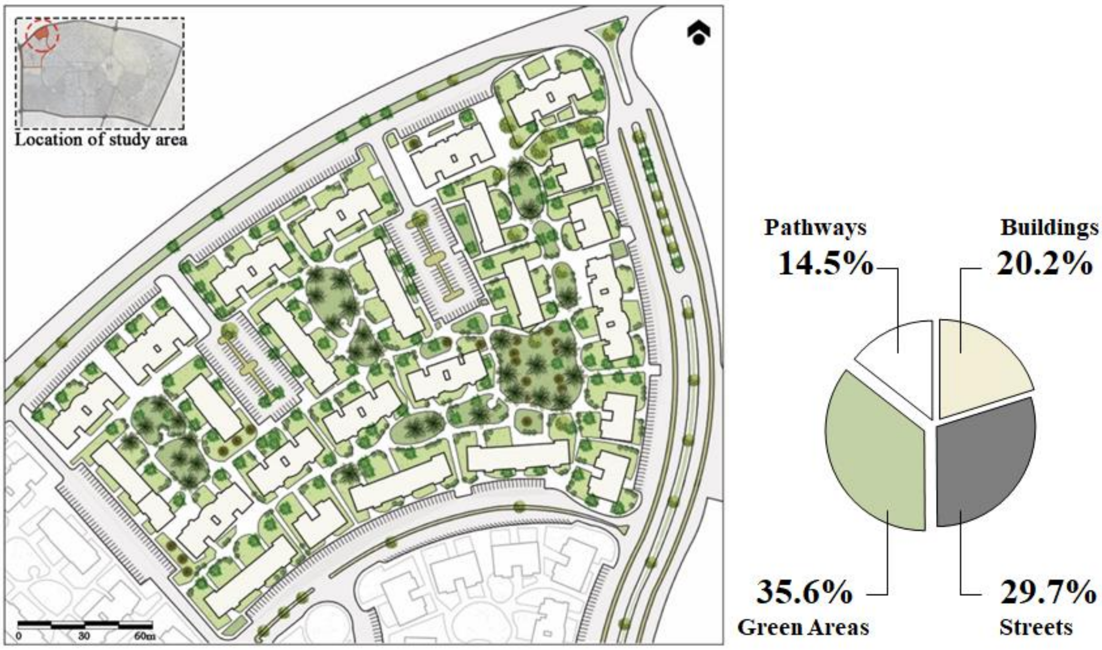

Figure (4). Map of Study Area 1 showing the land-use percentage.
Source: Authors based on field survey, 2019.

There are 4 types of plants used in this area. Lawns comprise 98.4% of the green space, 178 trees comprise 0.48% of the green space, around 400 shrubs making up 1.1% of the green space, and 30 palm trees making up only 0.08% of the landscape. Trees, shrubs, and palm trees together make up only 1.6% of the entire area of green space in study area 1.

The plants' water demands are calculated by using a method mentioned in the Landscape Water Efficiency Guide (Zureikat & Husseini, 2011) prepared by the Center for the Study of the Built Environment. By using such a method, the following calculations were reached. Each square meter of groundcovers in Al-Rehab requires approximately 0.01m^3/day, which is the highest water demand. Trees require approximately 0.006m^3/m^2/day, shrubs require 0.005m^3/m^2/day, and palm trees need 0.002m^3/m^2/day to be sustained. Figure (5) illustrates the water requirements of the plants used in the area.

