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The Effect of Seawater Desalination on the Characteristics of Treated Effluents and Potential Reuse in the Gaza Strip

M.Sc. Thesis By

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A thesis submitted in partial fulfillment of the requirements the **Degree of Master** of Science in Civil Engineering, Infrastructure Engineering.

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إقـــــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

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نتيجة الحكم على أطروحة ماجستير

بناءً على موافقة عمادة البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **أحمد جهاد أحمد المناعمة** لنيل درجة الماجستير في كلية **الهندسة**/ برنامج **الهندسة المدنية/البنى التحتية** وموضوعها:

تأثير تحلية مياه البحر على خصائص المياه العادمة المعالجة وآفاق اعادة الاستخدام في قطاع غزة

The Effect of Seawater Desalination on the Characteristics of Treated Effluents and Potential Reuse in the Gaza Strip

وبعد المناقشة التي تمت اليوم السبت **1 ذو الحجة 1440**هـ الموافق **2019/08/03**م الساعة الحادية عشرة صباحاً، في **قاعة اجتماعات كلية الهندسة** اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله تعالى ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق،،،

عميد البحث العلمي والدراسات العليا

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Holy Quran

بِسْمِ ٱللَّهِ ٱلرَّحْمَٰنِ ٱلرَّحِيمِ

﴿ رَبِّ أَوْزِعْنِي أَنْ أَشْكُرَ نِعْمَتَكَ الَّتِي أَنْعَمْتَ عَلَيَّ وَعَلَىٰ وَالِدَيَّ وَأَنْ أَعْمَلَ
صَالِحًا تَرْضَاهُ وَأَدْخِلْنِي بِرَحْمَتِكَ فِي عِبَادِكَ الصَّالِحِينَ﴾

[النمل: 19]

"My Lord, enable me to be grateful for Your favor which You have bestowed upon me and upon my parents and to do righteousness of which You approve. And admit me by Your mercy into [the ranks of] Your righteous servants."

(An-Naml – 19)

Abstract

Gaza Strip suffers from water crisis due to the scarcity of water resources and the substantial increase of the population, which led to increasing the demand for water by all sectors including residential, industrial and agricultural. For a long time, the supply of fresh water to the population in Gaza depends overwhelmingly on the groundwater, causing the intrusion of seawater to groundwater and increasing the salinity in several areas. Therefore, the Palestinian Water Authority proposed other alternate sources; one of them is the seawater desalination. The desalination was planned to supply 13 MCM/y as short term measures that will be followed by long term measures that increasing these quantities to 55 MCM/y in the first phase, up to 110 MCM/y capacity in the second phase.

The study aimed to identify the effects of seawater desalination on the treated effluents and assess the potential improvements in wastewater reuse in the Gaza Strip.

According to the plans, an estimation was made for the future domestic water salinity, which will be reflected on the quality of wastewater treatment plant effluents, that will achieve significant improvements in the treated wastewater salinity. The estimation was made for the salinity of the NGEST effluent as a sample, which was estimated by around 755, 493 & 658 mg/l for years 2025, 2030 & 2035, respectively. This makes the ability to plant sensitive salinity horticultural crops. Evaluation for the effluents of intermediate and regional wastewater treatment plants was made and concluded to the ability to use the effluents for the regional plants.

The main horticultural crops need in Gaza Strip for years 2025,2030 & 2035 were calculated and the required agricultural lands were proposed. The distribution of crops on the proposed lands was made according to the areas famous for crops planting. Also, the available produced treated wastewater was considered. The self-sufficiency for the main horticultural crops was considered in the next years and the proposed of cultivated areas will be 76,545 & 87,878 & 100,890 dunums for the years 2025, 2030 & 2035, respectively. Also, the treated effluents will be used by 96.4%, 78.77 % & 73.71% from the produced quantities for the years 2025, 2030 & 2035, respectively.

The study recommended searching the ability of irrigation of new crops from the remaining treated wastewater quantities. Also, the related authorities should take actions to reserve agricultural lands without changes.

Abstract in Arabic (ملخص الدراسة)

يعاني قطاع غزة من ازمة في المياه؛ نتيجة ندرة مصادر المياه وتزايد كبير في عدد السكان؛ والذي أدى لزيادة الطلب على المياه من كافة القطاعات بما فيها السكانية والزراعية والصناعية. لوقت طويل يتم الاعتماد على الخزان الجوفي لتزويد السكان في قطاع غزة بالمياه الامر الذي أدي الى تداخل مياه البحر وزيادة في الملوحة في العديد من المناطق. لذا فإن سلطة المياه الفلسطينية اقترحت العديد من مصادر المياه البديلة والتي كان احداها تحلية مياه البحر. تم التخطيط لتحلية مياه البحر لتزويد قطاع غزة ب 13 مليون م3/سنويا كإجراءات لمرحلة قصيرة، يتبعها اجراءات طويلة المدى وتشمل زيادة هذه الكميات الى 55 مليون م3/سنويا كمرحلة اولى، لتصل الى 110 مليون م3/ سنويا كمرحلة ثانية.

تهدف هذه الدراسة لتحديد تأثير تحلية مياه البحر على المياه العادمة المعالجة وتقييم التحسن المتوقع على اعادة الاستخدام، في قطاع غزة.

وفقا للخطط المستقبلية، فقد تم تقدير ملوحة المياه المنزلية المستقبلية والتي ستنعكس على جودة مخارج محطات المعالجة حيث سيتحقق تحسن ملحوظ في ملوحة المياه العادمة المعالجة. تم تقدير ملوحة المياه الخارجة من محطة شمال قطاع غزة كمثال والتي قدرت ب 755 و493 و658 ملجم/لتر للأعوام 2025 و2030 و2035 على الترتيب. والتي ستتيح بزراعة أشجار حساسة للملوحة. تم تقييم مخارج محطات المعالجة متوسطة الامد والمحطات المركزية، واستنتاج امكانية استخدام المياه المعالجة من المحطات المركزية.

تم حساب احتياجات قطاع غزة لأهم محاصيل الاشجار للأعوام 2025 و2030 و2035 وعمل مقترح بالمساحات التي يلزم زراعتها. تم توزيع المحاصيل على الأراضي المقترحة بحسب شهرة المناطق لهذه المزروعات. كما تم الاخذ بعين الاعتبار كميات المياه المعالجة المتاحة. تم اعتبار تحقيق الاكتفاء الذاتي من هذه المحاصيل في الاعوام القادمة، فكانت مساحات الاراضي اللازمة المقترحة تقدر ب 76,545 و 87,878 و100,890 دونمات للأعوام 2025 و2030 و2035 على الترتيب. كما بلغت نسب المياه العادمة المعالجة و المستخدمة في الري من المياه المتاحة ب 96.4% و 78.77% و73.71% دونمات للأعوام 2025 و 2030 و 2035 على الترتيب.

الدراسة توصى ببحث امكانية زراعة محاصيل جديدة من كميات المياه المعالجة المتبقية. بالإضافة الى ضرورة قيام السلطات ذات العلاقة باتخاذ الاجراءات للمحافظة على الاراضي الزراعية.

Dedication

To the soul of my beloved father, who was hoping to see this day, but God's will.

To my beloved mother, who planted the success tree in us and irrigated it with her sweat, tears, and patience until yielding this achievement.

To my dear wife, on her patience and encouragement to accomplish this work.

To my beloved son Jehad and my daughter Jana, they were the source of my motivation and inspiration to continue.

To my brother Mohammed, to my dear sisters, the source of love and pride.

To all my teachers, friends and colleagues.

To every person who offers a useful science;

I dedicate my research, hoping that I made all of them proud.

Ahmed Jehad Al Manama

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List of Abbreviations

CM	Cubic Meter
CMWU	Coastal Municipalities Water Utility
EQA	Environmental Quality Authority
GCDP	Gaza Central Desalination Plant
GS	Gaza strip
IUG	Islamic University of Gaza
LINDO	Linear, INteractive, and Discrete Optimizer
m3/d	Cubic meter per day
MCM	Million Cubic Meters
mg/L	Milligram Per Liter
MOA	Ministry of Agriculture
MOH	Ministry of Health
MOP	Ministry of Planning
PCBS	Palestinian Central Bureau of Statistics
PNA	Palestinian National Authority
ppm	Parts per million
PWA	Palestinian Water Authority
RO	Reverse Osmosis
SDP	Seawater Desalination Plant
STLV	Short Term Low Volume
TDS	Total Dissolved Solids
TS	Total Solids
TSS	Total Suspended Solids
TWW	Treated Wastewater
UN	United Nations
UNDP	United Nations Development Program
UNRWA	United Nations Relief and Works Agency
WHO	World Health Organization
WWTPs	Wastewater Treatment Plants

Chapter 1

Introduction

Chapter 1
Introduction

1.1 Background

With the substantial increase of the population in Gaza Strip which led to growing the demand of water by all sectors including residential, industrial and agricultural and with the lack of water resources, the populations in Gaza Strip begin to suffer from water crisis (Al-Dadah and Gharbia, 2013).

Gaza Strip is a small area (365 km2) with a population reached 1.89 Million habitants in 2017 and expected to grow for more than 2 Million habitants by 2020 (PCBS, 2017), abstracts total amount of water around 200 MCM/year from aquifer. The supply of fresh water to the citizen in Gaza relies almost totally on the underlying groundwater which recovered annually by 55-60 MCM/year from rainfall. The aquifer has been exploited three times over its natural recharge capacity for several years, leading to seawater intrusion and lowering the groundwater level in several areas. This caused problems appeared in both quantity and quality of water (PWA, 2014a). The UN report (UN, 2012) indicates that Gaza aquifer is unusable and shall be irreversibly damaged by 2020.

Agriculture sector considers from the main water-consumer sectors. The quantity of water used in agriculture in Gaza Strip is estimated by approximately 90 million cubic meters annually (MOA, 2016).

Therefore, searching for alternative solutions for domestic water shortages became very necessary to overcome these issues which include reducing the deficit, minify the degradation of groundwater in addition to saving water for other sectors. The interventions that planned to implement by Palestinian Water Authority (PWA) included: management for water demand to minimize the needs for clean water in Gaza, reuse of wastewater to enhance the water availability in Gaza, import clean water to Gaza and seawater desalination in short and long terms (PWA, 2011b).

As recorded by Coastal Municipality Water Utility (CMWU) in 2016, around 130 million liters per day of wastewater are collected in wastewater treatment plants in Gaza

Strip (CMWU, 2016), about 100 million liters discharged to the sea as raw or partially treated wastewater.

A three new regional wastewater treatment plants were adopted to construction with a total capacity of 293 thousand cubic meters a day and will be able to remove pollutants such as organic loads and suspended solids and reduce Nitrogen concentrations and partially will remove organic detergents. The effluent of these treatment plants will be directed to either infiltration basins to recharge the aquifer or natural water wadis to revival the natural reserves along these wadis. The infiltrated water will be recovered and reused for irrigation (Ashour, 2013).

Three short term low volume desalination (STLV) plants were already constructed and it is expected that the operations will be completed by 2020. These plants represent short term mitigation of the existing deficit and to provide imperious relief with a relatively low capacity with 35,000 m3/day until a regional desalination facility, referred to as the Gaza Central Desalination Plant (GCDP) is implemented. GCDP is planned to implement in two phases to produce 110 MCM of desalinated seawater annually, with 55MCM/year (150,000 m3/day) for each phase. This will increase the supply of bulk water resources. (PWA, 2016)

In the Gaza Strip, pilot projects for using treated wastewater have existed for some years, and there are plans for reuse to be magnified soon. The main necessity, however, is the accomplishment of the regional wastewater treatment plants in Gaza Strip, as reuse cannot be presented at any large scale in the absence of high quality treated wastewater (Al Dadah, 2013).

1.2 Problem Statement

Due to increased water demand, groundwater is being abstracted from the coastal natural aquifer at almost three times the sustainable abstraction rate, thereby causing seawater intrusion. Seawater intrusion and sewage pollution made the resource largely non-potable (World Bank, 2018).

The main water quality problems are high salinity and high nitrate concentrations. Recent assessment for groundwater shows continues salinity increasing reached to 2000 mg/l and over in some areas along the coastline as a result of seawater intrusion. Also, Nitrate levels range from 100-200 mg/l which is above the World Health Organization (WHO) standard. This led only 3.9% of groundwater pumped is matching with the WHO limits (PWA, 2017).

Therefore, the Palestinian Water Authority proposed the seawater desalination as an option to providing safe & clean water for more than 2 million people and regeneration of the aquifer by minimizing the abstraction from it. The improved domestic water supply due to desalination will lead to improving the characteristics of effluent wastewater.

Besides, they proposed the reuse of treated effluent in agriculture as another option where it was limited before due to high salinity in the water and due to other reasons. However, the improved domestic water supply might have to change the behavior of farmers to use the domestic water for irrigation, which will negatively affect the main goals of desalination approach.

In the current research, the effects of the potential improvements on the reuse will be discussed.

1.3 Aim and Objectives

The study amid to identify the effects of seawater desalination on the treated effluents and assess the potential improvements in wastewater reuse. This can be achieved by:

1. Assess the improved domestic water quality on wastewater reuse and crop pattern.
2. Determine the horticultural agricultural demand and the quality & quantity of needed treated wastewater.
3. Evaluate the effect of improved water supply on the wastewater effluents.
4. Study the planned improvements for both water and wastewater sectors in Gaza Strip.

1.4 Thesis Structure

The research comprises six chapters structured & detailed as the following:

Chapter 1: Introduction, prefaces for water situation in Gaza Strip, the main objective definition and methodology.

Chapter 2: Literature review for the related topics.

Chapter 3: Study area, which includes general data and the situations of water, wastewater, and agriculture in the study area.

Chapter 4: Methodology.

Chapter 5: Describes the results and discussion.

Chapter 6: Defines conclusion and recommendations.

1.5 Research Methodology

To realize the objectives of the study, the following methodology will be applied:

- Gathering data from relevant institution, ministries, libraries, and the internet.
- Revise the published references such as books, reports, studies and researches relative to the subjects of this study which may relate with water & wastewater sectors status, water desalination, agriculture needs …etc.
- Define the situations of water and wastewater sectors in the Gaza Strip.
- Study the current status and the planned improvements for the water sector.
- Study the current and future statuses for the wastewater sector.
- Expect the effects of seawater desalination on wastewater effluent quality.
- Estimate the future wastewater quantities.
- Evaluate the treated wastewater for the intermediate and the regional WWTPs.
- Study the needs from the horticultural crops and the required lands to achieve the self – sufficiency in the Gaza Strip.
- Submit a proposal for distribution of the horticultural crops in the proposed areas.
- Conclusions and recommendations.

Chapter 2

Literature Review

Chapter 2
Literature Review

2.1 Introduction

Because of water scarcity, wastewater reuse has a large significance in several regions in the world. In the recent water resources plans, the treated wastewater is considered a valuable source. It can enhance the reliability of water resources and also can be used for wide sectors. However, using treated wastewater requires intensive measures to preserve public health and the environment. Strong wastewater reuse regulations and standards are developed for prospective uses. Endorsing unified regulations and guidelines is impossible that can fit for all countries in the world. This discrepancy can be attributed to many reasons, such as the economics of countries which affecting the chosen treatment technologies and moreover, the local condition for the region must be taken into account in adopting the standards (Kramer et al, 2008)

By volume, agricultural irrigation is the first consumers for treated wastewater, other major users include those who use water for processing and industrial cooling which categorized as direct reuse. The second category of reuse is indirect reuse. Treated wastewater can be used to recharge the aquifer after applying extreme treatment for wastewater. This is indirect reuse where the regained water will be mixed with the groundwater (Metcalf & Eddy, 2003).

2.2 Potential Reuse Applications of Treated Wastewater

Wastewater can be recycled and reused as a water source for many water demanding activities such as agriculture irrigation, aquifer recharge, aquaculture, fire fighting, industrial cooling, snow melting, flushing of toilets, golf course and parks wetting, creation the wetlands for wildlife habitats, and several other non-potable requirements. Prospective of reuses applications be based on the quality of the treated wastewater, that specified the techniques and required treatment levels. In common, agricultural reuse applications need lower quality treatment levels, while domestic reuse (direct or indirect potable and non-potable) require the highest levels of treatment. While the treatment for other reuse applications lies between these two extremes (Vigneswaran and Sundaravadivel, 2009).

In this section, the main types of reuse will be discussed:

2.2.1 Agriculture Use

Reuse of high quality treated wastewater for agriculture activities is important not only to protects the human health but also consider a good preservation strategy to reduce the consumption of limited drinking water for irrigation and to reduce fertilizer expenses especially in low-income countries. The irrigation water quality is not high that used for drinking purposes (Illungkoo and Vigneswaran, 2009).

In another context, salinity, sodium, trace elements, excessive chlorine residual, and nutrients are the main problems concern in using treated wastewater in agriculture. Predominantly, treated wastewater has higher concentrations of these components than the natural water resource (surface or groundwater). The composition and the amounts of these components in treated wastewater depend upon the source of the domestic water supply, the influent waste streams (i.e., domestic and industrial), amount and composition of infiltration in the wastewater collection system, the wastewater treatment methods, and the type of storage facilities. In most cases, the treated wastewater is quality acceptable if the municipal potable source is acceptable (Affifi, 2006).

Two types of agriculture irrigation were classified (Vigneswaran and Sundaravadivel, 2009):

- **Irrigation of food crops:**

High-quality treated wastewater is used to irrigate food crops. Many cautions in this type of application as follow:

- ✓ surface and groundwater pollution, if unwell planned and managed;
- ✓ effect of water quality on soil, and crops;
- ✓ marketing the crops and public acceptance;
- ✓ public health concerns related to pathogens.

So, these constraints must be considered and intensive measures should be applied to safe practice for treated wastewater in this kind of application.

- **Irrigation of landscape and recreational area:**

Applying the treated wastewater for landscape irrigation which may involve usage in gardens, urban green belts, golf courses, road medians, and recreational areas. This type of application is one of the most prevalent applications of wastewater reuse worldwide. It has a perspective to enhance the convenience of the urban environment. However, such systems must be carefully run to avert health problems for the surrounding communities. Because the public is may be exposed to the water used in areas, there is probable for human contact, so reuse water must be treated to accepted levels to escape the risks of spreading diseases but not as the irrigation for crops. Other expected issues for landscape irrigation related the aesthetics such as odor.

2.2.2 Groundwater Recharge

Artificial recharge of groundwater using treated wastewater continues to increase, particularly in arid and semi-arid countries. Enhancing the natural supply of groundwater aquifers by artificial recharge is becoming increasingly important in groundwater management.

Various methods have been used all over the world and can be concisely classified into two types as surface and sub-surface methods. In surface methods, water is collected and stored in open areas, sometimes referred to basins and let them permeate to the subsurface reservoir. In the Sub-Surface technique, the surface run-off water is directed to sub-surface layers directly through wells or shafts by natural flow or pumping it using mechanical pumps (Packialakshmi et al, 2015)**.**

A lot of purposes from recharge the groundwater by treated wastewater can be achieved as follow: (Affifi, 2006)

- Form saltwater intrusion barriers in coastal aquifers.
- Enhance the quality of treated wastewater for future reuse.
- Recompense the aquifers over abstractions for potable or non-potable uses.
- Provide natural, economical and environmental store for the reclaimed water.

As there are many advantages due to groundwater recharge, there are probable disadvantages to be considered (Oaksford, 1985) :

- Require wide land areas such basins.
- Power needs for recharge operations.
- Recharge may cause contamination for the aquifer. Aquifer remediation is tough, expensive, and may require many years to achieve.
- Lack of policies and laws for recharge may not protect water rights and may cause legal problems.
- The slow movement of groundwater can't meet the sudden increase of demand and not all added water may be recoverable.

2.2.3 Industrial Use

Industrial reuse of reclaimed wastewater represents major reuse next only to irrigation in both developed and developing countries. Treated wastewater is ideal for many industrial purposes, which do not require water of high quality. Depending on the type of industry, reclaimed water can be utilized for cooling water make-up, boiler feed-water, process water, etc..

A major problem associated with the reuse of wastewater for industrial purposes will be biofilm growth in the recirculation system. Presence of microorganisms (pathogens or otherwise) with nutrients such as nitrogen and phosphorus, in warm and well-aerated conditions, as found in cooling water towers, form ideal environments for biological growth.

2.3 Regulations and Standards for Using the Treated Wastewater

Regulations of wastewater reuse varying over the world and there are no unified standards due to varied climatic, geological and geographical conditions, water resources, type of crops and soils, economic and social situations, and policies towards using wastewater influents for irrigation purposes in countries. Some countries and agencies have already set up reuse standards such as the United States Environmental Protection Agency (USEPA), California, WHO, FAO, France, Italy. Most of the developing countries have adopted their standards from the leading standards set by either FAO, WHO, EPA, etc. (EPA, 2004).

2.3.1 WHO Guidelines

WHO developed guidelines for treated wastewater to protect the environments and human health since the year 1973, after an exhaustive audit of epidemiological investigations and other data, the guidelines were refreshed in 1989 (Ensink and Hoek, 2007). The recent review took place in 2006. These guidelines have been very valuable, and several countries have adopted them in their standards and excreta use practices.

WHO (1989) Guidelines for the safe use of wastewater in agriculture took into account all available epidemiological and microbiological data and are summarized in Annex (1-a).

The guidelines considered that the wastewater is a resource to be used safely. Fecal coliform guideline (e.g. =1000 FC/100ml for food crops eaten raw) was destined to protect against dangers from bacterial infections, and the intestinal nematode egg guideline was destined to protect against helminth infections (and also serve as indicator organisms for all of the large settable pathogens, including amoebic cysts). The exposed group that each guideline was intended to protect the exposed people (consumers, farmworkers, populations living near irrigated fields) against excess infection. Wastewater treatment expected to achieve the required microbiological guideline were clearly stated. Waste stabilization ponds were advocated as being both effective at the removal of pathogens and the most cost-effective treatment technology in many circumstances. Also, measures for comprising good reuse management practice are proposed alongside wastewater quality and treatment goals; restrictions on crops to be irrigated with wastewater; selection of irrigation methods providing increased health protection, and observation of good personal hygiene (including the use of protective clothing) (WHO, 1989).

2.3.2 Palestinian Standards

For long periods, Palestine did not have any specific wastewater regulations, references were usually made to the WHO recommendations or the neighbored country's standard (ex. Egypt, Jordan). Recently, the Environment Quality Authority (EQA) with coordination of Palestinian ministries have established specific wastewater reuse regulations titled ‘Standards for reuse of treated wastewater’(see annex 1-b) (EQA, 2014). There are three purposes for reuse which were discharging to the sea, irrigation, and infiltration for non-drinking water. They set up specific conditions and determine the limits for reuse for each purpose. A monitoring program should be conducted during the reuse period. The standards prevented the use of raw wastewater and the treated wastewater must meet the standards that varying according to the planned uses.