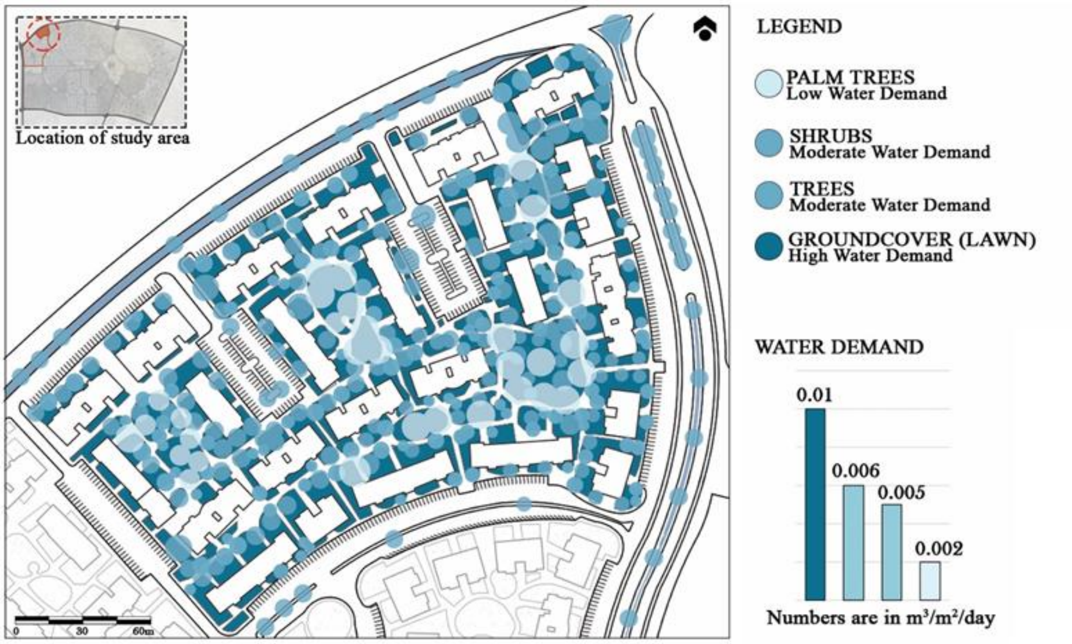

Figure (5). Map of Study Area 1 showing the irrigation water requirement.
Source: Authors based on field survey and analysis, 2019.

While the current irrigation water consumption of the same area is found to be slightly different from the demand. The settlement mainly uses sprinkler irrigation systems with the use of drip irrigation for palm trees (Deister, 2013). This leads to a uniformed irrigation practice. All plants in the region uptake 0.01m^3/m^2/day of irrigation water (Deister, 2013).

The only plant that receives the exact amount of water that it requires is the turf-grass, while the remaining receive more water than what they need. Plants, indeed, have the capability of consuming more water than what they demand, but only to some extent. This phenomenon, which is sometimes referred to as luxury consumption, is what is occurring in study area 1. Due to such, and given the uniform irrigation practice occurring in the region, each tree consumes 40% more water, each shrub consumes 50% more and each palm tree receives up to 80% more water than required. This adds up to around 2.83m^3/day or 0.77% of excess water.

1.2 Same Water-intake Scenario

Plants’ water demands could possibly increase by 20-25% (Pink, 2018; Tolba & Saab, 2009). This is due to the possible increase in temperatures discussed in the introduction section. To properly highlight the possible effects of such an increase, a theoretical scenario is proposed and applied to study area 1. The scenario, which is named “Same water-intake” scenario, assumes an increase of plant water demand by 20% while the existing irrigation water quantity remains the same as it is today. The results of the same-water intake scenario would be obtained by calculating each plant’s exact water requirement and assuming that it receives only that, without any luxury consumption occurring. Following that, the water demand of study area 1 is compared to the water availability to calculate the quantity of water deficit and map the possible vegetation loss.

Reducing the landscapes' irrigation demand is highly important. Due to such, ad following the results of the same-water intake scenario, an alternative of possible native plant substitutions would be outlined. It would suggest a substitution of part of the area's lawn with native grass species. The water demands of each native plant are then stated and the overall demand of the study area is calculated. Once again, such a demand is compared to the available water and the expected water deficit and vegetation loss in study area 1 are calculated and illustrated. Finally, the results obtained from the scenario and alternatives are then compared to reach a conclusion.

In the same water intake scenario, each plant's new demand is calculated by using the methods mentioned in 01) and outlined in Table 1, along with the new plant demands. Lawns, which have the highest water demands, would require an average of $0.012m^3/m^2$/day of irrigation water, trees would require $0.0072m^3$/tree (or /m^2) per day, shrubs would require $0.006m^3/m^2$/day, and palm trees would require $0.0024m^3/m^2$/day of irrigation water.

Table. 1. Current and expected water demands of plants in study area 1.