The standards have conditions for the treated wastewater reuse in agriculture as follow:

- When treated effluent is used for irrigation of fruit trees, cooked vegetables, and fodder crops. Irrigation must be ceased two weeks before collecting the products. Fallen fruit should be discarded;
- Usage of sprinkler systems for irrigation is prohibited;
- Usage of treated effluent in the irrigation of crops that can be eaten raw such as tomatoes, cucumber, carrots, lettuce, radish, mint, or parsley is prohibited before has the permission from EQA;
- Closed canals or lined channels must be used for transmission of treated wastewater in areas where the soil permeability is high, which can affect underground and surface water that could be used for potable purposes;
- Dilution of treated wastewater by mixing it with clean water to achieve the standard is permitted.

2.4 Wastewater Treatment Technologies

Wastewater treatment is a process used to convert wastewater into an effluent that can be returned to the water cycle with minimum impact on the environment, or directly reused. Recently, is called water reclamation because treated wastewater can then be used for other purposes. This will be achieved by a combination of physical, chemical, and biological processes and operations to remove solids, organic matter and, sometimes, nutrients from wastewater(Wikipedia, 2019a).

In the treatment process, wastewater must pass through numerous sewage treatment process stages before it can be used to provide several levels of treatment known as preliminary, primary, advanced primary, secondary, and tertiary (or advanced). There are several technologies used to treat wastewater for reuse. A combination of these technologies can meet strict treatment standards and make sure that the processed water is hygienically safe, meaning free from bacteria and viruses. The following are some of the typical technologies: Ozonation, ultrafiltration, aerobic treatment (membrane bioreactor), forward osmosis, reverse osmosis, advanced oxidation. Depending on the desired characteristics of the target water and treatment goals, unit techniques can be selectively employed. Table (2.1) summarizes the goals and typical operations of each level.

Table 2.1: Goals and technologies for each level of WWT

Treatment stages	Purpose	Technologies
Preliminary	Removal of large solids and grit particles	Screening, settling
Primary	Removal of suspended solids	Screening, sedimentation
Secondary	Biological treatment and removal of common biodegradable organic pollutants	Percolating or trickling filter, anaerobic treatment, activated sludge, waste stabilization ponds (oxidation ponds)
Tertiary (or advanced)	Removal of specific pollutants, such as nitrogen, color, odor, etc...	Sand filtration, membrane bioreactor, reverse osmosis, ozone treatment, chemical coagulation, activated carbon, disinfection.

After the treatment process, using disinfection is to substantially decrease the number of microorganisms in the water to be discharged back into the environment. Wastewater is generally treated to only secondary level treatment when used for irrigation.

2.5 Wastewater Reuse in Agriculture

2.5.1 Advantages and Disadvantages of Wastewater Reuse in Agriculture

When adopting the wastewater reuse for irrigation, an assessment of the advantages and disadvantages has to be made. The next paragraphs explore the main advantages, disadvantages regarding water conservation, different substances in the water and influences on the soil (SAI Platform, 2010).

- **Advantages**

There are many advantages for reuse of wastewater in agriculture, mainly related to the availability and reliability of water resources and the sustainability and security of food production. Several advantages include:

- ✓ An additional source for water irrigation.
- ✓ Saving of high quality water for other sectors.
- ✓ Low cost source of water supply
- ✓ A great method to dispose of wastewater and protect the environment from pollution and sanitary concerns.
- ✓ Continuous water source which allows several cultivation activities in a year.
- ✓ Provide the plant with nutrient contained in the wastewater (such as nitrogen and phosphorus)
- ✓ Provides further treatment of the wastewater before being reached to the groundwater
- ✓ Provide higher crop yields, a yearly production, and increases the range of crops that can be irrigated, particularly in arid and semi-arid areas.
- ✓ Can also minimize the needs for the fertilizers.

- **Disadvantages**

The use of wastewater for irrigation short of a suitable arrangement can create a stern issues especially to public health not only to the workers, but also the neighboring populations that living on or near the areas where wastewater is used, crops collectors and consumers of crops or meat and milk coming from livestock grazing on polluted fields. The main risk to health is a microbial risk which appears due to pathogens, i.e. disease-causing organisms, that are usually present in untreated or partially treated (and to some level also in treated) wastewater (Feachem, et al, 1983). Many related diseases can be spread by wastewater use in agriculture to those working in the wastewater-irrigated fields and those consuming wastewater-irrigated foods, especially when eaten uncooked. However, the consumption of wastewater-irrigated products is only one possible way of transmission, and this route may or may not be of local public health importance.

Some disadvantages are:

- ✓ Wastewater not properly treated can afford a predicted public health problem.
- ✓ Some of the soluble components in the wastewater could be present at concentrations toxic to plants.
- ✓ The treated wastewater may contain suspended solids at levels that may cause clogging in the irrigation networks, especially in the drip irrigation method.
- ✓ Health risk from pathogens. The risk is related to the nature of the pathogen in the compositions of wastewater.
- ✓ Contamination can occur, in the case of metals and some organic chemicals, through absorption from the soil, which strongly depends on the location (possible contamination sources), the environmental conditions (particularly the soil), bio-availability (in the case of some contaminants), type of plant and agricultural practices (quantity of water applied and irrigation method).
- ✓ Expected contamination of groundwater. The quality and depth of groundwater prior to wastewater irrigation determine the detrimental effects of salts, nitrates, metals, and pathogens reaching groundwater. The deeper the groundwater, the longer it will take to have such effects.
- ✓ Excess concentrations of nitrogen can lead to over-fertilization and cause excessive vegetative growth, delayed or uneven crop maturity and reduced quality.

By summarizing the positive and negative aspects it can be stated that wastewater, even when treated, is often associated with health and environmental risks. Also, there is often a time gap between producing wastewater and demand by irrigated agriculture, making sometimes costly storage capacities necessary.

2.5.2 Quality of the Treated Wastewater

The most significant parameters for evaluating the treated wastewater are as follows:

- ❖ Salinity (especially essential in arid zones).

- ❖ Heavy metals and harmful organic substances.
- ❖ Pathogenic germs.

Table 2.2 shows the main criteria for the treated wastewater quality and their importance (TAKASHI, 1998):

Table 2.2: Physio-chemical parameters and their significance for treated wastewater(TAKASHI, 1998)

Parameter	Significance
Total Suspended solids (TSS)	TSS can lead to sludge deposits and anaerobic conditions. Excessive amounts cause clogging of irrigation systems Measures of particles in wastewater can be related to microbial contamination, turbidity. Can interfere with disinfection effectiveness
Organic indicators TOC Degradable Organics (COD, BOD)	Measure of organic carbon Their biological decomposition can lead to depletion of oxygen. For irrigation only excessive amounts cause problems. Low to moderate concentrations are beneficial.
Nutrients N,P,K	When discharged into the aquatic environment they lead to eutrophication. In irrigation they are beneficial, nutrient source. Nitrate in excessive amounts, however, may lead to groundwater contamination.
Stable organics (e.g. phenols, pesticides, chlorinated hydrocarbons)	Some are toxic in the environment, accumulation processes in the soil.
pH	Affects metal solubility and alkalinity and structure of soil, and plant growth.
Heavy metals (Cd, Zn, Ni., etc.)	Accumulation processes in the soil, toxicity for plants
Pathogenic organisms	Measure of microbial health risks due to enteric viruses, pathogenic bacteria and protozoa
Dissolved Inorganics (TDS, EC, SAR)	Excessive salinity may damage crops. Chloride, Sodium, and Boron are toxic to some crops, extensive sodium may cause permeability problems

Water Quality for Irrigation was classified irrigation water into three groups based on salinity, sodicity, toxicity, and miscellaneous hazards, as shown in table 2.3 (Ayers and Westcot, 1985). These general water quality classification guidelines help to identify potential crop production problems associated with the use of conventional water sources. The guidelines are equally applicable to evaluate wastewaters for irrigation purposes in terms of their chemical constituents, such as dissolved salts, relative sodium content and toxic ions.

Table 2.3: Guidelines for interpretation of Water Quality for Irrigation(Ayers & Westcot, 1985)

Potential Irrigation Problem			Units	Degree of Restriction on Use		
				None	Slight to Moderate	Severe
Salinity *(affects crop water availability)*						
	EC_w[1]		dS/m	< 0.7	0.7 – 3.0	> 3.0
	(or)					
	TDS		mg/l	< 450	450 – 2000	> 2000
Infiltration *(affects infiltration rate of water into the soil. Evaluate using EC_w and SAR together)*						
SAR[2]	= 0 – 3	**and EC_w** =		> 0.7	0.7 – 0.2	< 0.2
	= 3 – 6	=		> 1.2	1.2 – 0.3	< 0.3
	= 6 – 12	=		> 1.9	1.9 – 0.5	< 0.5
	= 12 – 20	=		> 2.9	2.9 – 1.3	< 1.3
	= 20 – 40	=		> 5.0	5.0 – 2.9	< 2.9
Specific Ion Toxicity *(affects sensitive crops)*						
	Sodium (Na)					
	surface irrigation		SAR	< 3	3 – 9	> 9
	sprinkler irrigation		me/l	< 3	> 3	
	Chloride (Cl)					
	surface irrigation		me/l	< 4	4 – 10	> 10
	sprinkler irrigation		me/l	< 3	> 3	
	Boron (B)		mg/l	< 0.7	0.7 – 3.0	> 3.0
Miscellaneous Effects *(affects susceptible crops)*						
	Nitrogen (NO_3 – N)[3]		mg/l	< 5	5 – 30	> 30
	Bicarbonate (HCO_3)					
	(overhead sprinkling only)		me/l	< 1.5	1.5 – 8.5	> 8.5
	pH			**Normal Range 6.5 – 8.4**		

[1] EC_w means electrical conductivity in deciSiemens per metre at 25°C

[2] SAR means sodium adsorption ratio

[3] NO_3-N means nitrate nitrogen reported in terms of elemental nitrogen

2.5.3 Social Acceptance

Social impacts for reuse are the doubts expressed by the public about irrigation by treated wastewater. These concerns may include reducing the environmental quality, poor hygiene, food safety, odor, health & welfare, loss of property values and sustainability of land use. Natural resources may be exposed to risks such as pollution of water resources, loss of fish, wildlife, etc. (Christopher, et el, 2001).

This factor is essential for introducing, executing and sustaining a long-term wastewater reuse program. Hence, the development of related plans needs to include an acceptance of the social and cultural aspects of reuse. In the absence of social support, a reuse project may fail. Even for non-potable reuse purposes, the public attitude plays an important role, including the perception of water quality, inclination to pay or to accept any wastewater reuse project (Lazarova, et el, 2000).

In addition to aware the public along with the official acceptance, one has furthermore to recall that using the treated wastewater has various driving forces. It is an extra water resource in water rare areas and it can be a viable alternative for disposing of the treated effluents in rivers and shorelines. In addition, it is a driving force for regions with a humid climate.

2.5.4 Public Health Acceptance

From the main necessary procedures in any reuse program is protecting the public health, particularly of workers and consumers. Consequently, it is necessary to remove any contagious factors or pathogenic microorganisms that may be existed in the effluent. In some reuse execution, as irrigating of non-food crops, secondary treatment may be accepted. While for other applications, further disinfection, by such methods as chlorination or UV or ozonation, may be required.

The essential prerequisite for wastewater reclamation is that implementation will not lead to inadmissible human health hazards. Non-treated effluent constitutes an earnest danger of water-borne illness, such as cholera, typhoid, dysentery, plague, and helminthes. With medicinal progression, and human health relations between non treated effluent and illness have become better comprehend, and measures to reduce exposing to such pathogenic organisms have been presented. Some of the main microorganisms that are existing in untreated effluent with survival times in many media are enumerated in Table (2.4) (EPA, 2004).

While effluent reuse has essential advantages, a health hazards assessment should be done in excess attention. These hazards can be minimized through appropriate treatment, disinfection, and controlled use of treated wastewater. If sufficient measures to reduce risk can't be performed constantly, effluent reuse shouldn't be permitted.

Table 2.4: Microorganisms in untreated effluent (EPA, 2004)

Pathogen	Types	Survival Times at 20 – 30°C (in days)		
		Freshwater and sewage	Crops	Soil
Water-borne bacteria	Salmonella, Legionellaceae, Vibrio cholerae	< 60 but usually < 30	< 30 but usually < 15	< 70 but usually <20
Protozoa	Giardia lamblia, Cryptosporidium	< 30 but usually < 15	< 10 but usually < 2	< 70 but usually <20
Helminths	Ancylostoma (hookworm), Ascaris, Toxocara, Taenia (tapeworm)	Many Month	< 60 but usually < 30	Many Month
Viruses	Enteroviruses , Hepatitis A virus, Rotaviruses	< 120 but usually < 50	< 60 but usually < 15	< 100 but usually <20

Effluent reclaim has been experienced for different purposes in several zones of the globe. In most situation, disinfection is a fundamental stage before the effluent reuse to reduce ecological and health hazards. The goal of disinfection is to eliminate or deactivate pathogenic organisms from effluent. Usually, disinfection is performed by powerful oxidizers such as chlorine, ozone, and bromine, however, they don't deactivate helminthes eggs.

Also, health risks from chemicals are caused by heavy metals (e.g., cadmium, lead, and mercury) and many organic compounds (e.g., pesticides). These mostly derive from industrial wastewaters and, if these are discharged to public sewers, they are present in municipal wastewaters. The health effects of prolonged exposure to many of these chemicals are well known (e.g., cancers). There is an emerging class of chemical contaminants, the so-called "anthropogenic‟ compounds, which include pharmaceuticals, hormones, and endocrine disruptors, antimicrobials and antibiotics, and personal care products, the long-term health effects of which are less clearly understood (Bhandari et al., 2009).

2.5.5 Reuse Options in View of the High TDS Concentration

Effective agricultural effluent reuse strongly depends on the given quality characteristics. One important parameter that has a direct influence on the crop production potential is the TDS concentrations in the effluent.

Salt concentration and composition of irrigation treated water are the main factors determining the suitability of crops, together with other factors such as the presence of pathogens, soil, and climate. The different types of plants can only tolerate a certain salt content of irrigation water.

This does not mean a salt sensitive crop cannot tolerate being irrigated with water of higher salt concentration, but it does mean that the specific productivity of that specific crop will decline by a certain percentage if irrigated with the effluent of higher salt concentration. It also means that the effluent is unsuitable for existing salt sensitive crops.

Table 2.5 gives an overview of the sensitivity of selected crops towards increasing TDS concentrations. The table indicates that especially many vegetables and fruits are salt sensitive (FAO,1985)

In view to the future agricultural effluent reuse, responding adequately to the high TDS concentrations in the influent might result in the following actions:

- ✓ reduction of TDS concentration in the influent,
- ✓ adaptation of the current crop composition towards more salt tolerant crops, and/or
- ✓ blending (mixing) of effluent with other freshwater sources before irrigation (if any).

Table 2.5: Sensitivity of crops towards increasing TDS concentrations

Crop sensitivity	Electrical conductivity mS/cm	TDS mg/l	Crop example
sensitive	0 – 1.5	0 – 960	bean, pea, onion, carrot, orange, peach, clover, berseem
moderately sensitive	1.5 – 3.0	960 – 1920	maize, broad bean, alfalfa, tomato, grape
moderately tolerant	3.0 – 6.0	1920 – 3840	sorghum, soybean, wheat, red beet
tolerant	6.0 – 10	3840 – 6400	barley, cotton, sugar beet, date palm
very tolerant	> 10	> 6400	species of Atriplex (orache), Agropyron (couch gras)
no plant growth	> 30-40		

Chapter 3
Study Area

Chapter 3
Study Area

3.1 Location, Population, and Geography

The Gaza Strip is located on the south-western part of Palestine. The total area of the Gaza Strip is 365 km² with approximately 45 km long and 6-12 km wide (El Baba et. al., 2015). Gaza Strip is divided into five governorates, the North, Gaza, Middle, Khan Younis and Rafah as shown in Fig(3.1).

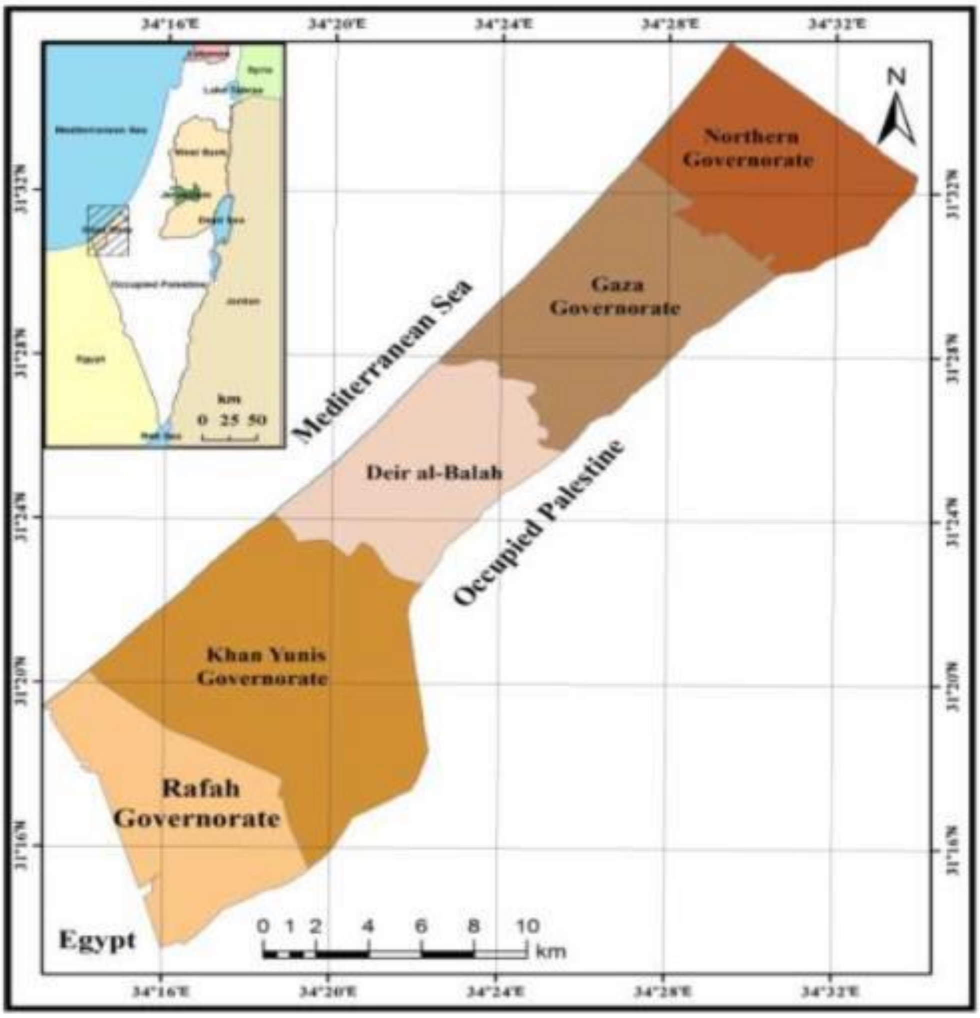


Figure 3.1: Gaza Strip Governorates

The latest census results executed in 2017 recorded more than 1.899 million inhabitants distributed across the five Governorates as shown in table (3.1) (PCBS, 2017). Thus, Gaza holds the highest population density in the world with over than 5000 persons per square kilometer.

Table 3.1: Gaza Strip Population (2017)

Governorate	Area (km^2)	Population (Person)
North Gaza	61	368,978
Gaza	74	652,597
Middle	58	273,200
Khan Younis	108	370,638
Rafah	64	233,878
Total Area	**365**	**1,899,291**

Gaza Strip is one of the semi-arid areas, with average temperature values varying from 12-14^{0}C in January, to 26-28 ^{0}C in August. The rainfall is falling in the winter season from September to April, the rate of rainfall is varying in the Gaza Strip and ranges between 200mm/year in the south to about 400mm/year in the north, while the long term average rainfall rate in all over the Gaza Strip is about 317mm/year (PWA, 2011a)

Figure (3.2) shows the top soil types of the Gaza Strip. It consists mainly of three types of soil; sand, clay, and loam. Along the shoreline, there is a zone of sand dunes and most of it was found to be medium to rough sand, which expands in the south and north, and narrower in the middle and in Gaza City.

A parallel area to the previous one is the loess soil (sandy clay loam) which is distinguished by having two types of soil forming, a combination of sand and silt. This area becomes narrower in the north and wider in the south. A third area can be observed on the east north and middle Gaza Strip. It is a clay soil that has kirkaria composition which appeared in the shape of chains extending from the north to south, and the low area which is mostly clay are found between these chains (Abu Samra, 2014).

Gaza Strip has alluvial, sandy and loess soils as shown in figure (3.2). Major crops include vegetables, strawberry, citrus, guava, dates, field crops, and almonds. Groundwater salinity and pollution are serious problems affecting crop production (CIRD, 2011).

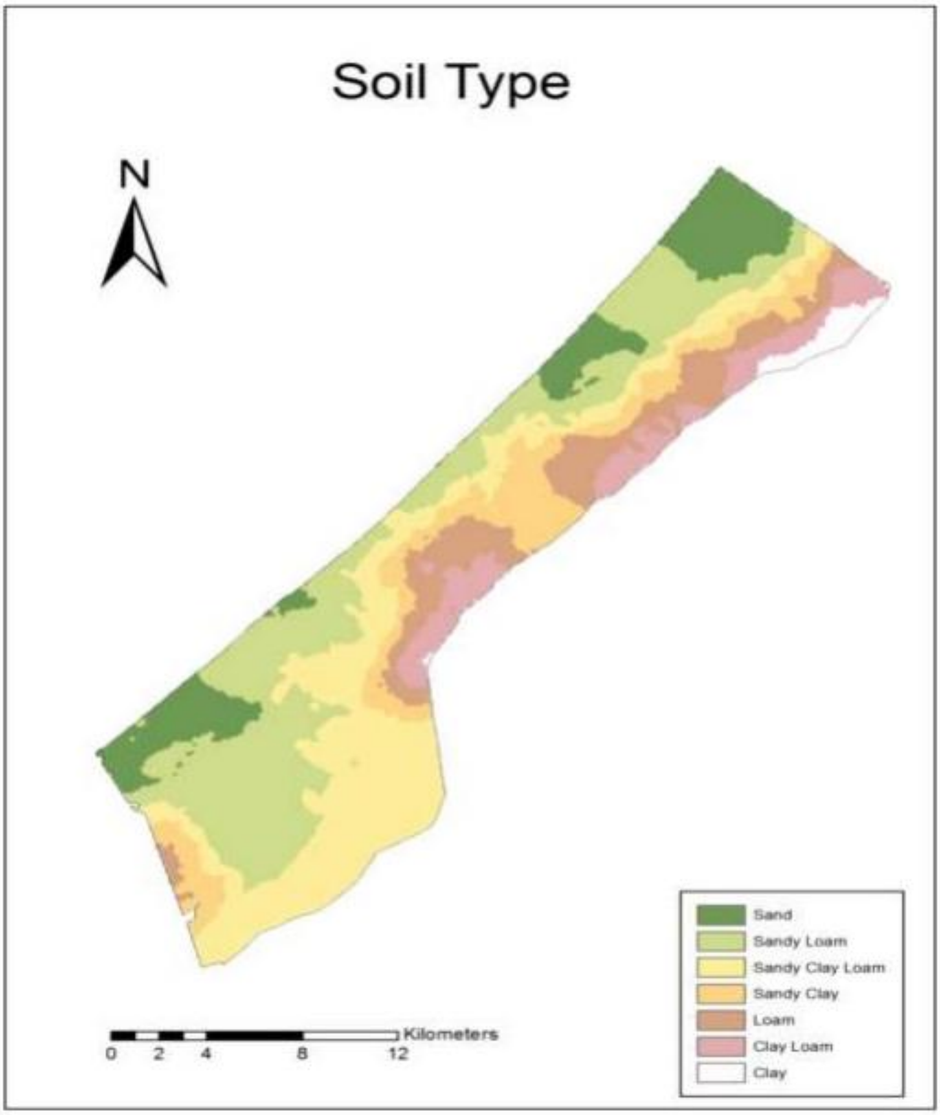


Figure 3.2: Top soil types in the Gaza Strip (Abu Samra, 2014)

3.2 Water Situation in Gaza Strip:

3.2.1 Water Demand in Gaza Strip

Groundwater from the coastal aquifer is the main source of water supply in the Gaza Strip and provides about 95% of all water supplies, while the remaining 5% is provided through purchasing from the Israeli water company (MEKOROT).

As recorded by PWA in 2017, the total water supply quantities for domestic use in the Gaza Strip is about 96,308 MCM gathered from 3 sources which were 81.702 MCM from municipal and UNRWA wells, 10.566 MCM from Mekorot (Israel national water company) and 4.039 MCM from desalination plants (Brackish and Seawater). The mean value of network distribution system efficiency is 62.3% as mean value (PWA, 2017).

Based on that, the average water consumption was 88.7 l/c/d, which is less than the minimum limit for WHO (100 l/c/d) to achieve full health and hygiene benefits.

The water quantities for agriculture purposes including the livestock are estimated as 95.3 MCM/Yr in the Gaza Strip (92.7 MCM for agriculture and 2.64 MCM for livestock according to MoA in 2014). (PWA, 2014a).

There are no large industrial facilities (chemical plants, cement factories, etc.) consuming high volumes of water in Gaza, and most industries are small factories that use the urban water supply network as their sole source of water. Some industrial facilities also use private wells, which are mainly registered as irrigation wells. According to PWA estimations, industrial consumption is very low and respected by 3% of domestic demand, (PWA, 2014b). So it equates approximately to 3 MCM/ year.

Therefore, the total water needs in the Gaza Strip including domestic, agriculture and industrial sectors are counted to 194.5 MCM/year distributed as shown in fig. (3.3).

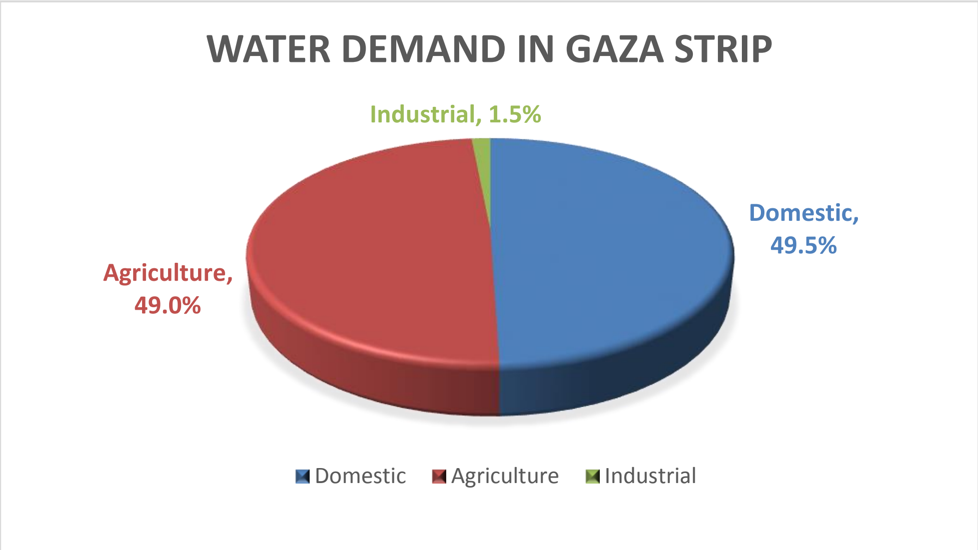


Figure 3.3: Water demand in Gaza Strip

3.2.2 Water Resources in Gaza Strip

3.2.2.1 Groundwater Resource

For a long time, the Coastal Aquifer is the only source of water in the Gaza Strip, with the thickness of the water bearing strata ranging from several meters in the east and south-east to about 120-150 m in the western regions and along the coast. The aquifer consists mainly of sand and gravel sand and sandstone (Kurkar) intercalated with clay and silt. Hard and non-productive layers of clay and marl with low permeability (Sakia Formation) with a thickness of about 800-1000 m are situated below the coastal aquifer. The yearly recharge volume, equaled to the sustainable yield for this limited volume aquifer, is in the range of 55-60 MCM/yr. While the Palestinian utilization from this aquifer in Gaza Strip is about 185 MCM in 2012 (PWA 2013b).

According to the assessment of the groundwater quality based on chemical analysis for 282 domestic wells which was conducted by PWA in 2017 shows continues salinity increasing. Chloride (Cl) content ranges between 150 mg/l to more than 2500 mg/l in general. Moreover, it is worth mentioned that Chloride (Cl) content for some wells located in the west part of Gaza Strip along shoreline reached to more than 12,000 mg/l as an outcome for seawater intrusion which was in north-west, south-west and towards from west to east of Gaza City, south-west of Rafah and west Deir El-Balah. Regarding Nitrate (NO_3) concentration, the result shows that most of the Gaza Strip have NO_3 of more than the WHO limits for drinking water (50 mg/l). Where it is in the range of 100-200 mg/l and is mainly located beneath the residential areas reflecting the percolation of the wastewater from the sewerage system.

Taking into consideration both the Cl and NO_3 concentration it is clear that 96.1 % of the groundwater pumped exceeding the WHO acceptable limit and only 3.9 % is matching with the WHO limit. Figure(3.4) shows the chloride and the nitrate concentration in the Gaza Strip,2017 (PWA, 2017).

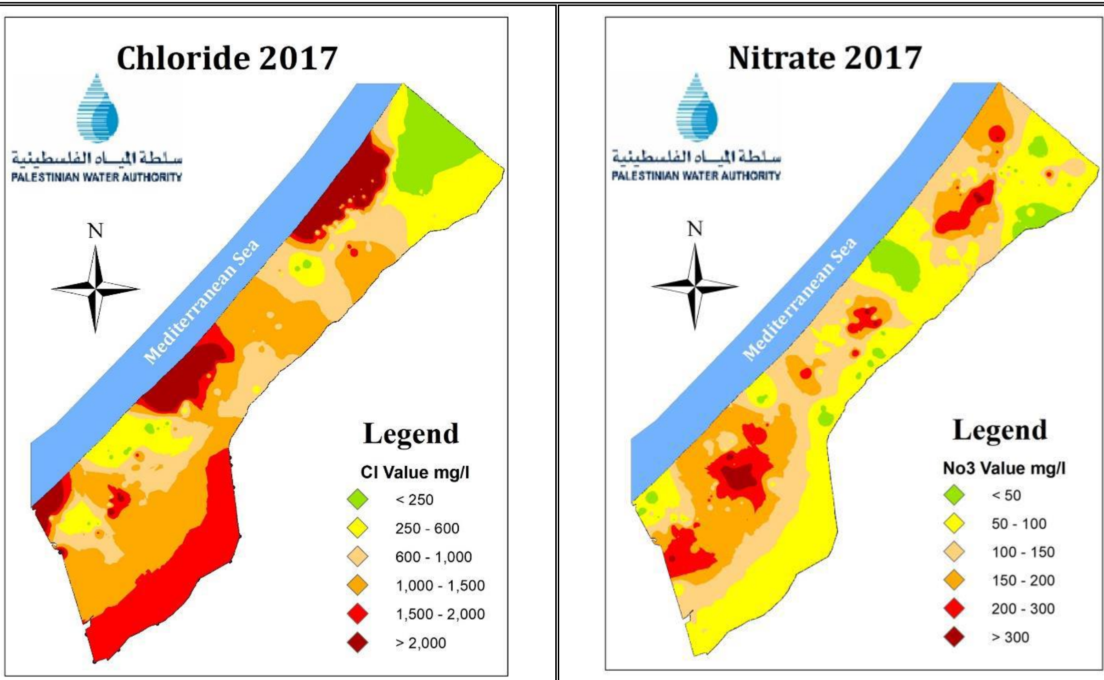


Figure 3.4: Chloride & Nitrate concentrations in the Gaza Strip, 2017

As a result, 97 percent of the population rely on informal and unregulated private water tankers and small-scale informal desalination plants for drinking water. Water provided through networked systems by formal providers is used for other domestic purposes. (World group bank, 2018)

3.2.2.2 Non –Conventional Water Resources

3.2.2.2.1 Treated Wastewater

Future of wastewater reuse seems to be promising in the Gaza Strip. The expected amount of wastewater to be used for irrigation will progressively increase in the coming twenty years saving more than half of groundwater needed for irrigation (Tubail et el, 2003).

In the Gaza context, pilot wastewater reuse schemes have existed for some years, and there are plans for these to be augmented shortly. The key requirement, however, is for the completion of the four major wastewater treatment plants scattered throughout Gaza, as reuse cannot be introduced at any significant scale in the absence of high-quality wastewater treatment.

It is estimated that the total water reuse quantities for these reuse activities are around one MCM/year (Aquapedia, 2014).

Wastewater reuse is difficult due to the absence of reconnaissance of such water by the Palestinian public as a non-conventional resource. In addition, all reuse pilot-scale projects were a failure as no rational use of this water is organized in most cases. Also, the lack of large-scale water reuse projects is due to the lack of funds and due to bad effluent quality from the existing sewage plants (Al-Sa`ed, 2007).

The reuse of treated effluent may become realistic only if effective treatment systems are installed. These systems provide effluents that comply with irrigation standards.

3.2.2.2.2 Desalinated Water

Desalination became a strategic option in the scarce-water countries, in general, and in Palestine in particular. Its cost competes with the costs of other non-conventional water resources such as wastewater reuse. Desalination of brackish and seawater have been used by the Palestinian Water Authority (PWA) to face water deficit and scarcity in reasonable technology and thus, providing sustainable and safe water to people in Gaza (El Sheikh, et al, 2003).

Over 150 small capacity brackish water desalination plants operate within the Gaza strip with just around 25 operated by the public utility authorities and the remainder by commercial operators which are largely unregulated. The brackish water desalination plants continue to exacerbate the deterioration of the Coastal Aquifer, the only naturally available source of fresh water for Gazans. As an urgent interim measure, CMWU installed over a dozen small capacity (50m3/h to 50 m^3/d) brackish water desalination plants to overcome the deficit in the potable water.

To reduce the abstraction from the aquifer, seawater desalination was adopted by PWA through two interventions on the short and long term.

As short term measures, construction of three Seawater Desalination Plants (SDP), also referred to as Short Term Low Volume (STLV) have been identified as the key interim intervention to provide urgent relief and implemented within a short term with a relatively low volume. The three SDPs consist of the 20,000m3/d Southern Gaza SDP, North Gaza SDP to produce 10,000m3/d and the Middle Gaza SDP with a 5,000m3/d capacity.

The longer term Gaza Central Desalination Plant (GCDP) is planned for implementation in two phases to produce a total of 110 MCM of desalinated water annually, with 55MCM/year (150,000 m3/d) during each phase (Peiris, M. et al., 2017). The design of water quality parameters are (PWA, 2016):

- ✓ PH: 6.5 - 8.5,
- ✓ Total Dissolved Solids (mg/l): <300,
- ✓ Chloride (mg/l): <50,
- ✓ Total Alkalinity (as mg CaCO3/l): 65-100,
- ✓ Boron (mg/l): <0.4,
- ✓ Fluoride (as mg F/l): <1.5,
- ✓ Turbidity NTU/JTU: <1.0

3.2.2.2.3 Purchased Water

As pointed in annual reports for domestic water supply in the Gaza Strip, showing an annual increase in the purchased quantities of fresh water from the Israeli water utility (Mekorot). In 2017, Gaza imports around 10.566 MCM which denote 5 % of the water needs in that year, whereas the quantity was 3.54 MCM in 2014.

On the long-term, any significant increase in water imports are not anticipated as Mekorot itself is becoming increasingly reliant on expensive desalination water and Israel has expressed willingness to increase water sales, but the price could be rather high. Moreover, negotiations with Mekorot are tainted by the complex political relationship between the two countries. Although the constant political issues with Israel discourage PWA from relying on water supply imports, however, and considering the operational cost for desalination, the strategy of PWA has been developed on the hypothesis that imports from Israel (or any other country) to Gaza will increase. PWA estimated that the imported water may reach 21 MCM (PWA, 2013a).

3.2.3 Plans for Domestic Water Supply in Gaza Strip

With these problems and challenges facing the water sector mentioned previously, PWA made deep attentions on domestic water supply field and set up the plans to overcome these issues which appear clearly in the quantity and the salinity of domestic water supply. The domestic water will depend on three water resources, seawater desalination, and groundwater and Mekorate water supply. The produced water will be blended in scattered reservoirs that will be connected through north- south carrier line with total length consists of 42,530 meters.

In particular, for each reservoir was evaluated the final concentration of chloride in output to comply with the standard limits of chloride concentration to 400 mg/I in years 2020-2025 and 250 mg/l for 2030-2035. The planned figure for domestic demand will be 110 l/c/d in 2025. And will be 120 l/c/d for years 2030-2035 (PWA, 2016).

3.3 Wastewater Situation in Gaza Strip

3.3.1 Present Situation of Wastewater in Gaza Strip

In the Gaza Strip, some areas linked to sewage facilities and served by the well-functioning system while some areas not linked at all to the sewage system and depend on cesspits as a wastewater disposal method. On average, it is estimated that about 74 % from the residential areas in Gaza Strip are linked with sewerage networks. (World Bank 2018).

Approximately, 70-80 % of the domestic wastewater produced in Gaza is discharged into the environment without enough treatment, either directly, after collection in cesspits, or through leakages and overloaded treatment plants.

Eight centralized wastewater treatment plants in the Gaza strip was set up or planned, three of them considered intermediate plants located in Beit Lahia, Gaza and Rafah areas as well as two temporary treatment plants in Khan Younis (Mawasi area) and Wadi Gaza WWTP. While there are three eastern regional plants will be in service soon. North Gaza WWTP, Buriej WWTP, and Khan Younis WWTP. CMWU in 2016, recorded 47.6 MCM reached the operating plants as shown in the table (3.2). All WWTPs have discharge pipe to the Mediterranean sea except BLWWTP. These plants suffer from many problems concerning the operation and maintenance for them such as the received quantities are more than the design capacities, lack of power, lack of spare parts, etc.. This lead to poor quality of the produced effluents, which is away below WHO guidelines and Palestinian standards for use in irrigation or discharging.

Table 3.2: WWTP in Gaza Strip (CMWU 2016)

Plant	Average Daily Flow m3/day	Total Annual Flow m3/Year
Bait Lahia WWTP (BLWWTP)	33,132	12,093,120
Gaza WWTP (GWWTP)	58,395	21,313,860
Wadi Gaza WWTP (WGWWTP)	12,035	4,392,720
Khan Younis Temporary WWTP (KhWWTP - Temporary)	13,516	4,933,020
Rafah WWTP (RWWTP)	13,358	4,875,468
Total	130,434	47,608,188

3.3.2 Wastewater Treatment Plants in Gaza Strip

3.3.2.1 Traditional WWTPs

1. **Beit Lahia Wastewater Treatment Plant**

Bait Lahia Wastewater treatment plant (BLWWTP) was established in the 1970s in northern of Gaza Strip to handle 5,000 m3/day. Through years, the population increased resulted in the deterioration of BLWWTP performance and it was unable to handle the wastewater quantities. The excess quantities were pumped into the surrounding sand dunes resulting in a formation of random lake. In 2004, the lake volume reached 3 MCM of sewage and occupied around 30 hectares of land. It was a serious threatening to the neighboring communities in terms of inevitable flooding risk, health disaster and aquifer pollution. The maximum capacity equaled to 23,000m3/d. And it was operated using 2 anaerobic ponds, 2 aerated ponds, 2 facultative ponds, 1 polishing pond, and two stormwater infiltration basins. It receives around 35,000 m^3/day and the effluent is pumped up to North Gaza WWTP. This plant has been suffering overloaded inflow volume, poor effluent quality and low infiltration capacity of the basin, moreover the health and environmental situation threats to the communities surrounding it. Therefore, the plant can be considered out of service and will be closed soon.

2. Gaza Wastewater Treatment Plant

The GWWTP plant is located on an elevated location to the south of the city (the area of Sheikh Ejleen). It has an area of 130,000 m2. Originally the plant was constructed in 1977 as a two-pond treatment system. It has been enlarged and developed through years until 2013 to a capacity reached 65,000 m3/day.

The sewage is collected at a series of pump stations and conveyed to the Sheikh Ajleen WWTP. It comprises of (Inlet structure, bar screens, and grit removal, 4 Anaerobic ponds, 6 Bio towers; 2 old and 4 new, 2 bio towers pump stations, Aerated pond, Settling channel, Facultative pond, Effluent pump station, Two sludge holding ponds, sludge drying beds and other facilities)

There are three effluent pipelines from the plant. Two discharges directly to the sea. The other discharge either by gravity to the infiltration lagoons or, by pumping to Wadi Gaza. This pipeline was originally installed for effluent reuse, with irrigation connections along its length, but it is understood that it was never used for this purpose. Nowadays, most of the effluent is discharged directly to the sea with some used for a pilot infiltration/recovery project.

3. Rafah Wastewater Treatment Plant (RWWTP)

RWWTP located in southern of Gaza Strip to serve the population in Rafah City. As the other treatment plant in Gaza strip, many expansion and development are conducted to serve the increased growth of population, the last development of the plant was held between 2008 and 2011, several extension works were conducted, to increase the treatment capacity to 20,000 m3/day.

RWWTP consists of:

- An inlet structure containing a grit removal channel.
- 2 anaerobic ponds.
- 2 bio-towers, supplied by a pumping station.
- Settling pond.
- Pumping station for the discharge of the treated wastewater to the sea.

As an alternative, a pilot project collects ~5% of the treated waters for their disposal via reed beds and an infiltration pond (not functioning). The total flow in 2008 was measured to be over 7,800 m3/d and in 2016 increased to 13,300 m3/d .

4. **Khan Younis Temporary Treatment Plant**

Khan Younis Temporary Treatment Plant (KhWWTP - Temporary) was established in Al Mawassi area by 2009 as lagoons. Those lagoons were constructed to pump the water from Hai El-Amal lagoons to mitigate and reduce the risk of the rising water level in lagoons as a step to save the neighborhood from humanitarians and environmental crisis which was expected to occur in winter of 2007. Hai El-Amal lagoons were established in 2003 to collect and infiltrate storm water of Khan Younis, but due to the frequent closure and the Israeli harassments during the establishment of the project, the project was suspended and the logon was changed to wastewater. Therefore, and as an urgent response, local authorities with CMWU established alternative lagoons to collect and treat wastewater before pumping it to the sea. This solution will be valid until the construction of Khan Younis WWTP. The total flow as recorded by CMWU reached to be over 13,500 m3/d.

5. **Wadi Gaza Interim Wastewater Treatment Plant**

Wadi Gaza Interim Wastewater Treatment Plant (Wadi Gaza WWTP) is located at the end of Wadi Gaza and west of Al Rasheed Street. It was established to provide an environmentally sound solution to solve the wastewater accumulated in Wadi Gaza and treating the collected wastewater to a quality suitable for safe disposal to the sea. The design life of the Interim WWTP was 5 years with a capacity of 12,000m3/d until the permanent WWTP east of Al Bureij camp will be constructed.

Currently, a huge quantity of wastewater reached the Wadi Gaza area estimated by 20,000 m3/d which lead the plant to be overloaded inflow volume, poor effluent quality, which made it out of service and working as a bypass of wastewater to the sea.

3.3.2.2 Regional WWTPs

1. **North Gaza Wastewater Treatment Plant**

The new Northern Gaza Wastewater Treatment Plant (NGWWTP) aiming to provide a satisfactory long-term solution to the treatment of wastewater for the northern governorate in Gaza. The first phase of the NGWWTP is almost completed and started the operation at the beginning of 2018, to treat up to 35,600 m3 of sewage daily and infiltrate them through nine infiltration basins. Future expansion of the plant would bring the total treatment capacity to 69,000 m3/day and will require the construction of an additional infiltration basin.

It comprising three treatment modules for secondary biological treatment through activated sludge basins and clarifiers, as well as sludge treatment, digestion, dewatering, drying, and storage. In addition, energy recovery of the biogas produced by the anaerobic digestion to cover 60% of plant, power demand. The treated effluent quality as designed are (BOD5 mg/l 10-20, SS mg/l 15-20, Total Nitrogen mg/l 10-15, Helminthes No/l <1, Fecal Coliform MPN/100 ml <200).

2. Buriej Wastewater Treatment Plant

The Buriej WWTP (BWWTP) is located south of the Wadi Gaza, next to the Israeli border at 17–28 MSL. The site of the WWTP has a size of about 26 ha. The plant is designed to serve the central area of Gaza Strip, covering the Gaza and the Middle Governorates.

The main treatment steps are primary clarifier, activated sludge and final clarifier. No disinfection of the effluent is provided but constructed wetlands in the wadi would provide additional polishing.

The WWTP is designed for the flow quantities for the target year 2025 (Stage 1 will have a start capacity of 60,000m^3/d, to be increased in stages of 30,000m3/d up to the Phase 1 capacity of 120,000°m3/d). The full capacity of the plant will be increased to 180MCM (Final phase).

Under the initial implementation Stage 1, an overall treatment efficiency for BOD, COD, and TSS of more than 90°% will be achieved by mechanical and biological wastewater treatment, at relatively low efficiency for N removal. After upgrade of the process for intermittent denitrification, and source control regarding high salinity and very high Nitrogen influent concentrations the treatment efficiency for N removal will exceed 75°%. In stage 1, the WWTP will meet an effluent standard of 40 mg BOD5/l, 60 mg TSS/l and 25 mg TN/l, suitable for intended discharge to Wadi Gaza.