Type of Plant	Area/Number of Plants	Current water needs/Plant or /m^2	Current water needs/day **Total**	New water needs/Plant or /m^2	New water needs/day **Total**
Lawns	$35,030m^2$	$0.01m^3$	$350.3m^3$	$0.012m^3$	$420.36m^3$
Trees	178 trees	$0.006m^3$	$1.068m^3$	$0.0072m^3$	$1.28m^3$
Shrubs	400 shrubs	$0.005m^3$	$2m^3$	$0.006m^3$	$2.4m^3$
Palm Trees	30 palm trees	$0.002m^3$	$0.06m^3$	$0.0024m^3$	$0.072m^3$

Source: Authors based on calculations and (Zureikat & Husseini, 2011).

This expected rise in demand would require the utilization of native plant species to reduce any possible water deficits and overcome probable vegetation losses. Such plants would mostly rely on rainwater and only a few would require irrigation water to keep them green (0). This would not only potentially save water and sustain the landscapes, but it would also enhance biodiversity.

1.2.1 Plant substitutions

Possible substitutions for the same water-intake's plantations are proposed to determine the effect of such alternatives on the water demand. Ideally, if this area were not already implemented and could possibly be redesigned, significant changes in the spaces' designs would have been suggested. Those changes would mostly include decreasing the surface area of lawns by using alternative landscape features such as mulching, using ornamental low maintenance plants, increasing pathways, etc. Such landscape features will not only decrease the lawn's surface areas but will also add color, versatility, and uniqueness to each space.

However, as already stated, such alternatives are feasible in unimplemented regions that could still undergo design alterations. Hence, only mild substitutions are suggested for study area 1's plantations.

The species of grass or lawn currently used in the settlement is Cynodon Dactylon (0); which is one of the Bermuda grass species. When compared to other similar turf grasses, it is found that it is relatively low-water demanding and is actually one of the most drought-tolerant grass species (Error! Reference source not found.). It is perfectly capable of going dormant (survive under deficit irrigation) for long periods but will eventually respond to this drought if the water shortage becomes permanent. Due to such, it is rather suggested to substitute it with lawn alternatives that would include some native grass species and evergreen shrubs. The use of Ammochloa Palaestina (which will be referred to as AP), Cenchrus Orientalis (common name: Oriental Fountain Grass (OFG)), and Cistus Parviflorus (Common name: Grayswood Pink (GP)) are suggested by the researcher as substitutes. AP and OFG are both native grass species, according to the "Grasses of Egypt" article (Error! Reference source not found.], while GP is a native evergreen shrub (0).

It is suggested that all the current lawn (Bermuda grass) used in the region's public spaces is removed and those 3 types of plants are used instead. The zoning of functions in one of those public spaces of study area 1 is conducted to illustrate how such substitutions could occur (Figure (6)). It should be mentioned that the existing trees and palm trees in the area are left as they are in this alternative.

Based on the average water demand of drought tolerant groundcovers, stated by (Zureikat & Husseini, 2011) it is assumed that the 3 plants have similar water demands. This is estimated to be $0.06m^3/m^2$/month once established (Leinauer et al., 2012). However, given that the same water-intake scenario has a 20% theoretical increase in water demand; this could lead those plants to require $0.072m^3/m^2$/month or $0.0024m^3/m^2$/day (2.4 litres/m^2/day). This quantity is approximately 1/5 that of the same-water intake scenario, which is 12litres/m^2/day. This plant substitution is proposed only in the public green spaces in the region. This is because those are the regions that could suffer most from the possible vegetation losses after being deliberately chosen not to receive irrigation water. Furthermore, those plants are assumed to be distributed to cover the entire area of public spaces that currently comprises of Bermuda grass.

The combined areas of the public green spaces are approximately 6,559m^2. Assuming the substitution of all lawn areas with the 3 suggested plants; this would lead to an irrigation water demand of approximately 20m^3/day in the public areas along with irrigating the trees, shrubs, and palm trees in the entire area. Furthermore, there are 2 tree species and 1 palm tree species in this area; *Ficus Benjamina*, *Ficus Microcarpa*, and *Pheonix Dactylifera*; with the latter being the only species of palm trees. Palm trees are the least water consuming plants in Al-Rehab, and even with the proposed 20% increase in demand it would be sufficiently irrigated and sustained. Therefore, palm trees are not to be altered in any way in this alternative.

Subsequently, 2 different native low water-demand trees are suggested. One of which is the Dragon Tree (*Dracaena Ombet*) and the other is the Jerusalem Thron (*Parkinsonian Aculeata*). According to the Egyptian Biodiversity Strategy and Action Plan [2015-2030] prepared by Egypt's Ministry of Environment, Dragon Tree (mainly found in Gabal Elba in Egypt) is threatened to go extinct 0 2016). Climate change is even thought to be one of the reasons behind the endangerment of the species (Error! Reference source not found.). Accordingly, the use of this tree is proposed in this alternative to not only use drought-tolerant trees but also contribute to saving it. It is also worth mentioning that dragon trees grow very slowly and are long-lived trees (0). Given that there is only a small number of this species that still exists in Egypt, it is not suggested to be used in the entire settlement.

Figure (6). Zoning of a public space in study area 1, showing possible lawn substitutions. Source: Authors

Perhaps other endangered native species such as *Ficus sycamorus*, *Zizyphus spina christi*, *Acacia seyal*, etc. (Error! Reference source not found.); could be considered.

Once the 2 proposed tree species are established, they are estimated to have a water demand of approximately 0.006m^3/m^2/month or 0.002m^3/m^2/day (2litres/m^2/day) (Zureikat & Husseini, 2011; Radwan et al., 2010), But there is the assumed 20% rise in each plant's water demand which would lead to those trees having a water demand of approximately 0.0024m^3/m^2/day. In this alternative, public spaces would require 16m^3/day (assuming alternative one's substitution). Trees in the study area would therefore require 0.42m^3/day, palm trees 0.072m^3/day, and shrubs would require 2.256m^3/day. An illustrative section E-E (Figure (7)) in part of study area 1 is taken to show the different plants suggested in the alternative, with the section line shown in Figure (8).

2. RESULTS

The same water-intake scenario assumes a similar quantity of available water in study area 1 to be used for irrigation. That is, 365m^3/day. Apart from the groundcover, water will be sufficient to attain all the plants' water requirements. Approximately 80-84% of the lawn would be able to receive enough water, while the remaining percentage could possibly lose their vegetation. Overall, 12-16% of the region's vegetation could be lost with a water deficit of approximately 16-20%. Figure (8) shows the possible vegetation loss in study area 1 within the variables of the same-water intake scenario. Moreover, the irrigation and vegetation variables of study area one are shown in Table. 2.