The treated effluent is discharged to Wadi Gaza at an elevation of about 11 MSL and flows through newly constructed polishing ponds. The effluent from these ponds partly infiltrates the bottom of the wadi and the surplus water will finally reach the sea.

3. Khan Younis wastewater treatment plant (Kh WWTP)

Khan Younis wastewater treatment plant is situated on a long strip of land (171 m x 680 m) in Al Foukhary area. At present, only Khan Younis city is served by a temporary wastewater treatment plant that located in Al Mawasi area and considered as a temporary emergency system, while the other areas are not served and depends on cesspits as wastewater disposal.

Kh WWTP is planned to serve KY Governorate, thus effluents to be treated at KY WWTP include effluents from Khan Younis City and effluents from Eastern villages.

The plant is designed for incoming flows quantities as 26,000 m^3/d in the first stage and will be increased to 44,000 m^3/d. According to the design, the secondary treatment by activated sludge process technology is chosen. Sand filtration followed by UV disinfection is proposed for tertiary treatment. The treated effluent is based on required effluent quality for infiltration and irrigation (<20 mg BOD5/l, <15mg TSS/l and <25 mg TN/l). Treated effluent disposal to the sea is limited to emergency situations only.

The figure (3.5) below shows the current and future WWTP.

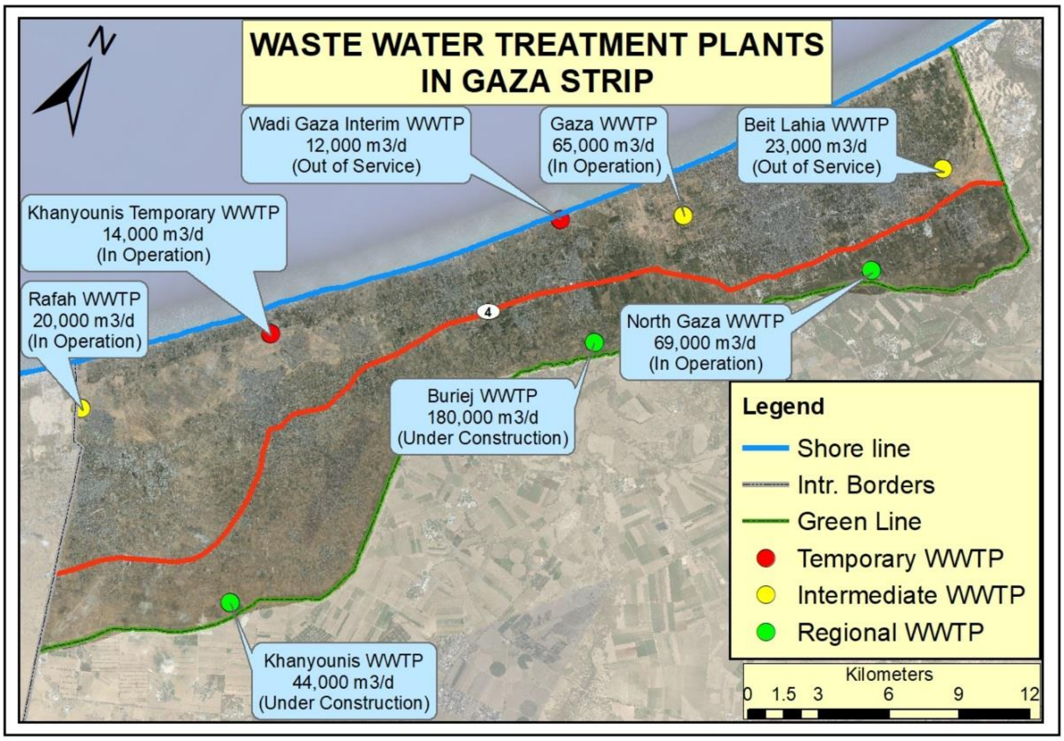


Figure 3.5: Current and future WWTP

3.3.2.3 Treated Wastewater Quality

Based on the environmental record, the quality of the treatment plants was measured by the operator CMWU based on composed samples collected from influent and effluents of the WWTPs. BOD, COD, and TSS were monitored on a monthly basis for the year 2016. The Average BOD &TSS Removal efficiency achieved 78.23% in all plants (CMWU, 2016). The results tabulated in Table (3.3).

Table 3.3: Test results for parameters of treatment plants, (CMWU, 2016)

Plant	Treatment Process Type	Influent			Effluent			Average BOD &TSS Removal efficiency %
		BOD (mg/l)	COD (mg/l)	TSS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	
BLWWTP	Aerated Lagoons	422	942	455	86	206	87	80.28%
GWWTP	Bio Towers /Lagoons	436	910	447	96	299	94	78.54%
GWWTP	Aerated Lagoons	480	1,062	512	133	312	130	73.45%
KhWWTP - Temporary	Aerated Lagoons	499	1,117	532	131	291	118	75.78%
RWWTP	Bio Towers	578	1,298	616	129	306	119	79.18%

3.3.3 Wastewater Reuse in Gaza Strip

One of the first start practices in the Gaza Strip for using treated wastewater in agriculture was in 2003 under the Ministry of Agriculture and the PWA supervision. Two areas in Gaza Strip were selected for this pilot project. The first area was Beit Lahia in the northern area of Om Al Naser village where TWW from Beit Lahia WWTP was used. The second area was in the Sheikh Ejleen area southwest of Gaza city, TWW from Gaza WWTP. After that, another pilot project was established in Al Mawasi area in Khan Younis near the treatment plant. Brief for these projects as following:

1. Beit Lahia Pilot Project

The first pilot located in Beit Lahia aims to demonstrate in the Bedouin village that uses water from the artificial lake (constituted by the effluent of treated wastewater of the Beit Lahia).

- ✓ Fodder crops (alfalfa, Sudan grass, and ray grass) irrigated and used for feeding the small animals. The total area cultivated by alfalfa is extended to 45 dunums and enlarged to 140 dunums in 2010.
- ✓ A comprehensive monitoring system is also carried out to examine and detect the hygienic and environmental problem and it is extended to cover crop, soil, groundwater, and the effluent.

- ✓ Short training course for the farmers as well the agricultural engineers to qualify the target groups and strengthen the capacity building in PWA, MoA and NGO's besides launching public awareness for the interested farmers and agricultural associations.

- ✓ A field visit for 4 farmers to Jordan has been organized to introduce the Jordanian expertise and pilot projects in Jordan.

2. Sheikh Ejleen Pilot Project

It aimed to demonstrate the interest of using treated wastewater for the irrigation of citrus & olive orchards. Farmers interested in experiencing this new source of water have been contacted in the area around the Sheikh Ejleen wastewater treatment plant.

- ✓ This area is located around the Salah Eldeen road, close to the network conveying the TWW from Gaza WWTP to the infiltration basins and wadi Gaza.

- ✓ The project was established to use TWW from GWWTP to irrigate around 100 dunums of citrus and olive trees under supervision from PWA and Municipality of Gaza with coordination with the MoH and MoA.

This project was comparatively success, but due to Israeli invasion in 2008, which led to the destruction of some of the infrastructure of the project. However, rehabilitation is done and the project was operated again on November 2010 covering 186 dunums.

3. Al Mawasi Pilot Project (Khan Younis pilot project)

A small pilot project for reuse of treated effluent in Al Mawasi area close to Khan Younis temporary WWTP was lunched with soil aquifer treatment system. The project started with 60 dunums in 2008 and expanded to 90 dunums in 2010 cultivated with Guava and Palm trees. The BOD resulted from the recovery wells reaches 20-25 mg/l.

3.4 Agriculture Situation in Gaza Strip

Agriculture is the dominant sector for Gaza economy and contributes to 32% of its economic production. Moreover, it is a politically sensitive sector as all of its inputs such as seeds, fertilizers and pesticides are imported from Israel. Therefore, any political crisis influences it directly while the agricultural sector is considered to be the main part of Palestinian life. The contribution to the national Gross Domestic Production (GDP) has reduced from 9.1% in 2000 to about 7.0% in 2005.

Most of the agricultural areas are located within and surrounding the denser residential areas. Therefore, this type of agriculture could be classified as urban agriculture due to its location. Furthermore, some of the green houses are irrigated from the municipal water network within the residential areas. Fruit trees are cultivated within and close to the built-up areas. While rain fed crops occupying the eastern area of the Gaza Strip. Farmers used to cultivate this land to feed their animals without having a real agricultural infrastructure or water for irrigation (Al Najar, 2007).

The agricultural sector in Gaza Strip on average consumes around 90 MCM annually from the groundwater. There is an absence of direct measurement of water withdrawal for agriculture as most of the agricultural wells distributed all over Gaza Strip are unmetered, not functioning well or not installed absolutely. Most of the irrigated areas depend on the agricultural groundwater wells. Table 3.4 shows the seasonal crop (MOA, 2017).

Table 3.4: Seasonal crops in Gaza Strip (MOA, 2017)

Crop	Cultivated Area (Dunam)	% of total area
Horticulture trees	81,959	49.3
Vegetables	58,503	35.2
Field crops	25,730	15.5
Herbs	51	0.03
Total	166,243	100

According to the master plan held by the Ministry of Planning (MOP) in 2005, the land uses were classified and identified as shown in figure (3.6). The agricultural areas were classified into agricultural lands A&B with total area was 173,682.678 Dunum. But with the rapid increase in the population, an expansion for residential lands occurred at the expense of the agricultural areas and especially in the west part of Gaza Strip.

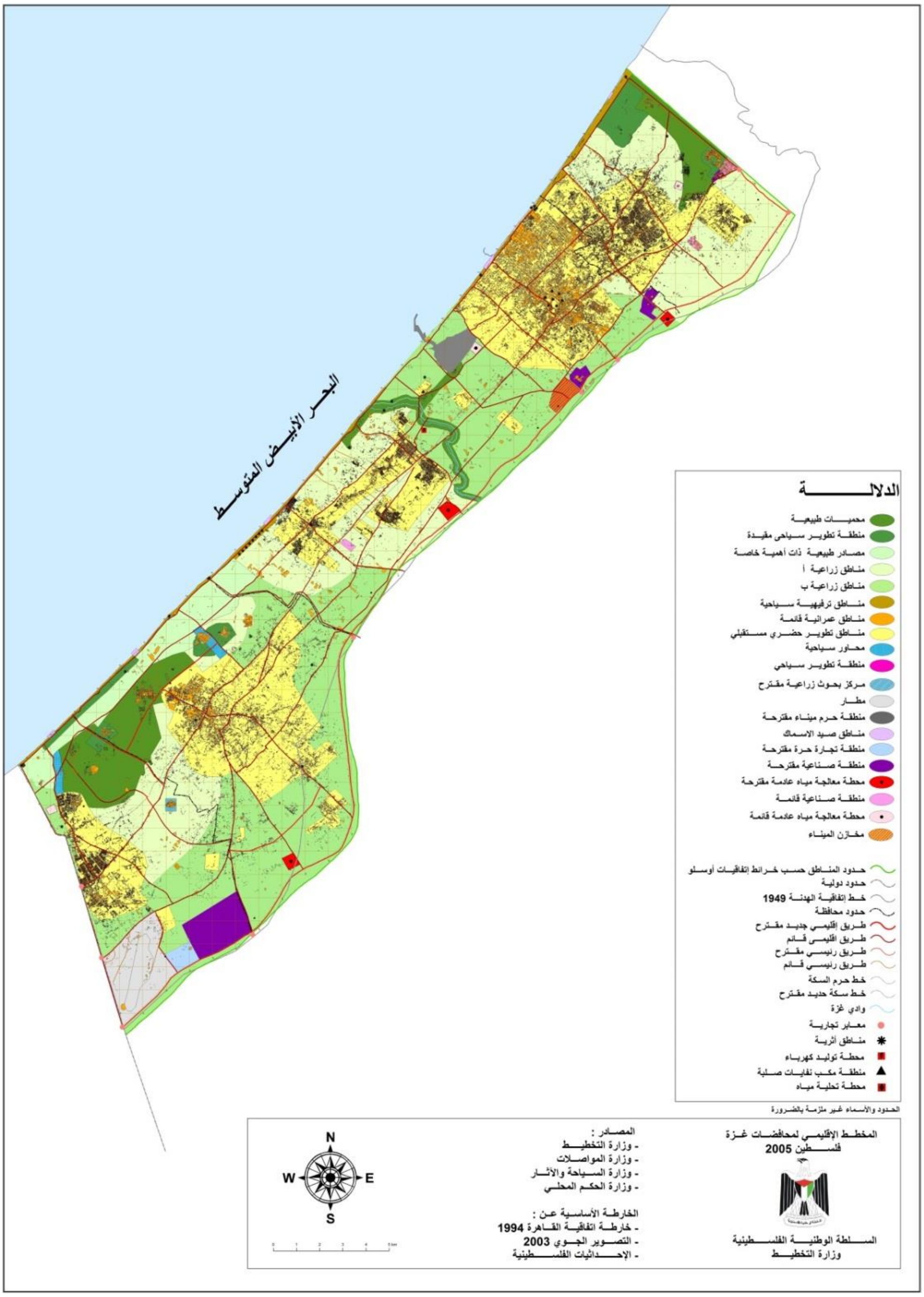


Figure 3.6: Land Uses in the Gaza Strip (MOP, 2005)

Chapter 4

Methodology

Chapter 4
Methodology

This chapter will highlight an outline of procedures and research methods that were followed in the study, therefore the methodology of the study divided into four parts, first part define the stages of water and wastewater sectors situations in Gaza Strip, the second part estimate the wastewater quantities through stages, the third part evaluate the produced treated wastewater and the final part search the potential horticulture trees to be irrigated by treated wastewater.

4.1 Define the Situations of Water and Wastewater Sectors in Gaza Strip

A desk review for previous data, reports, and studies that conducted by PWA, CMWU, and the related authorities were made by the researcher to standing over the current and future situations for water and wastewater sectors in Gaza Strip. The reviews include the strategic plans, interventions and action plans that prepared to face the challenges of water and wastewater sectors and to provide a safe environment for Gazan citizens. Also, a review was made for the current situation and the gathering the required data. Moreover, the researcher held a lot of meetings with the mangers of the related authorities to identify the progress of the implementations of the planned projects.

The strategic objectives that setup in the "National Water and Wastewater Policy and Strategy for Palestine" was considered in the research. The situation will be developed to provide water and wastewater services matching the standards in the Palestinian territories.

4.2 Estimate the Wastewater Quantities

4.2.1 Population Estimation

The Palestinian central bureau of statistics (PCBS) conducted the last field survey in 2017and the total population reached 1,899,291 inhabitants. PCBS indicated that the annual growth rate was 2.8% in Gaza Strip. The population projection for the years 2020, 2025, 2030& 2035 was calculated by using the following formula:

$$P_t = P_o(1 + r)^n$$

Where,

P_t= population after time (t).

P_o= present or initial population.

n = number of years, and

r = population growth rate.

4.2.2 Wastewater Quantities Estimation

To identify the whole quantities of the available reclaimed water that can be used in the irrigation, an estimation for the wastewater quantities that will be produced through stages and for each governorate in Gaza Strip were calculated by using the following formula:

$$Quantity = average\ number\ of\ population \times average\ water\ consumption\ rate \times \%\ of\ wastewater\ generated\ as\ a\ portion\ of\ the\ consumed\ water \times coverage\ by\ wastewater\ networks\ factor$$

The main assumptions and considerations used for the wastewater quantities projections are:

- ✓ Population in 2017 with a growth rate of 2.8%.
- ✓ The current wastewater connection coverage as identified by the operators and municipalities for each governorate and will be increased gradually to reach a value of 90, 95 % by 2025 and 2035 respectively as specified in the strategy of Palestine.
- ✓ The water consumption rate as recorded by PWA and will be increased gradually to reach a value of 110, 120 L/C/D by 2025 and 2035 respectively as mentioned in the strategy of Palestine.
- ✓ The wastewater production rate is 80% of water consumption.

4.3 Evaluation of the Treated Wastewater

4.3.1 Evaluation of the Effluents

An Evaluation for the produced treated wastewater from intermediate and regional wastewater treatment plants was conducted and compared the treated effluents with the Palestinian standards for the irrigation. The evaluation was for the main parameters that measured or expected for the influents and effluents which describes the quality of the treated wastewater as the following:

- **Biochemical Oxygen Demand (BOD5)**

The most extensively used parameter of organic pollution applied to wastewater is the 5-day BOD (BOD5). The BOD5 is usually exerted by dissolved and colloidal organic matter and imposes a load on the biological units of the treatment plant. Oxygen must be provided so that bacteria can grow and oxidize the organic matter. An added BOD5 load, caused by an increase in organic waste, requires more bacterial activity, more oxygen, and greater biological-unit capacity for its treatment. The determination of the BOD5 involves the measurement of the dissolved oxygen used by microorganisms in the biochemical oxidation of organic matter.

- **Chemical Oxygen Demand (COD)**

The chemical oxygen demand (COD) is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. In general, COD values in wastewater is higher than that of the BOD5 because more compounds can be chemically oxidized than can be biologically oxidized. The ratio of COD to BOD5 is usually 1.5: 2 for industrial wastewater containing biodegradable material (e.g. Food Industry). For wastewater with ratios higher than 3, it is assumed that some oxidizable material in the sample is not biodegradable. Non-biodegradable material sometimes is called refractory and found mainly in wastewater from chemical, pulp, and paper industries.

- **Total Suspended Solids (TSS)**

Analytically, the total solids content of wastewater is defined as all the matter that remains as residue upon evaporation at 103 to 105 °C. Matter that has a significant vapor pressure at this temperature is lost during evaporation & is not defined as a solid. Settable solids are those solids that will settle to the bottom of a cone-shaped container (called an Imhoff cone) in 60 minutes. Settable solids, expressed as mg/l, are an approximate measure of the quantity of sludge that will be removed by primary sedimentation. Total solids, or residue upon evaporation, can be further classified as non-filterable (suspended) or filterable by passing a known volume of liquid through a filter. The filterable-solids fraction consists of colloidal and dissolved solids. The colloidal fraction consists of the particulate matter with an approximate size range of from 0.001 to 1μm. The dissolved solids consist of both organic & inorganic molecules and ions that are present in true solution in water. The colloidal fraction cannot be 40 removed by settling. Generally, biological oxidation or coagulation, followed by sedimentation, is required to remove these particles from suspension. The suspended solids were found in considerable quantity in many industrial wastewaters, such as cannery and paper-mill effluents. They are screened and/or settled out at the treatment plant. Solids removed by settling and separated from wash water are called sludge, which may then be pumped to drying beds or filtered for extraction of additional water (dewatering). Each of the categories of solids may be further classified based on their volatility at 550 + 50C°. The organic fraction will oxidize and will be driven off as gas at this temperature, and the inorganic fraction remains behind as ash. Thus the terms "Volatile suspended solids" and "Fixed suspended solids" refer, respectively, to the organic and inorganic (or mineral) content of the suspended solids. The volatile-solids analysis is applied most commonly to wastewater sludge to measure their biological stability.

- **Fecal Coliform (FC)**

The concentration of fecal coliforms organisms in water is measured to determine the probability of pollution by micro-biological bacteria. For estimation of FC bacterial populations, The Membrane Filtration (MF) technique is performed. In the initial step, several dilutions of the sample volume are passed through a membrane filter with a pore size small enough (0.45 microns) to retain the bacteria present. The filter is placed on an absorbent pad saturated with a culture medium that is selective for coliform growth (CFU). The pad dish containing the filter and pad is incubated, upside down, for 24 hours at the appropriate temperature (44.5 ± 0.2C°). After incubation, the colonies that have blue color are identified and counted using a low-power microscope. Few colonies from each plate were picked and biochemical tests were performed to confirm the identity.

- **Total Dissolved Solid (TDS)**

TDS refers to total dissolved solids particles contained in a water sample. TDS can be measured by evaporating the water passed from TSS test at 180°C for one hour, TDS can also be estimated by measuring EC and using the relation TDS (ppm) = 640*EC (dS/m) or simply TDS can measure by TDS meter. TDS is measured in ppm or mg/l.

4.3.2 Intermediate Wastewater Treatment Plants

There are three intermediate WWTPs in Gaza Strip which will be in operation until the alternative WWTPs will be in service for each area. These plants are Bait Lahia WWTP (BLWWTP), Gaza WWTP (GWWTP) and Rafah WWTP (RWWTP). An evaluation was made by comparing the results of the effluents for the above parameters with the Palestinian standards.

4.3.3 Regional Wastewater Treatment Plants

In the Gaza Strip, North Gaza Wastewater Treatment Plant operated from the beginning of 2018 and gradually closure for Beit Lahiya treatment plant will be done. It is expected to close the Gaza treatment plant as soon as Buriej WWTP (BWWTP) is operating, and to close the temporary Khan Younis WWTP as soon as Khan Younis WWTP (Kh WWTP) starts to operate. The evaluation of the treated wastewater was performed for plants design for the previous parameters.

4.4 Planning for Potential Horticulture Trees to be Irrigated by Treated Wastewater

A consequence of transferring the wastewater treatment plants to the eastern side of Gaza Strip with high technologies and due to the availability of agriculture areas in the eastern parts of Gaza Strip which imputes to use the treated wastewater far away from the residential areas for health and safety reasons, a proposal was made by the researcher to cultivate a horticulture trees according to the calculated annual needs from them along the defined stages. The restrictions for using the treated wastewater in horticultural crops are less than other crops. This approach will save the groundwater for domestic use and can magnify the uses of treated wastewater. Moreover, it will reduce the costs of fruit production, and as a consequence will increase farm profits, considering the water resources crisis. It will also optimize the use of state owned land on the eastern border.

4.4.1 Software Applications

1. Arch Map

ArcMap is the main component of Esri's ArcGIS suite of geospatial processing programs and is used primarily to view, edit, create, and analyze geospatial data. ArcMap allows the user to explore data within a data set, symbolize features accordingly, and create maps (Wikipedia, 2019b).

The program was used in selecting the proposed agricultural areas to make sure that the chosen areas still for agriculture purposes. It was made by using a satellite image captured in 2018. Also, it was used in preparing the maps as shown in chapter 5.

2. LINDO

LINDO (Linear, INteractive, and Discrete Optimizer) is a convenient, but powerful tool for solving linear, integer, and quadratic programming problems. These problems occur in areas of business, industry, research, and government. Specific application areas where LINDO has proven to be of great use would include product distribution, ingredient blending, production and personnel scheduling, inventory management, etc..

The simplified version of this software based on using syntax system to identify the problem in order to build a model. Mainly, this model contains target and constraints syntaxes. After running the model, results can be obtained in the result window.