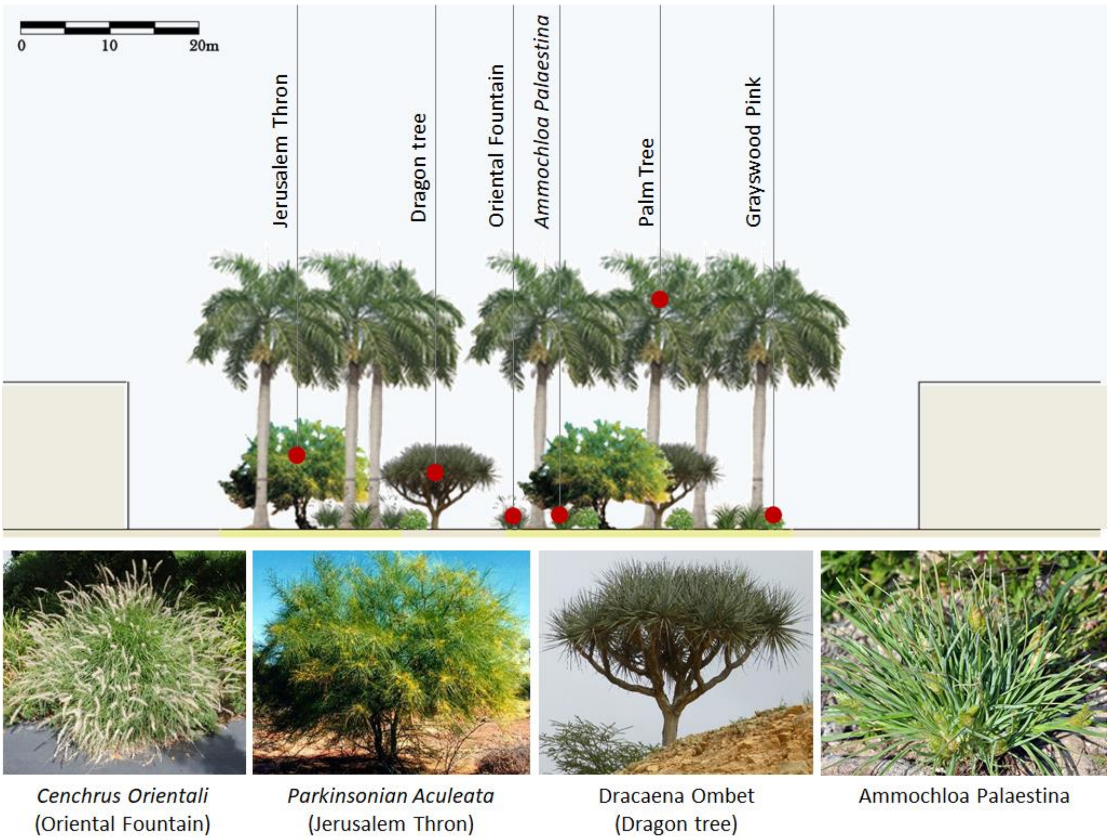

Figure (7). Section E-E showing the alternative's plantations.
Source: Authors

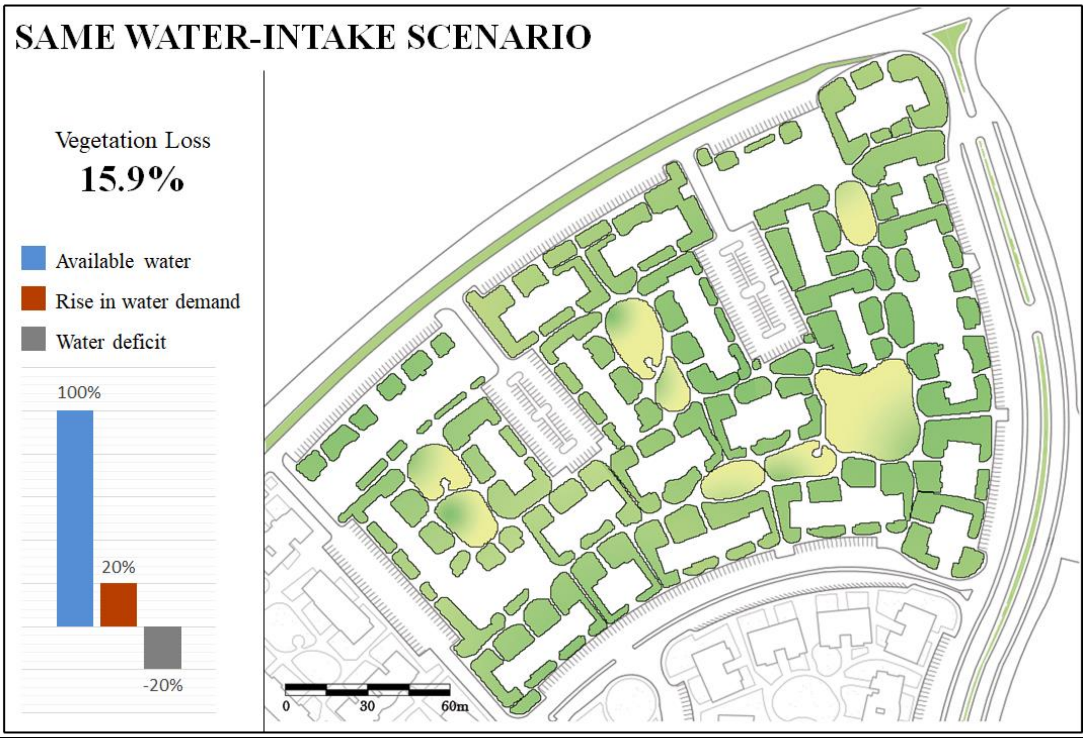

Figure (8). Possible vegetation loss in the "same water-intake" scenario.
Source: Authors based on calculations and analyses, 2020.

Table. 2. Comparison b/w the current status and same water-intake scenario of study area 1.

Variables / Scenario	Available Water	Irrigation practice	Rise in plant water demand	Vegetation loss	Water deficit/surplus
Current Status	365m^3/day	Uniform	0%	0%	+ (0.5-1.5%)
Same water-intake	365m^3/day	Facilitated	20%	12-16%	- (16-20%)

Source: Authors based on calculations, 2022.

As shown in Figure (8), public spaces were the ones deliberately chosen to not receive irrigation water and, theoretically, lose their vegetation. This is because if such scenarios were to occur, private green spaces (or the ones directly surrounding the residential buildings) would probably be prioritized in terms of maintenance.

While in the alternative of grass substitution, around 345m^3 of water/day were available to irrigate 29,348m^2 of lawn extensive spaces in study area 1. Consequently, around 97.8% of study area 1's green spaces could be able to receive sufficient irrigation water. In theory, such an alternative would lead to an overall vegetation loss of 2 to 2.5% and a water deficit of 1.9 to 2.4% (as shown in Figure (9)).

Figure (9). Map of study area 1 showing the open spaces where native plants are proposed, along with vegetation loss results of substituting Bermuda Grass.
Source: Authors based on calculations and analysis, 2020.

Given that this is considered a noticeable loss, tree species were theoretically substituted as well to examine the possibility of any further reductions in water requirements. By doing so, 346.2m^3/day of water is estimated to be available to irrigate the lawn extensive regions. Subsequently, around 98.4% of study area 1 could be sustained while the remaining 1 to 1.6% could lose its vegetation. This leads to a possible water deficit of 0.9 to 1.5%. The following Table. 3 summarizes the results of the scenario and the 2 different plant alternatives in the study area.

Table. 3. Results obtained from the climate change scenario and plant substitutions.

Variables / Scenario/Alternative	Avail. water	Increase in demand	Utilized plants	Drought tolerance	Possible veg. loss	Water deficit
Same water-intake scenario	100%	20%	CD, FB, FM*	Low	12-16%	16-20%
Grass substitutions	100%	20%	AP, GP, OFG**	High	2-2.5%	1.9-2.4%
Grass and tree substitutions	100%	20%	AP, DT, GP, JT, OFG***	High	1-1.6%	1.5-1.9%

*CD: Cynodon Dactylon, FB: Ficus Benjamina, FM: Ficus Microcarpa
** AP: Ammochloa Palaestina, GP: Grayswood Pink, OFG: Oriental Fountain Grass
*** DT: Dragon Tree, JT: Jerusalem Thron
Source: Authors based on literature and calculations, 2021.

3. DISCUSSION

The proposed adaptation for the same water-intake scenario has several indicators. The alternative, which suggested the removal of Bermuda grass from approximately 18% of the spaces and its substitution with 3 other species, led to a possible vegetation loss reduction from an approximate 16% to 2.5%.

Given the same variables of the same-water intake scenario, an approximate 13.5% reduction of vegetation loss is thought to be significant. Additionally, substituting the existing trees with other low water demanding ones got examined. One of the trees suggested (Dragon tree) is an endangered species. This was perhaps proposed to increase awareness of the municipal landscape’s responsibility towards those species and possibly rely on the country’s own plant repertoire more often. When moderate-demand trees were substituted with low-demand ones, the possible vegetation loss further decreased to 1.6%. Such results point out that substituting the current vegetation with native and drought-tolerant ones could in fact lead to a water surplus in study area 1. Furthermore, the possible vegetation loss indicates that the excessive use of lawns is most probably the major contributor to the settlement’s water consumption rate, and by decreasing their use, such rate could significantly decrease.

4. CONCLUSIONS

As indicated by the climate change scenario results, a potentially significant impact could occur and this, therefore, needs to be further investigated through computational modelling of possible climate change scenarios. If irrigation were to be uniformed, just as it is in the current-status, the possible vegetation losses could increase significantly. This is another indicator that, indeed, the region receives and uses more water than is needed. Furthermore, it indicates that precise irrigation facilitation according to the plants' exact water demands is necessary. Especially given the expected water shortages that could occur in Egypt and the extreme weather events that might impact the urban vegetation in ways not yet modelled.