Note: (Lindo user’s manual, http://www.lindo.com)

Chapter 5

Results and Discussion

Chapter 5
Results and Discussion

5.1 Define the Future Situations of Water and Wastewater Sectors in Gaza Strip

A lot of interventions and plans resulted from the strategic objectives in the National Strategy was set up to overcome the challenges and develop the water and wastewater sectors in Gaza Strip. A deep review for PWA & CMWU and related authorities reports was made by the researcher and in addition to meetings held with managers in these agencies. The review involved the development of the current & future facilities for these sectors. The researcher concluded that the situation of water and wastewater sectors in Gaza Strip will pass through three phases as shown in table (5.1):

***Table* 5.*1*: Future situations for water and wastewater sectors in Gaza Strip**

Phase no.	Year	Expected Situation
Phase 1	Year 2020	Presence of intermediate WWTP's and groundwater source for domestic water supply. " Current Situation".
Phase 2	Year 2025	Presence of intermediate WWTP's, first phases of regional WWTP's and short term seawater desalination interventions for domestic water supply.
Phase 3	Year 2035	Presence of final phases of regional WWTP's and long term seawater desalination interventions for domestic water supply.

Also, the researcher considered 2017 as a baseline year in this study due to the availability of recent and updated data in that year.

5.1.1 Domestic Water Improvements

Currently, the domestic water supply in Gaza Strip depends mainly on the groundwater and minor quantities from Mekrot & seawater desalination. The water quota for each capita varying from municipality to others which considered the main provider of water in their areas as shown in Annex 2. Many reasons for these varying which were the availability of water resources, the capability of each municipality, water networks efficiencies and others.

As indicated in the strategy, progressive improvements for the quality, quotas and networks efficiencies will occur. This will be achieved by finding other water sources and implementing new facilities. Figures (5.1 & 5.2) shows these progressive relating the quantity as indicated in the strategy:

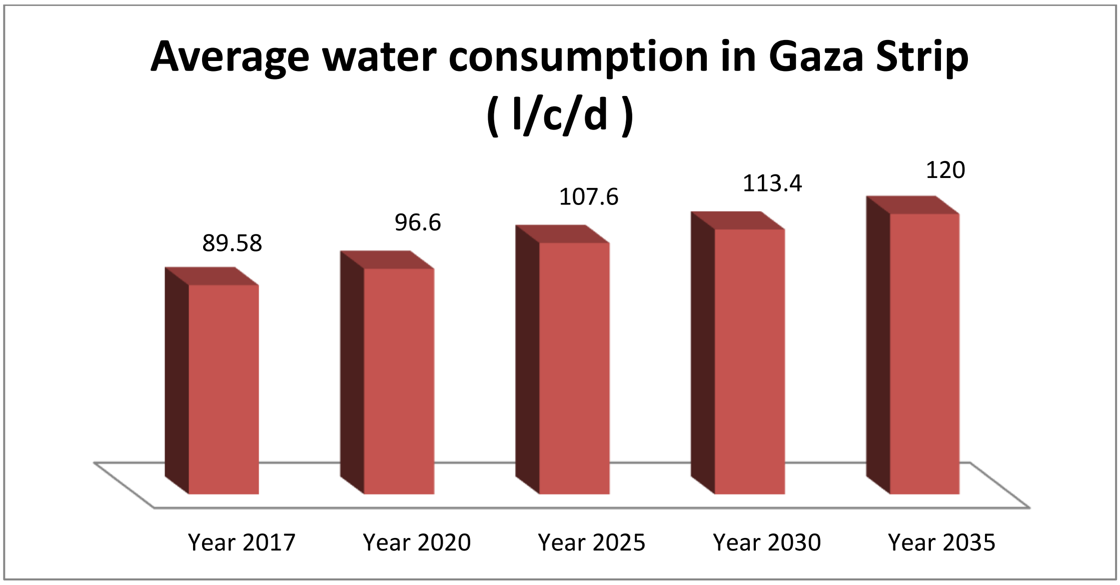


***Figure 5.1*: Average water consumption in the Gaza Strip**

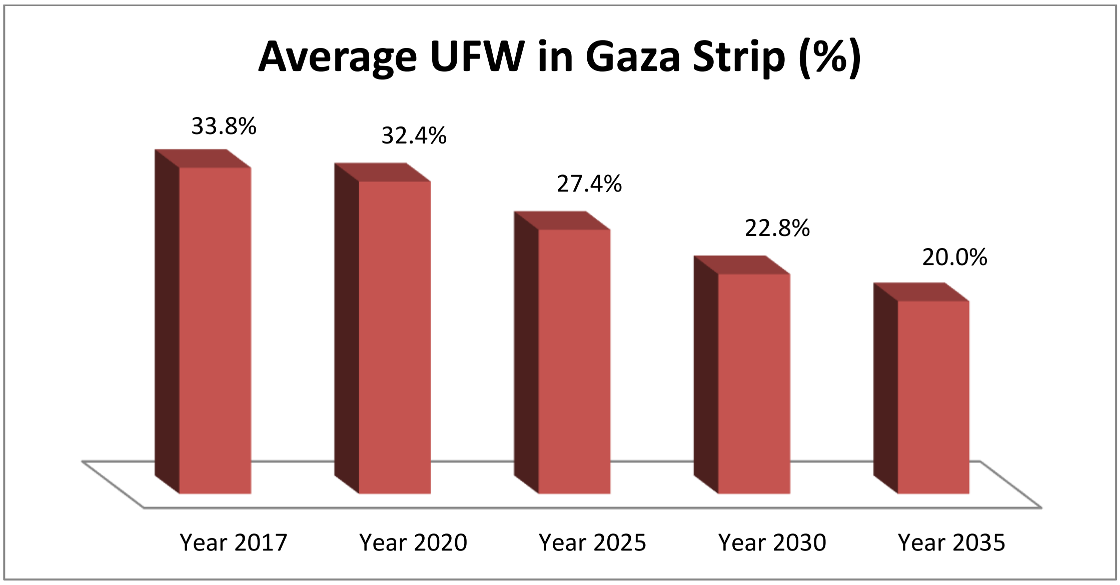


***Figure 5.2*: Average unaccounted-for water in Gaza Strip**

For the quality improvements, seawater desalination will be the main option to be used. Also, the quantities from the MEKOTE source will be increased. These two sources will be blended with the groundwater in scattered reservoirs in Gaza Strip. Moreover, a carrier line will be extended from the north to the south will connect these reservoirs to supply the required quality for all population in Gaza Strip.

The water quality standards to be achieved are for an interim period (up to 2025), a chloride concentration of 400 mg/l and ultimately only 250 mg/l, the latter is also the WHO limit. PWA prepared the studies to determine the needs of each source to achieve the target quality in terms of chloride only.

To estimate the TDS parameter, the researcher considered the North Governorate as an example and calculated the produced TDS for the reservoirs in North Governorate. Noting that all governorates have the same plans. Table (5.2) shows the water production forecast for water sources in North Governorate by 2025,2030 & 2035.

***Table 5.2*: Northern Governorate – Water production forecast (PWA,2016)**

Year	Water Production (CM/d)	Mekorot (CM/d)	STLV (CM/d)	CGDP (CM/d)	Ground-water (CM/d)
2025	73055	0	0	21933	51122
2030	93974	0	0	67979	25994
2035	106691	0	0	58961	47730

The quantities mentioned in the above table will be blended in seven reservoirs distributed in the governorate. As an example, the TDS was estimated for one reservoir identified by ' BL-T01 ' located in Beit Lahia. The feeding sources as listed in table 5.3.

***Table 5.3*: BL-T01 RESERVOIR – Municipality of Beit Lahia – Northern Governorate – Water Demand Forecast (PWA, 2016)**

Year	Water Demand (CM/d)	Water Production (CM/d)	Mekorot (CM/d)	STLV (CM/d)	CGDP (CM/d)	Ground-water (CM/d)
2025	7032	9132.5	0	0	2996.5	6136
2030	9301	11626.3	0	0	8874.3	2752
2035	10627	13283.8	0	0	8047.8	5236

The table shows that the tank will be fed from groundwater and CGDP. As planned by PWA, 4 wells will feed the tank. The MOH executes a monitoring program for the domestic water wells in Gaza Strip. Based on that, the researcher predicted TDS values for these wells for years 2025, 2030 & 2035 with referring to the history of wells from the year 2009 up to 2017. Fig(5.3) shows the TDS predications for Well named by Al Sheekh Zayed Well "A-205". (See Annex 4 for the other wells).

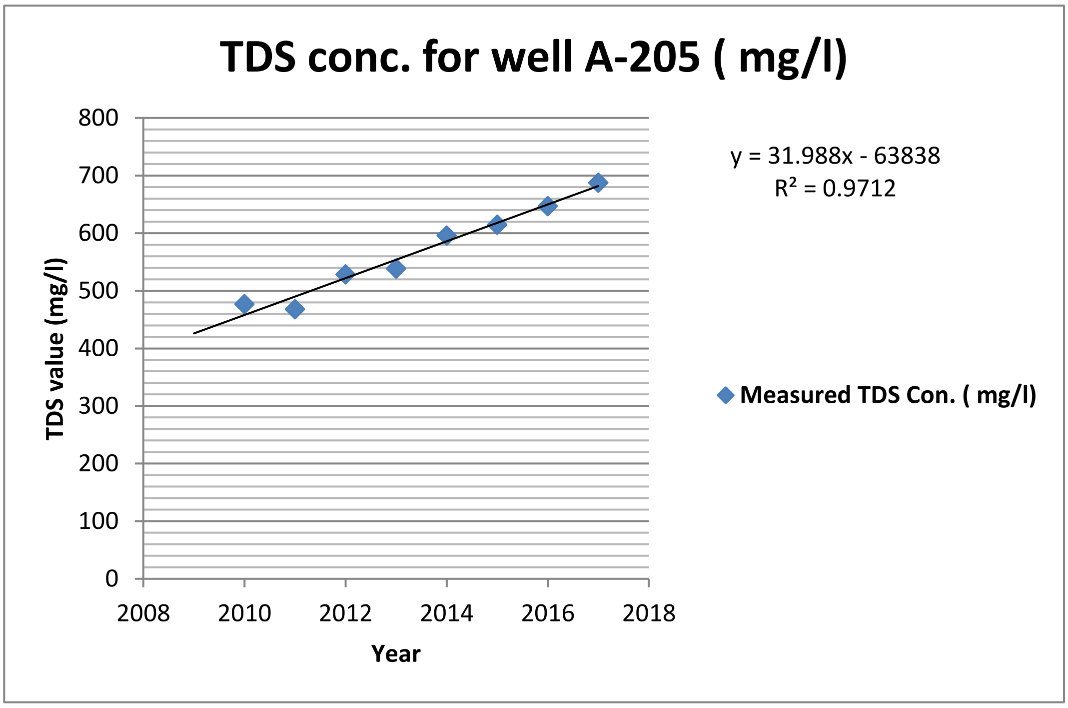


***Figure 5.3*: TDS conc. For well A-205 (mg/l)**

The predictions were made for other wells and the average TDS of the feeder wells was predicted to be 856, 953 & 1050 for years 2025, 2030 & 2035, respectively. While the TDS value for the CGDP will be 300 mg/l as it designed. Each source will share with the TDS values as the percent of the quantity.

Finally, the TDS for this tank was estimated to be 674, 455 & 595 for years 2025, 2030 & 2035, respectively.

In all over the North governorate, the TDS for domestic water was estimated to be 763, 498 & 665 for years 2025, 2030 & 2035, respectively. (See Annex 4).

5.1.2 Wastewater Improvements

As indicated in chapter 3, the wastewater collected in five traditional treatment plants from Gaza Strip Governorates. Annex 3 shows the coverage of wastewater networks in each municipality. Fig. (5.4) shows the improvements in the network's coverage along with the define phases. A new regional WWTP's will be in service with high technologies in treatment as explained in section 3.3.2, which will open the prospective for the reuse.

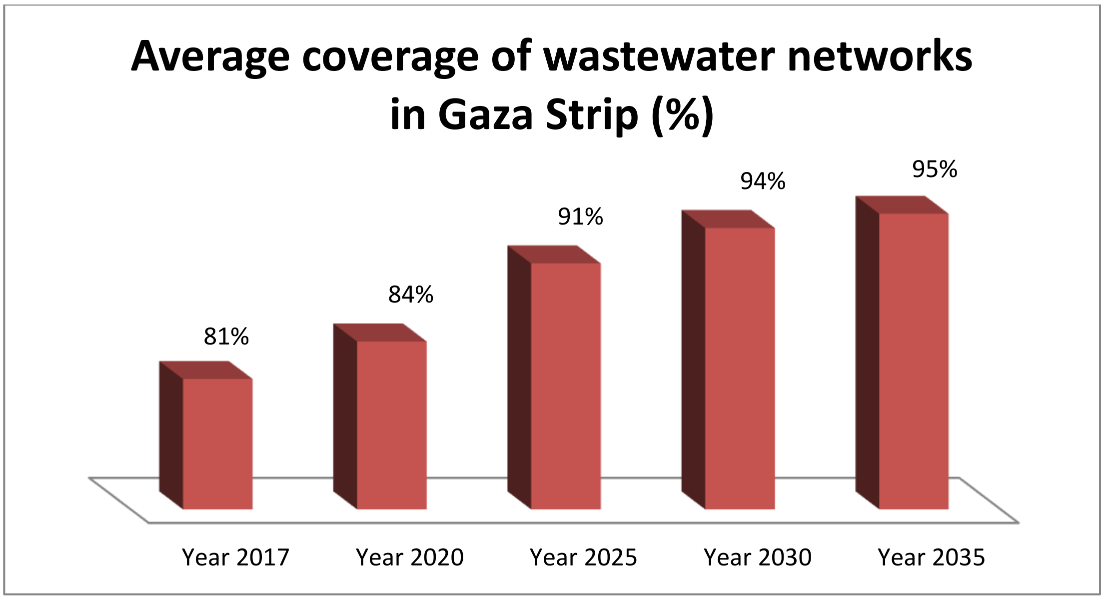


***Figure 5.4*: Average coverage of wastewater networks in the Gaza Strip**

Potential improvements will befall the salinity of the treated wastewater as a result of enhancing the domestic water salinity. In the study example, the average TDS for the domestic water at the maximum was estimated to be 763 mg/l in year 2025. Due to the domestic uses, the salinity increases by 10%. Therefore, TDS was estimated to be around 839 mg/l in raw sewage. The treatment plants may remove around 10% of salinity. Thus, wastewater effluent was predicted with salinity around 755 mg/l. The estimations for 2030& 2035 were around 493 and 658 mg/l , respectively. These values are valuable which open the field for the reuse of the treated wastewater as long as achieving the standards for other parameters.

5.2 Estimate the Wastewater Quantities

5.2.1 Population Estimation

Population projections applied for years 2020, 2025, 2030 and 2035 using the equation in section 4.2.1 with population growth rate 2.8% as identified by PCBS and year 2017 considered as a base year. Table 5.4 shows the total population for each area for the mentioned years. It is noticed that the population density will increase from 5024 pop./km 2 in 2017 to reach 6490, 7450 and 8555 pop./km^2 for 2025, 2030 and 2035, respectively. This increasing forecasts a great needs for resources including lands, water, agriculture, and others to provide a fit life for the population.

Table 5.4: Population projections for 2020, 2025& 2035

Area	Year 2017	Year 2020	Year 2025	Year 2030	Year 2035
North Gaza	368,978	400,848	460,199	528,337	606,564
Gaza	631,215	685,736	787,267	903,832	1,037,656
Middle	294,582	320,026	367,410	421,810	484,264
Khan Younis	370,638	402,651	462,269	530,714	609,293
Rafah	233,878	254,079	291,699	334,888	384,473
Total Population (inhab.)	**1,899,291**	**2,063,340**	**2,368,844**	**2,719,58 1**	**3,122,249**

5.2.2 Wastewater Quantities Estimation

The estimation was conducted for the five areas in Gaza Strip for years 2020, 2025, 2030 and 2035 in the next tables. Population projections and data from the Water Sector Regulatory Council (WSRC) in 2017 concerning the water consumption, UFW and coverage of wastewater networks were considered (Referring to Annex 2). Due to the planned enhancements, the average water consumption, UFW and coverage of wastewater networks will reach to 120 lcd , 20% and 95% in year 2035 respectively. Years 2020, 2025 and 2030 will be affected until reaching the targets in year 2035.

5.2.2.1 North Gaza

The north area has been served by BLWWTP for a long time as intermediate plant and lately, NGEST replaced BLWWTP as a regional plant which was operated from the start of 2018 as a tentative period. Noting that the wastewater quantities recorded for BLWWTP were 33,130 m^3/d in 2017. Table 5.5 shows the estimated quantities for the next years.

Table 5.5: Estimated wastewater quantities for the north area

North Gaza	Year 2017	Year 2020	Year 2025	Year 2030	Year 2035
Population	368,978	400,848	460,199	528,337	606,564
% households connected to sewers	91%	93%	95%	95%	95%
Water used per capita (lcd)	102	105	110	115	120
UFW (%)	38%	35%	28%	23%	20%
% used water that is rejected	80%	80%	80%	80%	80%
Calculated wastewater collected by sewers (m3/day)	**27,623**	**31,314**	**38,473**	**46,177**	**55,319**
Actual estimating for wastewater quantities (m3/day)	**33,130**	**35,992**	**38,473**	**46,177**	**55,319**

Actual estimating for wastewater quantities (MCM/year)	**12.09**	**13.14**	**14.04**	**16.85**	**20.19**

It is obvious that the calculated quantities are less than the actual estimating especially in the years 2017 and 2020. The researcher imputes this difference due to the high percentage of UFW in that years which were as a result from illegal connections, defects in water meter and the illegal wells that feeding houses connected with wastewater networks. So, the recorded quantity is considered for the year 2017 and the researcher used formula 4.1 to estimate the quantities for the year 2020 due to the predicted high percentage of UFW. While the calculated quantities are considered for years 2025, 2030 and 2035.

5.2.2.2 Gaza

Currently, Gaza is has been served by GWWTP as intermediate plant and will be served by BWWTP as a regional plant noting that the wastewater quantities recorded for GWWTP were 58,395 m^3/d in 2017. Table 5.6 shows the estimated quantities.

Table 5.6: Estimated wastewater quantities for Gaza

Gaza	Year 2017	Year 2020	Year 2025	Year 2030	Year 2035
Population	631,215	685,736	787,267	903,832	1,037,656
% households connected to sewers	89%	92%	95%	95%	95%
Water used per capita (lcd)	92	98	107	113	120
UFW (%)	35%	33%	28%	23%	20%
% used water that is rejected	80%	80%	80%	80%	80%
Calculated wastewater collected by sewers (m3/day)	**41,347**	**49,461**	**64,021**	**77,621**	**94,634**
Actual estimating for wastewater quantities (m3/day)	**58,395**	**63,439**	**68,918**	**77,621**	**94,634**
Actual estimating for wastewater quantities (MCM/year)	**21.31**	**23.16**	**25.16**	**28.33**	**34.54**

It is clear that the calculated quantities are less than the actual estimating especially in the years 2017 and 2020. The researcher imputes this difference due to the high percentage of UFW in that years which were a result from illegal connections, defect in water meter and the uncontrolled wells that feeding high buildings in Gaza city connected with wastewater networks. Moreover, Gaza city is the main city in Gaza Strip and which include the governmental buildings, universities and industrial activities. Those consumers often have private wells. So, the recorded quantity is considered for the year 2017 and the researcher used formula 4.1 to estimate the quantities for years 2020 & 2025 due to the predicted high percentage of UFW. While the calculated quantities are considered for years 2030 and 2035 with potentials for controlling the external sources.

5.2.2.3 Middle Area

The wastewater in the middle area is collected in the WGWWTP as temporary plant and some quantities pumped directly to Wadi Gaza. While it will be served by BWWTP as a regional plant noting that the wastewater quantities recorded for Wadi Gaza WWTP were 12,035 m^3/d in 2017. Table 5.7 shows that the calculated quantities are more than the quantities recorded in WGWWTP. This is due to the quantities that pumped directly to Wadi Gaza, the calculated quantities will be considered.

Table 5.7: Estimated wastewater quantities for Middle area

Middle	Year 2017	Year 2020	Year 2025	Year 2030	Year 2035
Population	294,582	320,026	367,410	421,810	484,264
% households connected to sewers	84%	83%	87%	92%	95%
Water used per capita (lcd)	87	95	107	113	120
UFW (%)	37%	38%	28%	23%	20%
% used water that is rejected	80%	80%	80%	80%	80%
Calculated wastewater collected by sewers (m3/day)	**17,236**	**20,187**	**27,362**	**35,081**	**44,165**
Actual estimating for wastewater quantities (m3/day)	**17,236**	**20,187**	**27,362**	**35,081**	**44,165**
Actual estimating for wastewater quantities (MCM/year)	**6.29**	**7.37**	**9.99**	**12.80**	**16.12**

5.2.2.4 Khan Younis Area

Khan Younis area is considered the least area has wastewater networks with an average of 57 % in 2017. The wastewater is collected mainly from Khan Younis city in the (KhWWTP – Temporary) as a temporary plant and the governorate will be served by KhWWTP as a regional plant noting that the wastewater quantities recorded for (KhWWTP – Temporary) were 13,516 m^3/d in 2017. Table 5.8 shows the estimated quantities. The calculated quantities are considered which will be more accurate in the target years.

Table 5.8: Estimated wastewater quantities for Khan Younis area

Khan Younis	Year 2017	Year 2020	Year 2025	Year 2030	Year 2035
Population	370,638	402,651	462,269	530,714	609,293
% households connected to sewers	57%	65%	87%	92%	95%
Water used per capita (lcd)	86	95	107	113	120
UFW (%)	28%	26%	25%	22%	20%
% used water that is rejected	80%	80%	80%	80%	80%
Calculated wastewater collected by sewers (m3/day)	**14,536**	**19,891**	**34,426**	**44,138**	**55,567**
Actual estimating for wastewater quantities (m3/day)	**14,536**	**19,891**	**34,426**	**44,138**	**55,567**
Actual estimating for wastewater quantities (MCM/year)	**5.31**	**7.26**	**12.57**	**16.11**	**20.28**

5.2.2.5 Rafah Area

The wastewater is collected in RWWTP as intermediate plant and will be served by KhWWTP as a regional plant according to CMWU. As listed in table 3.2 the wastewater quantities received by RWWTP were 13,358 m^3/d in 2017. Table 5.9 shows the estimated quantities. The calculated quantities are considered.

Table 5.9: Estimated wastewater quantities for Rafah area

Rafah	Year 2017	Year 2020	Year 2025	Year 2030	Year 2035
Population	233,878	254,079	291,699	334,888	384,473
% households connected to sewers	84%	88%	90%	95%	95%
Water used per capita (lcd)	80	90	107	113	120
UFW (%)	31%	30%	28%	23%	20%
% used water that is rejected	80%	80%	80%	80%	80%
Calculated wastewater collected by sewers (m3/day)	**12,575**	**16,098**	**22,472**	**28,760**	**35,064**
Actual estimating for wastewater quantities (m3/day)	**13,358**	**16,098**	**22,472**	**28,760**	**35,064**

Actual estimating for wastewater quantities (MCM/year)	4.88	5.88	8.20	10.50	12.80

Fig(5.5) shows the total wastewater quantities for the years 2017, 2020, 2025, 2030 & 2035.