The reliance on green spaces with vast surface areas of lawns in Egypt's new communities should be reconsidered. Reducing the use of high-water demanding plants in those urban spaces should gain more recognition. Preferably, it ought to be a national strategy that is adopted by the government and enforced by the private sector.

There is only one main native plant nursery in Egypt; located in Al-Hammam city. The use of native plants, and the expansion of such nurseries, is extremely important. Moreover, there is a need to further experiment with such plants along with their use in urban landscapes in Egypt. In that effect, seemingly, a few consultants suggested the use of native plants as a proposed measure for future developments implemented by Al-Rehab city's developer. With that in mind, three main classifications are used to summarize the recommendations of this research.

The first is education-based recommendations. They entail to educate potential researchers on drought-tolerant native plants that require less water and maintenance and aid in mitigating climate change effects. In addition, focusing the teachings of landscape design in Egypt on the concepts and executions of desert landscapes is highly important. Finally, there should be an integration of the topic of climate change into the environmental sciences that are taught to school and college students.

Research-based recommendations, on the other hand, suggest the conductance of more research on the benefits of native plants. Especially in their role in supporting biodiversity and their possible integration within the urban environment. Moreover, it would be distinctly beneficial to increase the studies of climate change effects on municipal landscape and water consumption in Egypt. And to enhance the comprehensibility of relevant research, studies that test the use of subsurface, bubbler, furrow, and smart-sensor based irrigation systems in Egypt's urban landscapes as alternatives to sprinkler irrigation systems should gain more recognition. While also preparing rough economic analyses of the cost of implementing such techniques.

Finally, implementation-based recommendations suggest several adaptations. One of which is increasing the utilization of native plant species that are highly drought tolerant in Egypt's green spaces. Secondly, reducing the use of high-water demanding groundcovers that would probably suffer the most if water depletions were to occur. And lastly, if economically wise, highly water-efficient irrigation systems ought to be used for green space maintenance.

AUTHORS' CONTRIBUTIONS

Professor Nabeel Elhady contributed to the entire conception and design of the research's content. He also had a role in interpreting most of the outlined data and substantively revised the entire manuscript. Sarah Asar performed the mapping, calculations, and analyses of the data and generated the findings of the research while writing the manuscript. All authors read and approved the final manuscript.

REFERENCES

الجهاز المركزي للتعبئة العامة والإحصاء. (٢٠١٩). مصر في ارقام ٢٠١٩ – الموارد المائية. النشرة السنوية لإحصاء الري والموارد المائية عام ٢٠١٩.

CAPMAS. (2019). *Egypt in Figures 2019 - Water Resources.* Annual Bulletin of Irrigation and Water Resources 2019.

10 Tooba. (n.d.). *Safe Water: The Built Environment Deprivation Indicator*. Retrieved April 2018, from http://10tooba.org/bedi/en.

Alrehabcity. (n.d.). Al-Rehab New Cairo. Home Page: Welcome to Al Rehab City. Retrieved April 15, 2019 from https://www.alrehabcity.com

Bohl, D. K., Hanna, T. L., Scott, A. C., Jonathan D. Moyer, J. D., & Hedden, S. G. (2018). *Sustainable Development Goals Report: Egypt 2030.* UNDP & Frederick, S. Pardee Center. https://www.undp.org/egypt/publications/sustainable-development-goals-report-egypt-2030

Deister, L. (2013). *Designing Landscape as Infrastructure Water Sensitive Open Space Design in Cairo*. Unpublished Master of science thesis. University of Stuttgart, Germany.

Elnoby, S. K., Moustafa, A.R. (2017). *Impact of Climate Change on the Endangered Nubian Dragon Tree. (Dracaena ombet) in the Southeastern of Egypt.* Catrina: The International Journal of Environmental Sciences, 16(1), 25-31. https://doi.org/10.21608/cat.2017.14256

Elsaeed, G. (2012). *Effects of Climate Change on Egypt's Water Supply.* In: Fernando, H., Klaić, Z., McCulley, J. (eds) National Security and Human Health Implications of Climate Change. NATO Science for Peace and Security Series C: Environmental Security. Springer, Dordrecht. https://doi.org/10.1007/978-94-007-2430-3_30

Garzulia, M. (2006) *Threatened, endangered and vulnerable tree species: A comparison between FRA 2005 and the IUCN red list.* Working Paper 108/E, FAO, Forestry Department, Rome, Italy.

Gad, W.A. (2017). *Water Scarcity in Egypt: Causes and Consequences*. The IIOAB Journal, 8(4), 40-47. https://www.iioab.org/

Ghazali, U., Hatab, E-B., Dora, A., Arkeeb, H., Aoud, M., Ossman, G., Mansour, M., & El Nemery, H. (2008). *The globally endangered Dracaena ombet monitoring and assessment project in Gabel Elba protected area, Egypt.* Final Report, Conservation Leadership Programme. https://www.conservationleadershipprogramme.org/project/dracaena-ombet-gabel-elba-egypt/

Ibrahim, K. M., Hosni, H. A., & Peterson, P. M. (2016). *Grasses of Egypt*. Washington, D.C.: Smithsonian Contributions to Botany. https://doi.org/10.5479/si.19382812.103

Leinauer, B., Serena, M., Schiavon, M., Sevostianova, E. (2012). *Water Demands and Water Conservation Strategies in Turfgrass Management.* Article in Acta Horticulturae. 938, 113-120. https://doi.org/10.17660/ActaHortic.2012.938.14

Ministry of Environment (MOE). (2016). *Egyptian Biodiversity Strategy and Action Plan [2015-2030]*. https://www.cbd.int/doc/world/eg/eg-nbsap-v2-en.pdf.

Ministry of Water Resources and Irrigation (MWRI). (2005). *National Water Resources Plan for Egypt - 2017 (Water for the Future)*. https://www.fao.org/faolex/results/details/en/c/LEX-FAOC147082/

New Urban Communities Authority (NUCA). (n.d.). *New Cairo Figures*. Retrieved May 2019, from http://www.newcities.gov.eg/english/New_Communities/Cairo/default.aspx.

Ouda, S. A., & Zohry, A. E. (2016). *Management of Climate Induced Drought and Water Scarcity in Egypt: Unconventional Solutions*. Springer Briefs in Environmental Science. https://doi.org/10.1007/978-3-319-33660-2

Pink, R.M. (2018). The Middle East: Egypt, Israel, Jordan. In: The Climate Change Crisis. Palgrave Macmillan, Cham. https://doi.org/10.1007/978-3-319-71033-4_8

Radwan, A. A., El Awady, M. N., Hegazy, M. M., Mohamed, S. A. (2010). *Determining Plant Water Use and Landscape Coefficients of Selected Nursery and Landscape Plants.* Misr Journal of Agricultural Engineering 27(2): 521-529. https://doi.org/10.21608/MJAE.2010.105840

Tolba, M.K., Saab, N.W. (2009). *Arab Environment: Climate Change - Impact of Climate Change on Arab Countries*. Report of the Arab Forum for Environment and Development, Beirut, Lebanon.

Tsalikidis I.A., A. E. (2007). *Sustainable Landscape Architecture: Alternatives to Lawn in the Mediterranean Region*. In 18th int. annual ECLAS conference titled Landscape Assessment - From Theory to Practice: Applications in Planning and Design. Belgrade, Serbia.

World Bank Group. (2021). Climate Change Overview: Country Summary: Egypt. *Climate Change Knowledge Portal for Development Practitioners and Policy Makers*. Retrieved 4 June 2021 from https://climateknowledgeportal.worldbank.org/country/egypt.

Zureikat, L., & Husseini, D. (2011). *Landscape Water Efficiency Guide*. Center for the Study of the Built Environment (CSBE).

LIST OF ABBREVIATIONS

AP - Ammochloa Palaestina

CD - Cynodon Dactylon

DT - Dragon Tree

FB - Ficus Benjamina

FM - Ficus Microcarpa

GP - Grayswood Pink

JT - Jerusalem Thron

OFG - Oriental Fountain Grass