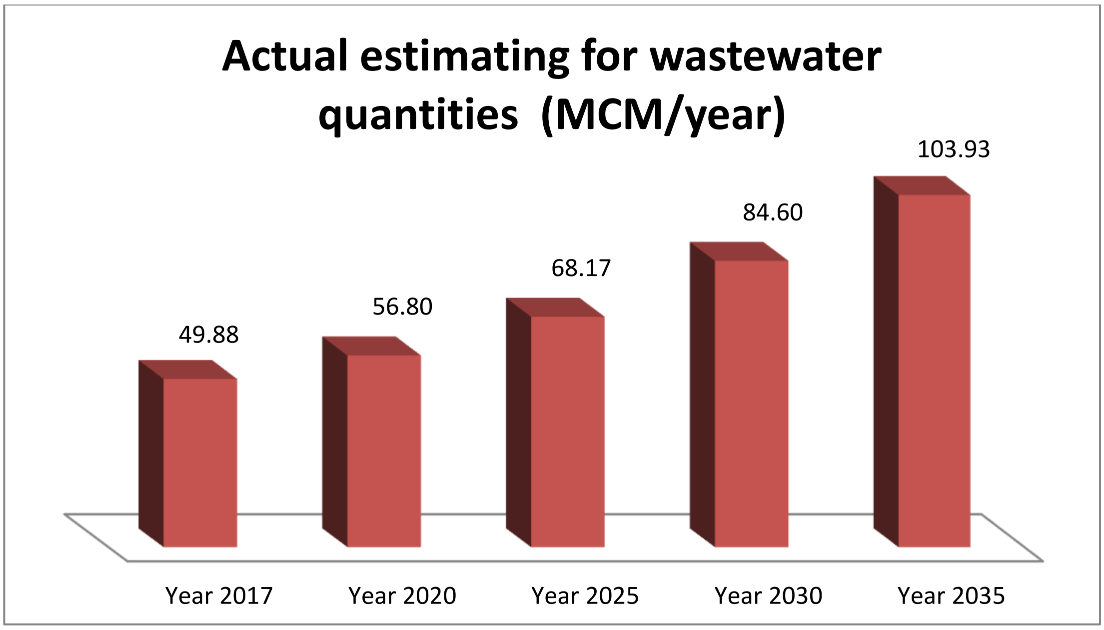


Figure 5.5: Estimating for wastewater quantities

5.3 Evaluation of the Treated Wastewater

5.3.1 Evaluation of the Effluents

The researcher evaluated the results of the treated wastewater from intermediate and for the design parameters of the regional wastewater treatment plants and comparing the products with the Palestinian standards for the selected horticultural crops in the study. The evaluation is for BOD, COD, TSS, TDS, T-N and F. Coliform which are considered the main parameters that describe the quality of the treated wastewater. Table (5.10) shows the standards that were considered in the evaluation.

Table 5.10: Palestinian standards for reuse of treated wastewater(EQA,2014 & MOA,2017)

Parameter	Palestinian Standards				
	Citrus & Almonds	Olives	Grapes	Date Palms	Guava
BOD (mg/L)	45	45	45	45	45
COD (mg/L)	90	90	90	90	90
TSS (mg/L)	40	40	40	40	40

TDS (mg/L) *	0-896	1920-3840	896 -1920	3840-6400	896 -1920
T-N (mg/L)	100	100	100	100	100
F. Coliform (MPN/100ml)	200	200	200	200	200

** N.A: MOA*

5.3.2 Intermediate Wastewater Treatment Plants

As indicated before and according to the wastewater sector plans, the intermediate WWTPs will be out of service by 2025. Until that, and with the first stage of desalination interventions, an evaluation for these plants was done to identify if the treated effluents can be used in the horticulture trees irrigations according to the Palestinian Standards. EQA executes a monitoring program for the WWTPs and records the test results in the environmental records as shown in annex 3. The test results belong the year 2017.

5.3.2.1 Bait Lahia WWTP (BLWWTP)

Due to the critical site of the plant which was located in a residential area that causes problems for the neighborhood and environment. NGEST, the alternative plant was constructed and operated firstly. Table (5.11) shows the test results of the Bait Lahia WWTP as recorded by EQA in 2017 (refer to annex 3).

Table 5.11: BLWWTP Test results (EQA, 2017)

Parameter	Inlet	Outlet
BOD (mg/L)	400	104
COD (mg/L)	896	255
TSS (mg/L)	458	76
TDS (mg/L)	1747	1528
F. Coliform (MPN/100ml)	-	**

***No disinfection unit*

The average value of BOD5, COD, and TSS for the effluent were 104,255 and 76 mg/l, respectively. In comparison for these values with the Palestinian standards, the results are excess the acceptable range. About the salinity, the value of TDS for the effluent was 1528 mg/l and the efficiency removal was around 12.5% which is confirmed that the plant concept is biological treatment and have nothing to do with the salt content of wastewater. Moreover, the plant has not a disinfection unit and the F. Coliform expected to be more than 1000 (MPN/100ml).

In general, the results of the effluent exceeded the Palestinian standards and the reuse of the treated wastewater is impossible. Besides, the alternative plant operated from the Mach 2018 and it will be closed soon.

5.3.1.2 Gaza WWTP (GWWTP)

Gaza WWTP is the largest intermediate plant in Gaza Strip. Many developments and expansions have been performed for the plant to convey the rapid increase in the wastewater quantities for Gaza City. Table (5.12) shows the test results of the Gaza WWTP as recorded by EQA in 2017 (refer to annex 3).

Table 5.12: GWWTP Test results (EQA, 2017)

Parameter	Inlet	Outlet
BOD (mg/L)	516	244
COD (mg/L)	1136	585
TSS (mg/L)	225	108
TDS (mg/L)	2974	2588
F. Coliform (MPN/100ml)	-	**

***No disinfection unit*

The average value of BOD5 for the effluent was 244 mg/l, Also COD value was 585 mg/l. To compare these results with the Palestinian standards, these results are not in the acceptable range. Also, the average value of TSS for the effluent was 108 mg/l, which is higher than the standard. Total suspended solids (TSS) gives a measure of the turbidity of the TWW, this value of TSS continues to be high stages and leading to high maintenance cost for the plant and cause plugging in irrigation systems, in addition, affect soil infiltration. No active disinfection unit in the plant and the F. Coliform expected to be more than 1000 (MPN/100ml).

In general, the results of the effluent exceeded the Palestinian standards and the reuse of the treated wastewater is impossible unless overcome all issues facing the operation.

5.3.1.3 Rafah WWTP (RWWTP)

Table (5.13) shows the test results of the Rafah WWTP as recorded by EQA in 2017 (refer to annex 3).

Table 5.13: RWWTP Test results (EQA, 2017)

Parameter	Inlet	Outlet
BOD (mg/L)	575	169
COD (mg/L)	1255	374

TSS (mg/L)	628	123
TDS (mg/L)	2791	2968
F. Coliform (MPN/100ml)	-	**

***No disinfection unit*

The average value of BOD5 for the effluent was 169 mg/l and COD was 374 mg/l. In comparison to both values of BOD and COD to meet the Palestinian standards, these results are excess the acceptable range. For TSS, the average value for the effluent was 123 mg/l, which is higher than the standard. Regarding the salinity, the value of TDS for the effluent was 2968 mg/l and excess the value of the inlet which was 2791 mg/l. This is due to relatively high temperature in Rafah city causing evaporation for the water and increasing the concentration of the salts. Moreover, the plant has not a disinfection unit and the F. Coliform expected to be more than 1000 (MPN/100ml).
In general, the results of the effluent exceeded the Palestinian standards and the reuse of the treated wastewater is impossible unless applying post treatment units.

In conclusion, the intermediate plants without additional treatment units and overcoming the operation complications, cannot treat the wastewater to the required limits all over the year even if enhancing the effluents salinity.

5.3.2 Regional Wastewater Treatment Plants

There are three regional WWTPs was planned and under implementation for treating the wastewater in Gaza Strip. The capacities of the plants will be enlarged to convey the produced wastewater increasing. The design parameters for each one was set up from the planner to match the Palestinian Standards and moreover the national standards for reuse. In this section, the researcher explored the design parameters for each one and compared them with the Palestinian standards.

5.3.2.1 Northern Gaza Wastewater Treatment Plant (NGWWTP)

The construction of the plant was completed and an operation period started for two years from the onset of 2018. It receives around the full capacity of the first stage and the second stage should be started soon.

As can be seen in the table (5.14) that the results for the tested parameters matched the quality design for the effluent and the Palestinian standards for the BOD, TSS, T-N. Also, it is expected that COD will be in the accepted range since the value of COD is approximate twice the BOD. While the salinity that measured in the Phase 1 period that defined in Sec. 5.1 (no desalination until now) equaled around 1300 mg/l. So, in this time, the effluent can be used for irrigating the moderate sensitive and tolerant crops for salts such as olives and date palms. After applying the desalination approach for the domestic uses, there will be enhancing in the salinity and will be in acceptable ranges for all target crops including the sensitive salinity crops as citrus and almonds as expected by the researcher in the study.

Table 5.14: Treated wastewater quality design and measured parameters for NGWWTP

Parameter	Outlet	
	Design	Measured Aug./2018**
BOD (mg/L)	10-20	17.4
COD (mg/L)	N.A	N.A
TSS (mg/L)	15-20	19.4
TDS (mg/L)	N.A	1298
T-N (mg/L)	10-15	13.3
F. Coliform (MPN/100ml)	<200	N.A

** N.A: Not Available* *** According to PWA records*

5.3.2.2 Buriej Wastewater Treatment Plant (BWWTP)

It is the biggest plant in Gaza Strip and will serve Gaza and middle governorates.

Table 5.15: Treated wastewater quality design parameters for BWWTP

Parameter	Outlet
BOD (mg/L)	40
COD (mg/L)	N.A
TSS (mg/L)	60
TDS (mg/L)	N.A
T-N (mg/L)	25
F. Coliform (MPN/100ml)	N.A

** N.A: Not Available*

It is noted from the table (5.15), quality design for the effluent will match the Palestinian standards for the BOD & T-N. Also, it is expected that COD will be in the accepted range since the value of COD is approximate twice the BOD. While the TSS is slightly more than the standards. In the first stage of the plant, there are no plans for the disinfection unit due to the salinity of the produced and the treated wastewater will discharge to wadi Gaza. The salinity of treated wastewater depends on the salinity of the supply water source. As shown in Fig. (3.4), Gaza Strip suffer from the salt groundwater due to a lot of reasons mentioned before. While after starting the seawater desalination for the domestic uses, there is a potential for enhancing the salinity in the treated effluents and will be in the acceptable ranges for all target crops as expected by the researcher in the study. So, it is recommended to add a disinfection unit which also reduces the TSS value to an acceptable range.

5.3.2.3 Khan Younis Wastewater Treatment Plant (Kh WWTP)

Table (5.16) shows that the design for the quality of the effluent will match the Palestinian standards for the BOD, TSS, T-N& F. Coliform. Also, it is expected that COD will be in the accepted range since the value of COD is approximate twice the BOD. The salinity as the same for other regional plants with a potential values in the light of desalinated seawater for the domestic uses.

Table 5.16: Treated wastewater quality design parameters for KhWWTP

Parameter	Outlet
BOD (mg/L)	<20
COD (mg/L)	N.A
TSS (mg/L)	<15
TDS (mg/L)	N.A
T-N (mg/L)	<25
F. Coliform (MPN/100ml)	<200

** N.A: Not Available*

Finally, it is seen from this evaluation for the regional plants a potential capability to use the produced treated wastewater in the irrigation of the horticultural crops. In addition to the high technologies for the regional WWTPs that be able to remove pollutants to the acceptable limits, the enhancing will occur for the salinity of the effluents which make the ability to plant sensitive slats crops in the area that faced salinity problems in the groundwater.

5.4 Planning for Potential Horticulture Trees to be Irrigated by Treated Wastewater.

5.4.1 Review the Current Situation

Based on the data form the MOA, there is a need quote from each crop for each person as shown in table (5.18). The MOA published the data for the cultivated areas from the horticultural crops and the productions for 2017 as listed in the table (5.17).

Table 5.17: Horticultural Crops and productions in the Gaza Strip (MoA, 2017)

Crops	Area			Production	
	Fruitful (Dunam)	Fruitless Dunam) (	Total (Dunam)	Production (Ton/Dunam)	Total Production (Ton)
Olives زيتون	28700	7050	35750	0.64	18275
Citrus					
Falensia orange فلنسيا	1750	445	2195	1.69	2955
Lemon ليمون	3880	2860	6740	3.23	12530
Naval orange أبو صرة	1300	1020	2320	2.64	3430
Shamoty orange شموطي	560	322	882	3.42	1915
Grapefruit جريب فروت	295	180	475	2.24	662
French orange فرنساوي	130	115	245	1.91	248
Pamplemousse بوملي	60	67	127	2.19	132
Bomaleet بومليت	40	15	55	2.00	80
Poppy مخال	3710	1260	4970	1.46	5430
Clement كلمتينا	285	135	420	1.10	312
Others أخرى	260	185	445	1.88	490
Total of Citrus	12270	6604	18874		28184
Grape					
Seed grape – Open	2606	458	3064	1.39	3610
Seed grape – تكاعيب	2305	275	2580	1.60	3700
Seedless grape – Normal	1237	271	1508	2.00	2468
Seedless grape – Green house	96	8	104	0.79	76
Total of Grapes	6244	1012	7256		9853
Others					
Date palm نخيل البلح	7695	3963	11658	1.82	13973
Guava جوافة	2000	375	2375	1.71	3422
Fig تين	750	365	1115	1.83	1372
Pomegranate رمان	435	175	610	1.56	678
Apple تفاح	380	80	460	2.92	1110
Almond لوز أخضر	675	137	812	1.96	1325
Peach خوخ	770	270	1040	1.85	1425
Apricot مشمش	355	165	520	1.49	531
Plum برقوق	150	65	215	1.70	255

Mango مانجا	285	105	390	1.36	388
Loquat اسكدنيا	81	30	111	1.73	140
Avocado أفوكادو	90	60	150	2.22	200
Annona قشطة	40	33	73	1.00	40
Aloe صبر	410	140	550	2.50	1025
Total	61330	20629	81959		82194

Fig(5.6) shows a comparison between the productions and the needs for 2017 for the main horticultural crops in Gaza Strip (Citrus, Almonds, Olives, Grapes, Guava, Date Palms) that was considered in the study.

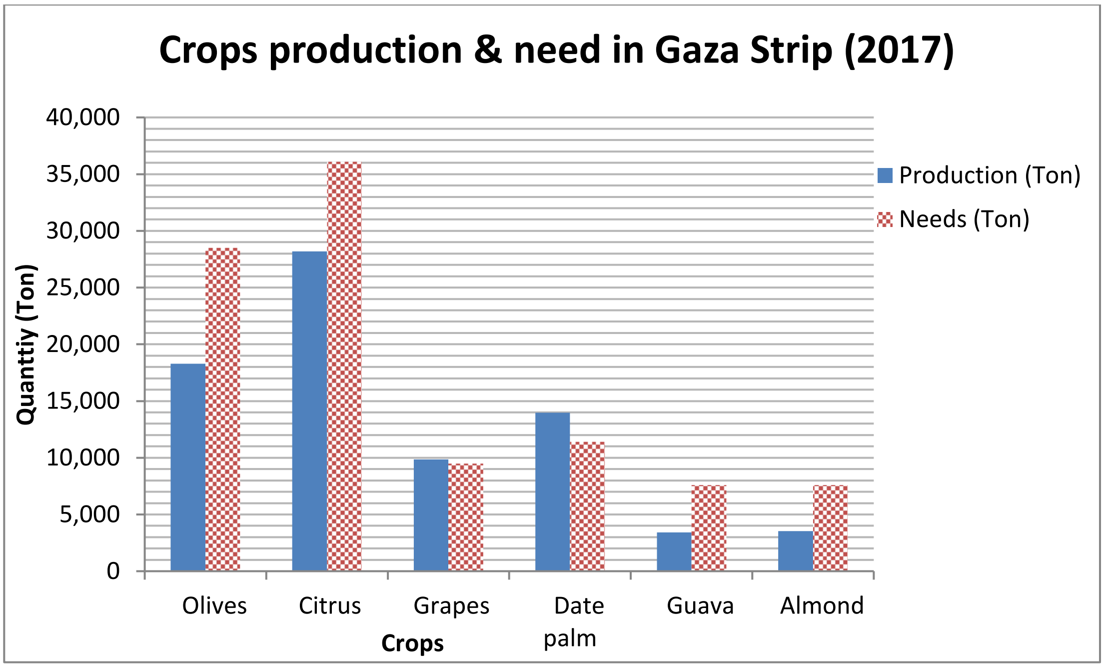


Figure 5.6: Crops productions & needs in the Gaza Strip (2017)

The figure shows that there is no self-sufficiency in many crops such as Olives, Citrus, Guava, and Almonds. While there was self-sufficiency in the Grapes and Date Palms.

To estimate the water consumption for the horticulture crops, average water requirements were identified for each crop using FAO-CropWat Model for Gaza Strip area as shown in table (5.18)(Al-Najar, 2011).

According to that, Fig(5.6) shows the estimated water consumption for the cultivated areas for the main horticultural crops in 2017 which estimated by 60.64 MCM/y.

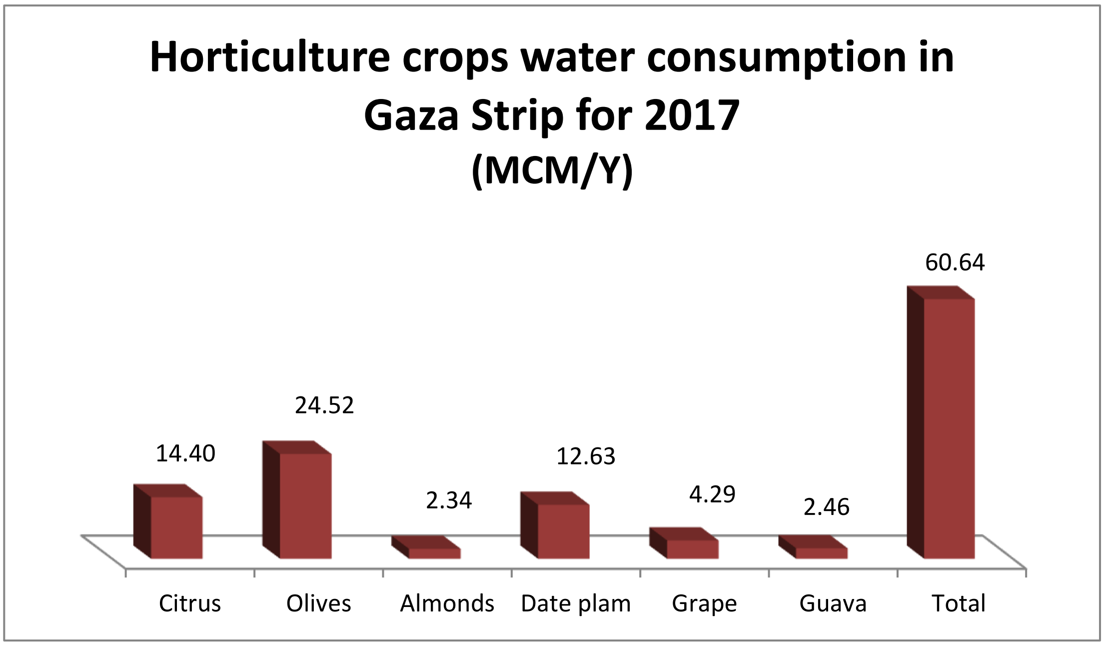


Figure 5.7: Horticulture crops water consumption in the Gaza Strip for 2017

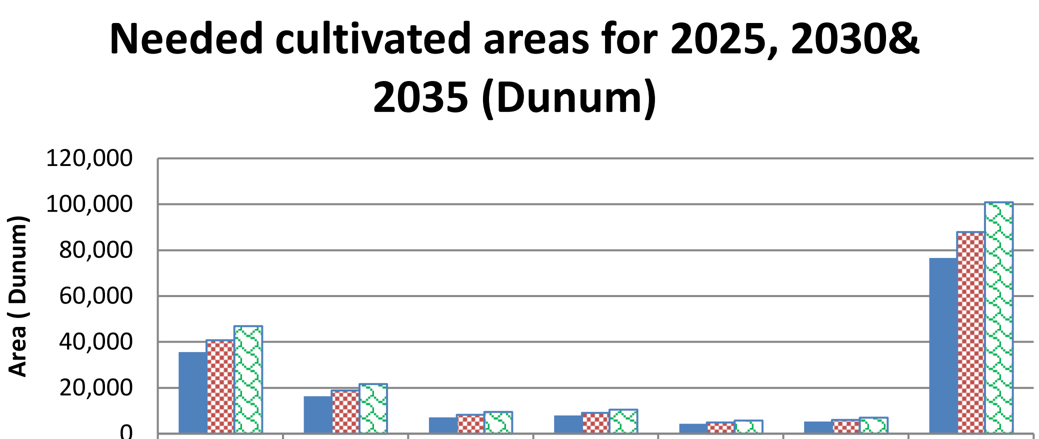
5.4.2 Estimating the Future Horticultural Crops Needs

The self-sufficiency for the horticulture crops was considered which is a strategy for the Ministry of Agriculture. The needed cultivated areas and water consumption needs for each crop for the periods (2025,2030& 2035) were calculated. The researcher assumed that the years (2025, 2030 & 2035) are the target years that they will precede with five years for executing the plans and allow the crops to reach the production period. The population projections mentioned above, each person quotes from each crops and the dunam production rate in Gaza Strip was considered as shown in table(5.18).

Table 5.18: Future horticultural crops need

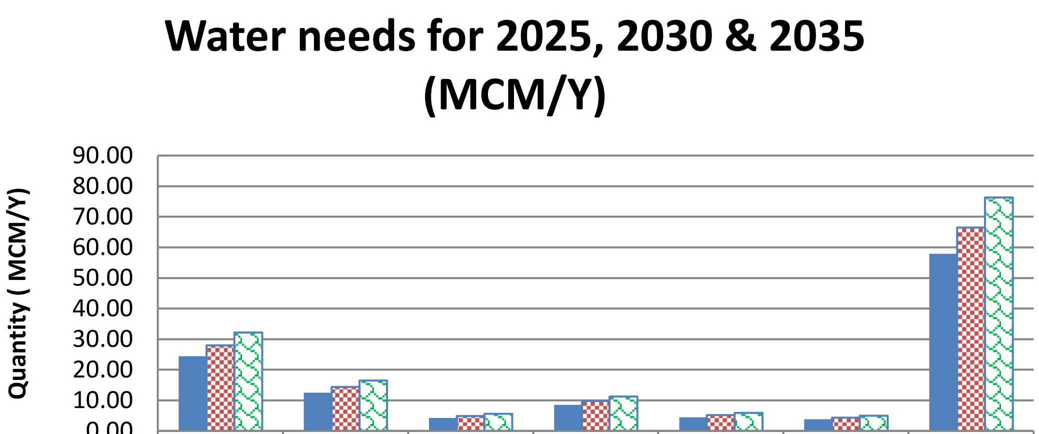
Year	Population	Item	Olives	Citrus	Grapes	Guava	Date Palms	Almonds
Year 2025	2,368,844	Average Water quota (M3/ Dunam/y)	686	763	591	1,036	1,083	722
		Average yearly quota (kg/capita)	15	19	5	4	6	4
		Total yearly needs (Ton)	35,533	45,008	11,844	9,475	14,213	9,475
		Average yearly production (Ton/dunam)	1.00	2.75	1.66	2.20	1.80	1.80
		Needed cultivated areas (Dunum)	**35,533**	**16,367**	**7,135**	**4,307**	**7,896**	**5,264**
		Water needs (MCM/Y)	**24.38**	**12.49**	**4.22**	**4.46**	**8.55**	**3.80**
Year 2030	2,719,581	Average Water quota (M3/ Dunam/y)	686	763	591	1,036	1,083	722
		Average yearly quota (kg/capita)	15	19	5	4	6	4
		Total yearly needs (Ton)	40,794	51,672	13,598	10,878	16,317	10,878
		Average yearly production (Ton/dunam)	1.00	2.75	1.66	2.20	1.80	1.80
		Needed cultivated areas (Dunum)	**40,794**	**18,790**	**8,192**	**4,945**	**9,065**	**6,044**
		Water needs (MCM/Y)	**27.98**	**14.34**	**4.84**	**5.12**	**9.82**	**4.36**
Year 2035	3,122,249	Average Water quota (M3/ Dunam/y)	686	763	591	1,036	1,083	722
		Average yearly quota (kg/capita)	15	19	5	4	6	4
		Total yearly needs (Ton)	46,834	59,323	15,611	12,489	18,733	12,489
		Average yearly production (Ton/dunam)	1.00	2.75	1.66	2.20	1.80	1.80
		Needed cultivated areas (Dunum)	**46,834**	**21,572**	**9,404**	**5,677**	**10,407**	**6,938**
		Water needs (MCM/Y)	**32.13**	**16.46**	**5.56**	**5.88**	**11.27**	**5.01**

Figures (5.8 & 5.9) summarize the needed cultivated areas from the horticulture crops and water needs for the periods 2025, 2030& 2035.



	Olives	Citrus	Grapes	Date Palms	Guava	Almonds	Total
Year 2025	35,533	16,367	7,178	7,896	4,307	5,264	76,545
Year 2030	40,794	18,790	8,241	9,065	4,945	6,044	87,878
Year 2035	46,834	21,572	9,461	10,407	5,677	6,938	100,890

Figure 5.8: Needed cultivated areas for 2025, 2030& 2035



	Olives	Citrus	Grapes	Date Palms	Guava	Almonds	Total
Year 2025	24.38	12.49	4.24	8.55	4.46	3.80	57.92
Year 2030	27.98	14.34	4.87	9.82	5.12	4.36	66.50
Year 2035	32.13	16.46	5.59	11.27	5.88	5.01	76.34

Figure 5.9: Water needs for 2025, 2030& 2035

5.4.3 Identifying the Main Agricultural Requirements

5.4.3.1 Agricultural Lands

Due to the urban expansion in western of Gaza Strip and the locations of the regional WWTPs in the eastern part, the proposed areas near and in the surrounding of the treatment plants were selected. The proposed areas classified for agricultural purposes according to the master plan prepared by MOP in 2005. Satellite image 2018 was used in selection to make sure that the areas still for agriculture purposes. Also, it is considered 10% of the selected areas for roads and services. The need for lands differs for each period and increase according to the crops production needs. The proposed lands were divided into two stages. Stage 1 for the year 2025 with total gross area 81481 dunum and extensions were made for years 2030&2035 to meet the needs as stage 2 to reach 113,894 dunum. Figures (5.10 & 5.11) show the proposed areas for the year 2025 and years 2030& 2035, respectively. Due to the adjacency of the proposed lands to the green line, a free space area with 300m width along the green line is reflected to achieve a safe situation for agricultural activities.

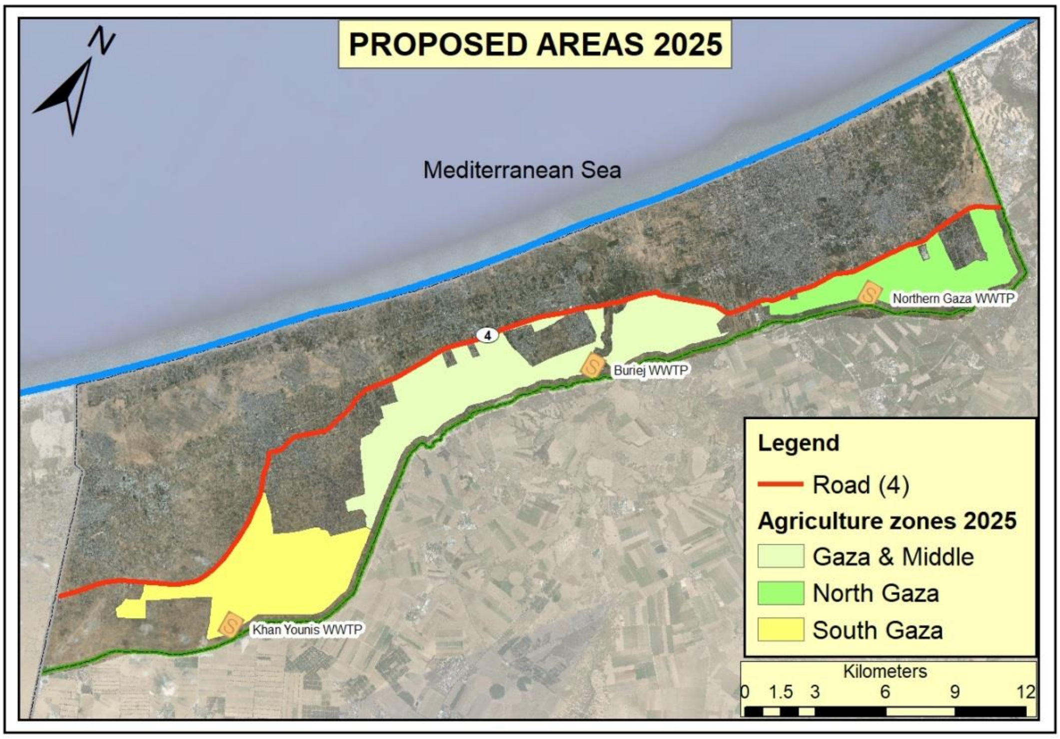


***Figure 5.10*: Proposed areas for 2025**

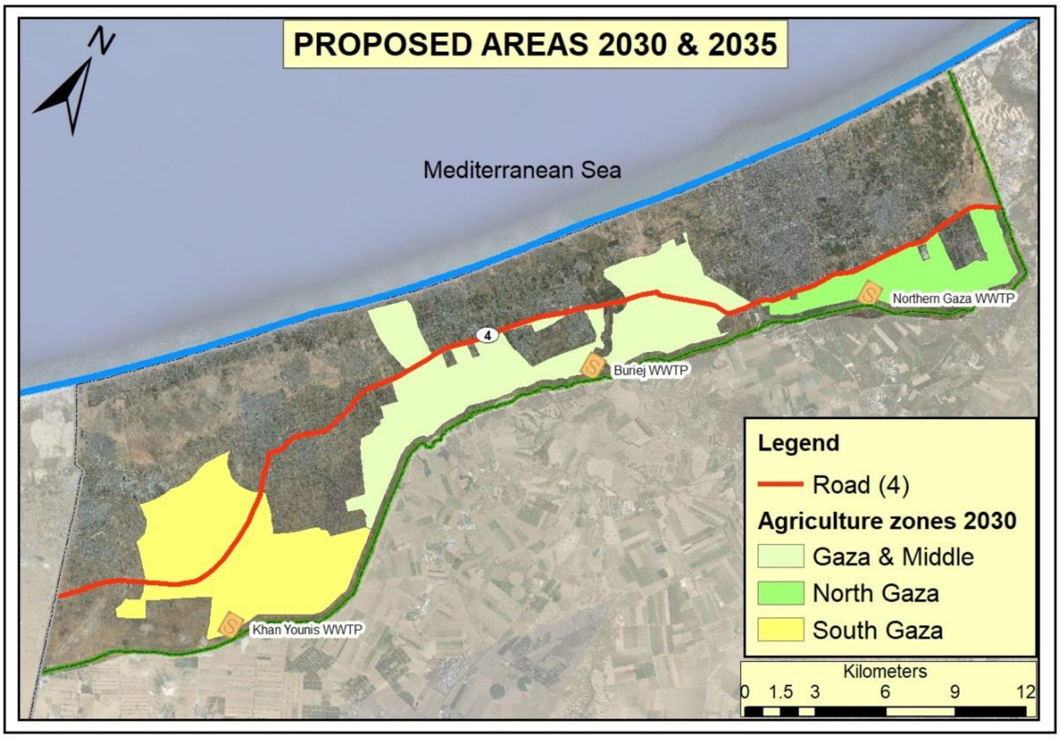


Figure 5.11: Proposed areas for 2030&2035

5.4.3.2 Water Resource

As one of the objectives for this study to use the treated wastewater in irrigation, the evaluation for the expected quality for the regional WWTPs and due to their locations, there are three sources for the treated wastewater to be used. The effluent for the NGEST for the north area, effluent for BWWTP for Gaza & Middle area and KHWWTP for the south area. The capacities will be increased according to the loads for each one. Fig(5.12) shows the available source of the treated wastewater that can be used.

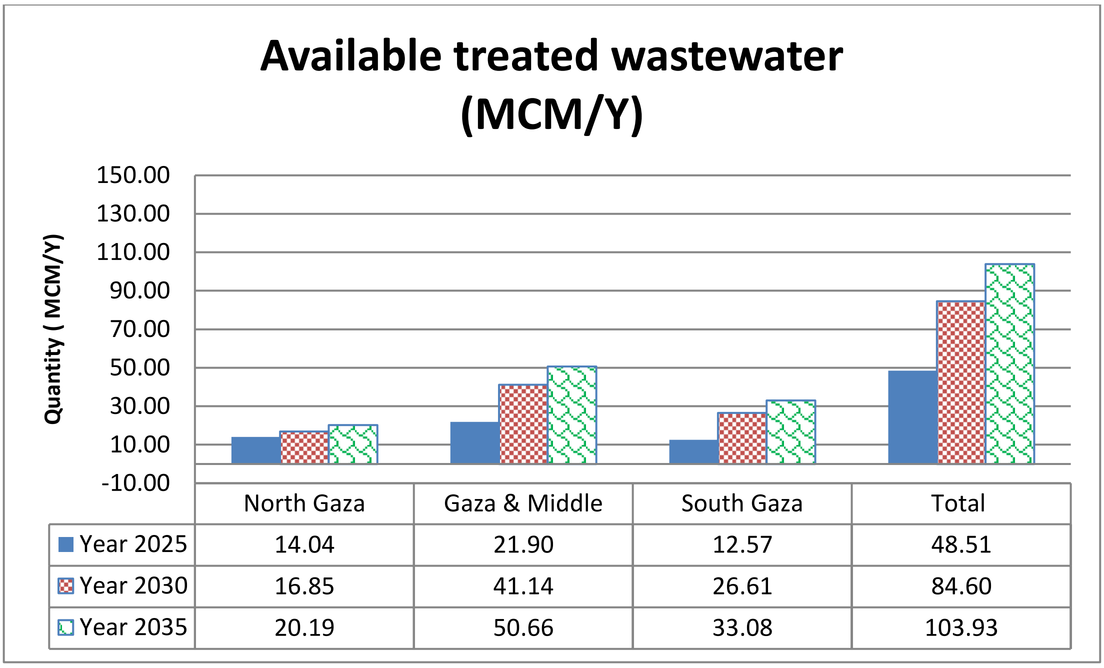


Figure 5.12: Available treated wastewater

5.4.4 Distribution the Horticultural Crops on the Agricultural Lands

The farmer experiences are the main factor were considered in the distribution of crops. Where all area was famous for the planting of many crops as indicated by the MOA. Olives are historical trees in Palestine and are planted in all areas. While the north area is famous for with planting Citrus and Almonds. Middle area is famous for with planting Citrus, Date palms and Grapes. South area is famous for with planting Guava, Date palms and Almonds. Also, the availability of treated water and availability of lands were considered. The software application was used called ' LINDO' for distributing the crops on the available areas after fed it with the previous considerations (See annex 5 for an example of the program input &output). The distribution as follow:

5.4.4.1 North Gaza Zone

The proposed area was located in the east part of the north governorate and Gaza City. It extends from road # 4 in the west, the green line from the east & north and Wadi Gaza from the south with total gross area 18,949 Dunum. The area is limited if it compares with the other areas. So, no extensions were made for the years 2030&2035. Figure (5.13) shows the proposed areas and the distribution for the years 2025, 2030 & 2035.

The target area was famous for with planting the Olives, Citrus and Almonds. The total net area is estimated by 17,000 dunum distributed as 7,900 Olives with 46.5% from the area. The second crop is the Citrus with 32.3% and a sequence for Grapes, Almonds and Guava with 1,600, 1100 and 900 dunums which represent 9.4%, 6.5%, and 5.3% respectively.

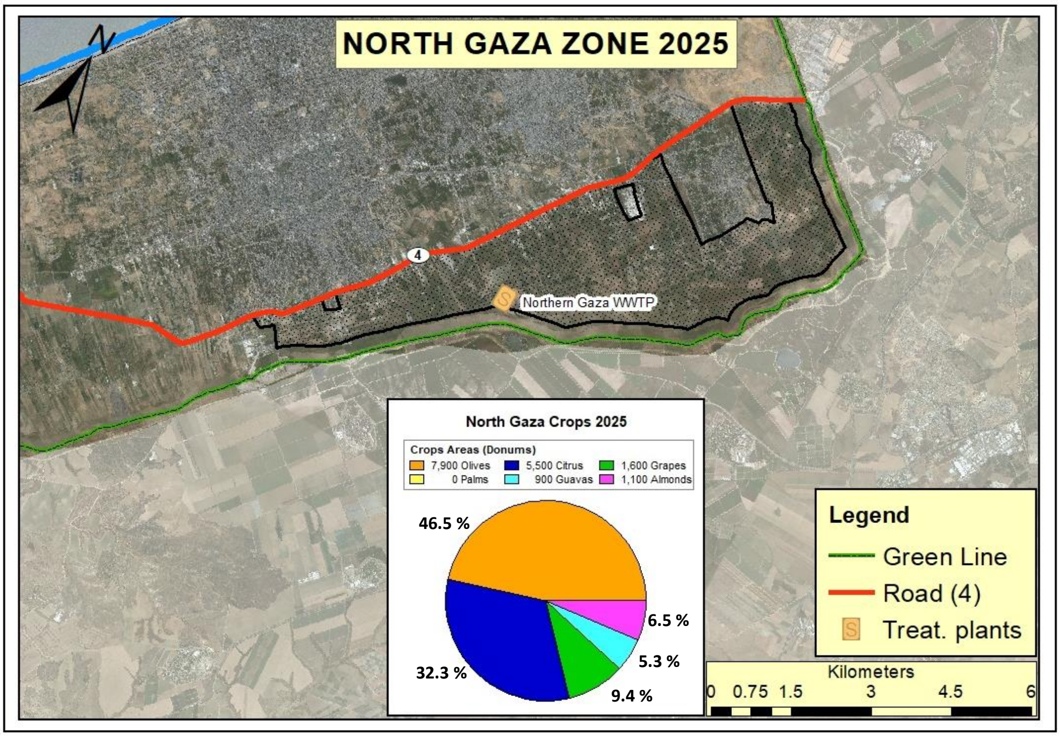


Figure 5.13: Distribution of crops in North Gaza zone - 2025

Due to the limited spaces in this region, no changes were occurred for years 2030& 2035 in the crops areas although the needs increase and distribution percentages will be the same as 2025 as shown in Figures(5.14 & 5.15). The other areas will cover this increase.

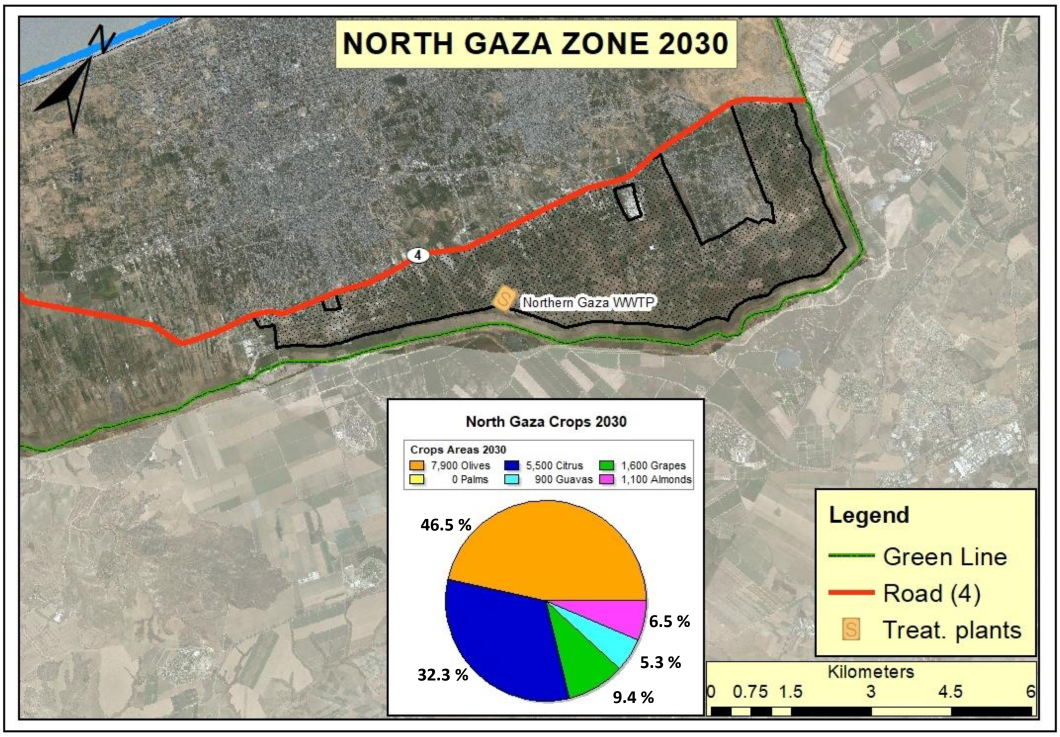


Figure 5.14: Distribution of crops in North Gaza zone - 2030

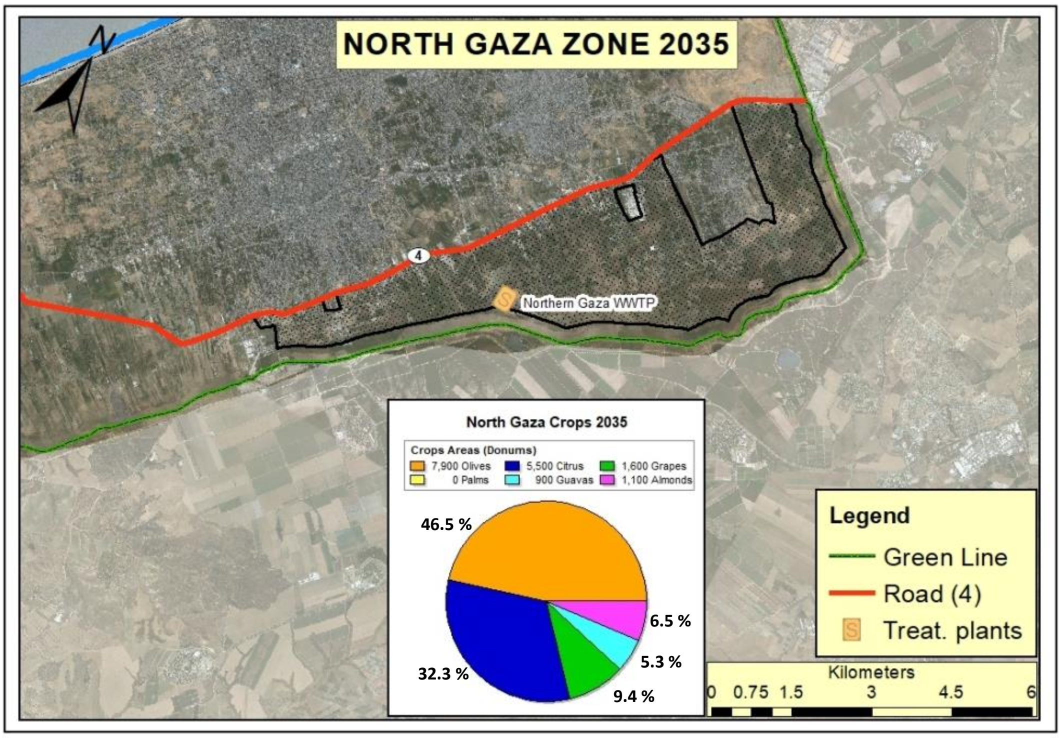


Figure 5.15: Distribution of crops in North Gaza zone - 2035

5.4.4.2 Gaza & Middle Zone

This area was famous for planting the Olives, Citrus Date Palms, and Grapes. For stage 1, for the year 2025, the proposed area extends in the east part of Wadi Gaza Village, eastern of the Middle Governorate and some parts of eastern of Khan Younis Governorate. The gross area is estimated by around 36,486 Dunum.

An extension should be made for stage 2 to cover the needs of years 2030&2035. The gross area for stage 2 was 50,698 Dunum. The extensions proposed in the south of Gaza City and South of Deir Al Balah City.

The total net area is estimated for 2025 by 33,000 dunum distributed as 15,300 Olives with 46.4% from the area. The second crop is the Citrus with 10,200 dunum that represent 30.9% from the area. The Grapes are the third crops with 4,000 dunum which represent 12.1%. Finally, the Date Palms will be planted on 3,500 dunum with 10.6% from the area. Figure (5.16) shows the proposed area and the distribution of crops. It is bounded from road # 4 in the west, the green line from the east.

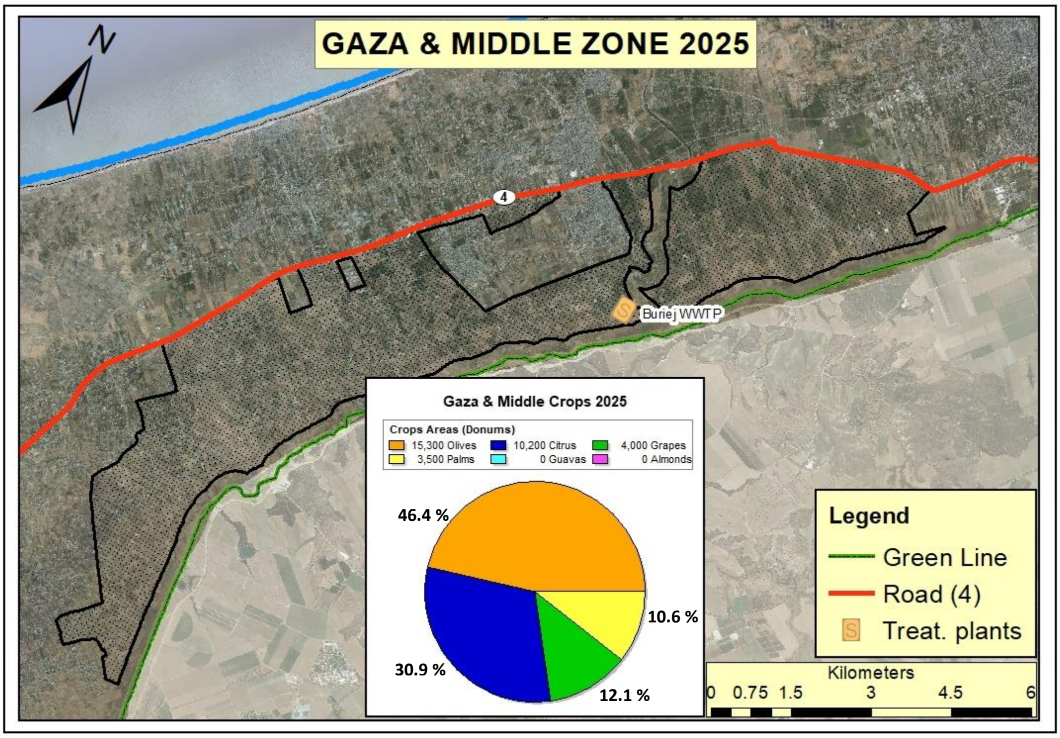


Figure 5.16: Distribution of crops in Gaza & Middle zone - 2025

Due to the big need for the Olives. They still keep their percent's in the first and new areas were added in each period. The distribution for 38,000 dunum that targeted in

2030 was as 17,600 Olives with 46.3%, Citrus with 12,400 dunum that represent 30.9% from the area. The Grapes were still as 2025 with 4,000 dunum which will represent 10.5%. Finally, the Date Palms will be increased to 4,000 dunum with 10.5% from the area. Figure (5.17) shows the proposed area and the distribution of crops for 2030.

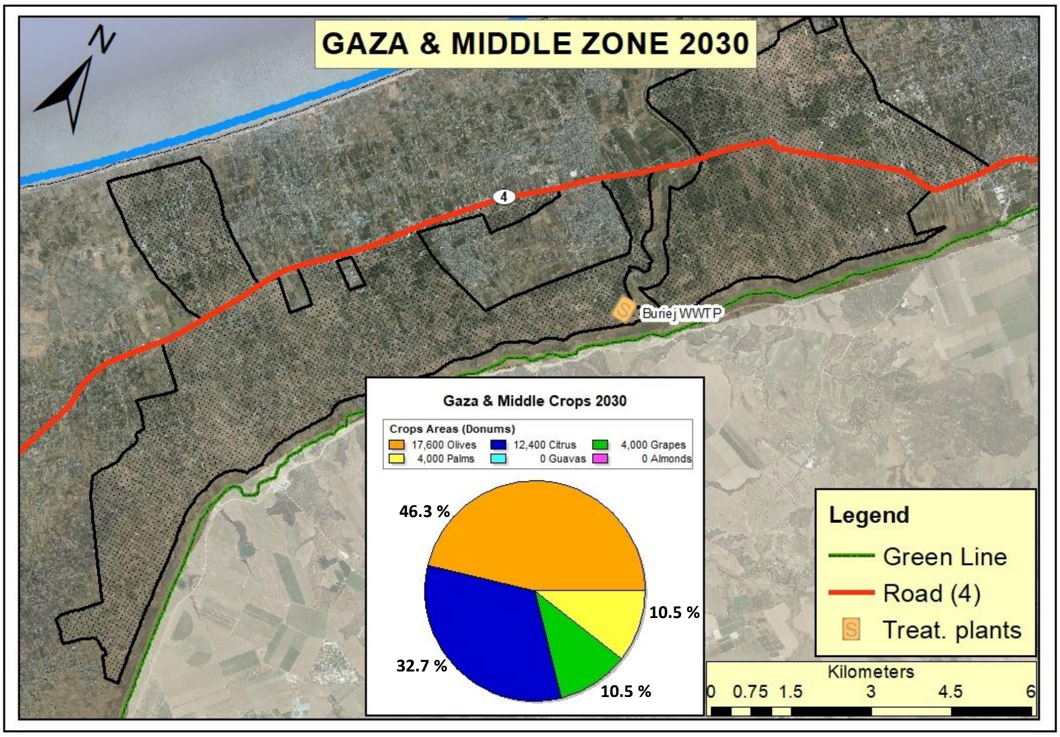


Figure 5.17: Distribution of crops in Gaza & Middle zone - 2030

A new 6,000 dunum is needed to reach 44,000 dunum in 2035 distributed as 20,400 Olives with 46.3%, Citrus with 13,100 dunum that represent 29.8% from the area. The Date Palms will be 5,400 dunum which will represent 12.3%. The Grapes will be 4,200 dunum which will represent 9.6%. Finally, the Almonds will be added with small areas estimated by 900 dunum with 2% from the area. Figure (5.18) shows the proposed area and the distribution of crops for 2035.

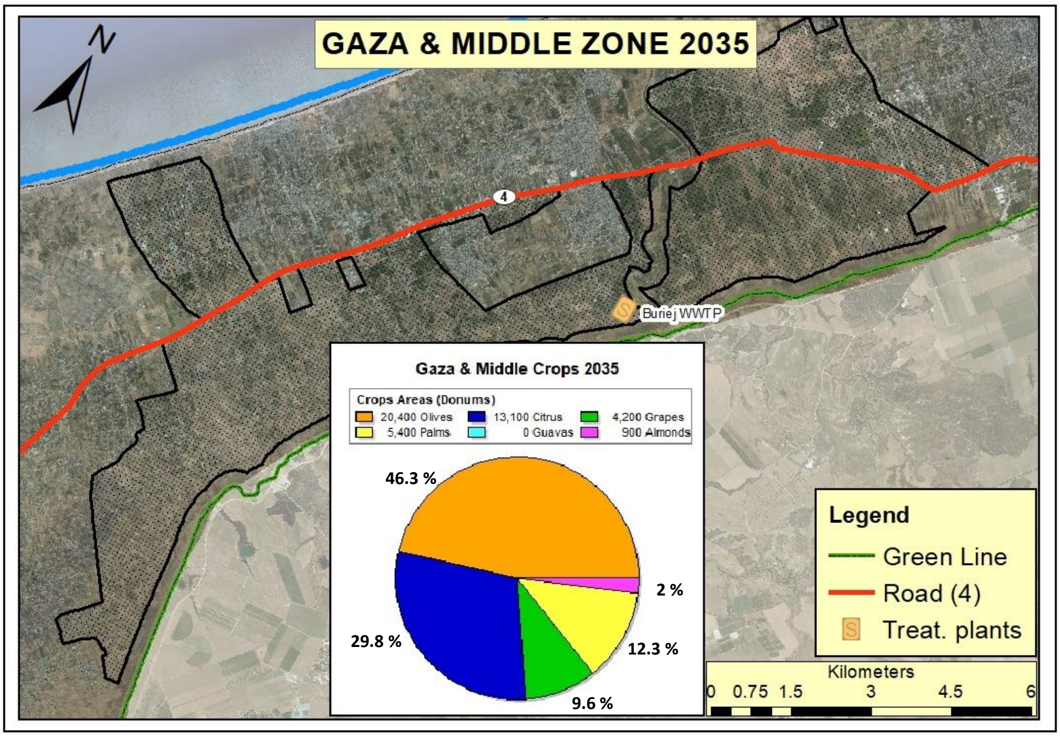


Figure 5.18: Distribution of crops in Gaza & Middle zone - 2035

5.4.4.3 South Gaza Zone

The proposed area was located in the eastern parts of Khan Younis and Rafah Governorates. For stage 1, the gross area is around 26,046 Dunum. The extensions for stage 2 reached 44,247 dunum as a gross area which is located in the west of road # 4 and in the area between Rafah and Khan Younis cities. The area was famous with planting the Olives, Guava, Almonds and Date Palms.

Figure (5.19) shows the proposed area and the distribution of crops for 2025. The total net area was 23,000 dunum and was distributed as 10,700 Olives with 46.5%, Date Palms with 4,200 dunum that represent 18.3% from the area. The Almonds will be 3,600 dunum which will represent 15.6%. The Guava will be 3,100 dunum which will represent 13.5%.

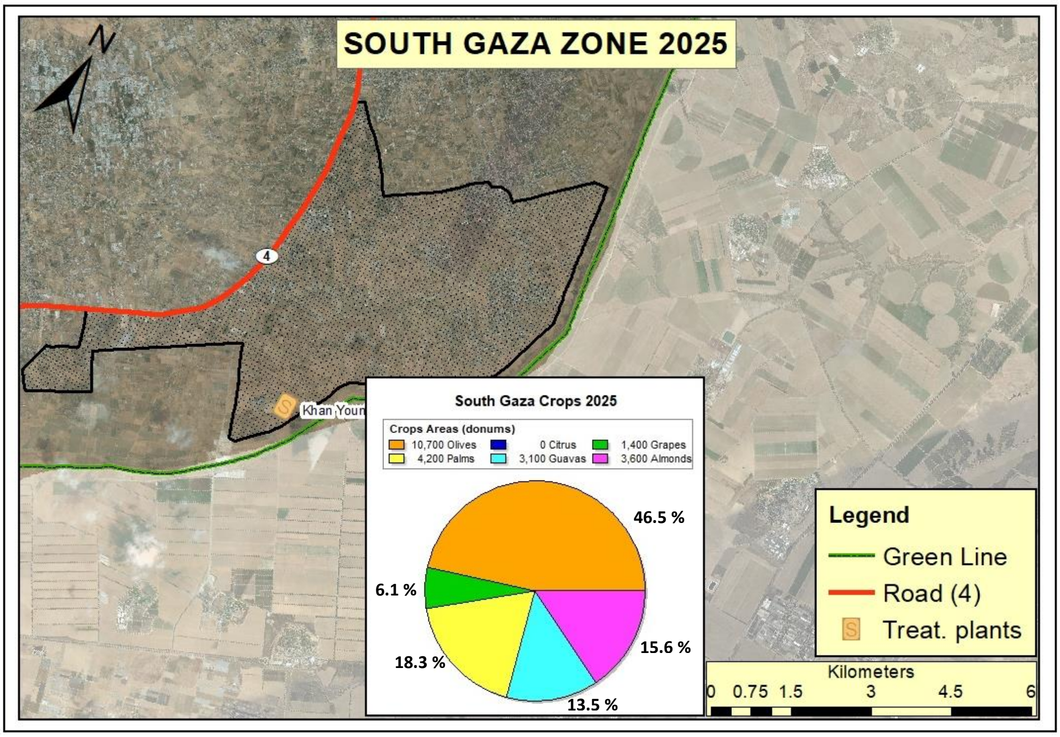


Figure 5.19: Distribution of crops in South Gaza zone - 2025

For the year 2030, the net area is around 33,000 Dunum. Figure (5.20) shows the proposed area and the distribution of crops. The distributed as 15,400 Olives with 46.7%, Date Palms with 5,200 dunum that represent 15.8% from the area. The Almonds will be 4,900 dunum which will represent 14.8%. The Grapes will be 2,600 dunum which will represent 7.9%. Finally, the Citrus will be added with small areas estimated by 800 dunum with 2.4% from the area.

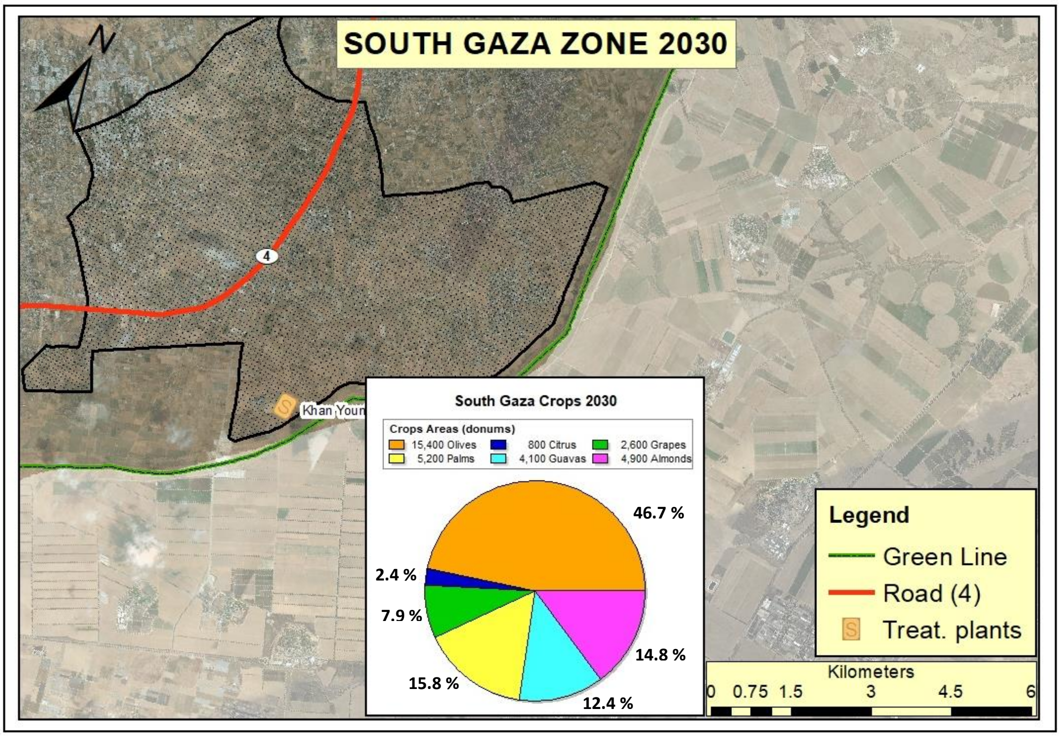


Figure 5.20: Distribution of crops in South Gaza zone - 2030

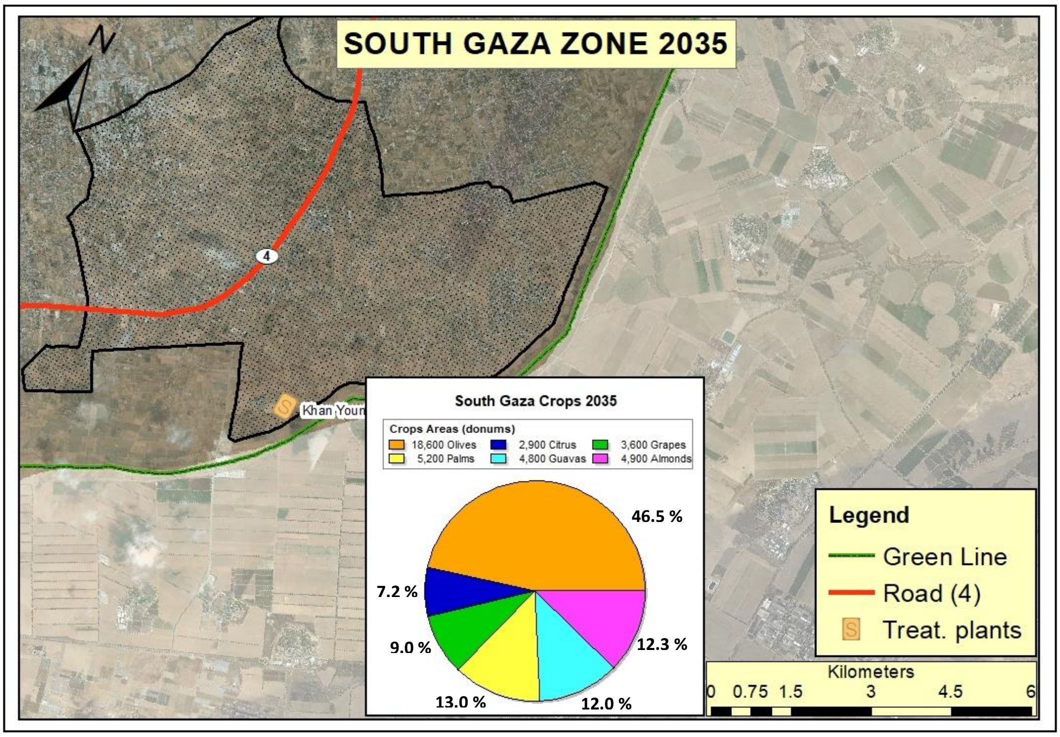


Figure 5.21: Distribution of crops in South Gaza zone - 2035

For the year 2035, a new 7,000 dunum were needed to reach 40,000 dunum and were distributed as 18,600 Olives with 46.5%. No new areas for planting the Date Palms and

Almonds needs were needed and the percentages will be 13% and 12.3% from the area, respectively. The Grapes will be 3,600 dunum which will represent 9 %. Finally, the Citrus will be 2,900 dunum with 7.2 % from the area. Figure (5.21) shows the proposed area and the distribution of crops for 2035.

5.4.5 Identifying the Water Consumption

In this section, the treated wastewater consumptions in this distribution from the three sources were estimated.

5.4.5.1 North Gaza Zone

The north governorate is served by NGEST from the start of 2018 with start capacity equals 35,600 m3/d. According to the estimation of wastewater quantities in section 5.2.2, the plant will be ability until 2023. So, the second stage should be started soon to reach the full capacity of 69,000 m3/d. The researcher considered that the upgrade will be executed and the increase in wastewater quantities will be available for irrigation for 2025. Fig(5.22) shows the available treated wastewater and the consumed quantities.

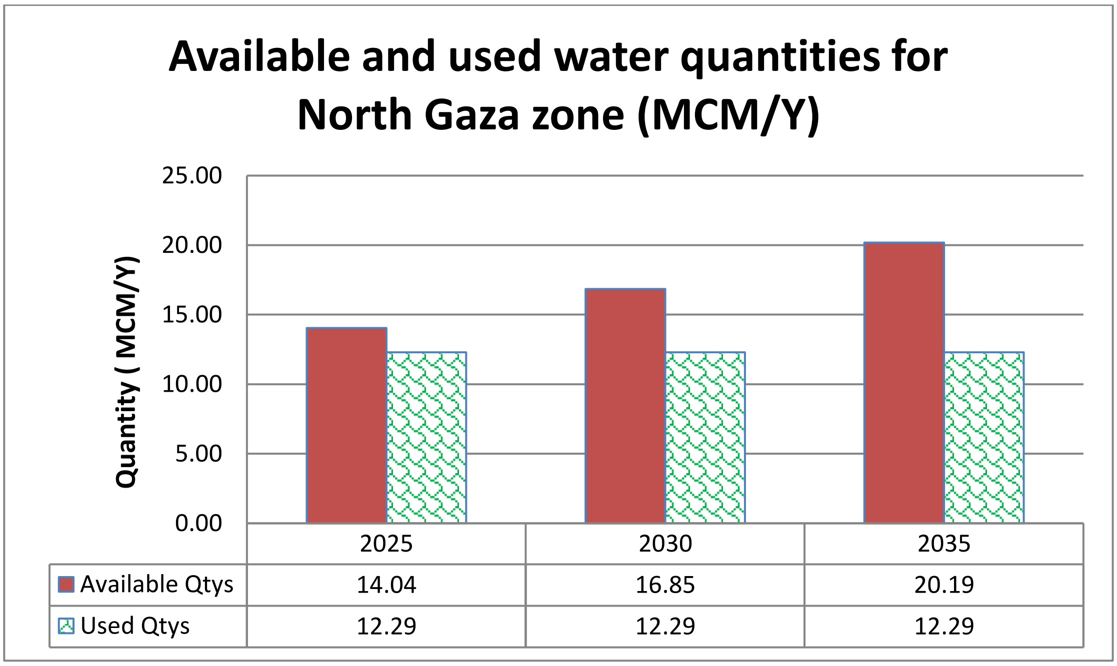
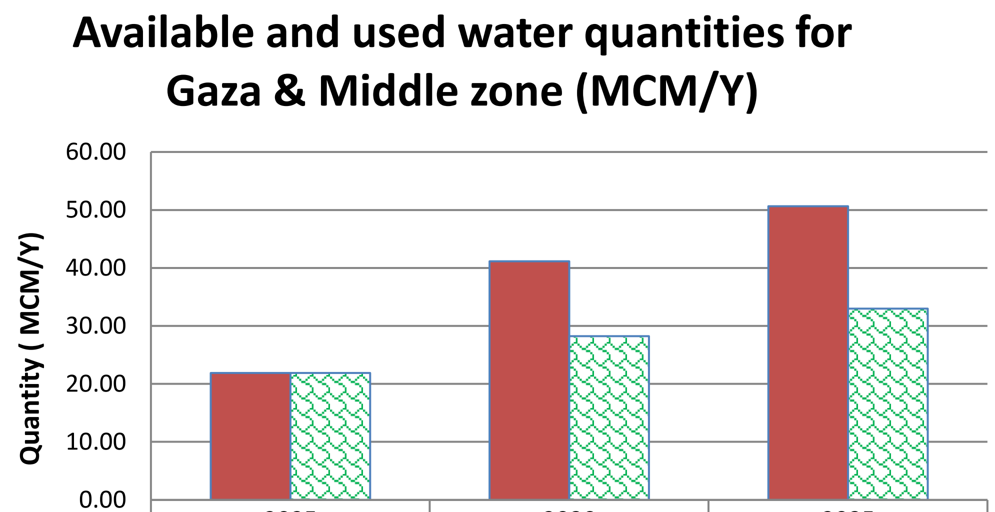


Figure 5.22: Available and used water quantities for the North Gaza zone

From the figure and due to the limited agricultural areas in North Gaza zone, there are surplus quantities in all target years. The percentages of the used quantities from the available represent 87.5%, 72.9% & 60.9% for years 2025, 2030 & 2035, respectively.

5.4.5.2 Gaza & Middle Zone

According to the CMWU, BWWTP will be in a start capacity reached 60,000 m^3/d by 2019 and will be served the Middle Governorate and the remaining from Gaza City. According to the CMWU, GWWTP will be out of service by 2025. So, the second stage should be started to reach the capacity of 120,000 m3/d & 140,000 m3/d by years 2030 and 2035, respectively. Fig(5.23) shows the available treated wastewater and the consumed quantities.



	2025	2030	2035
Available Qtys	21.90	41.14	50.66
Used Qtys	21.90	28.22	32.97

Figure 5.23: Available and used water quantities for Gaza & Middle zone

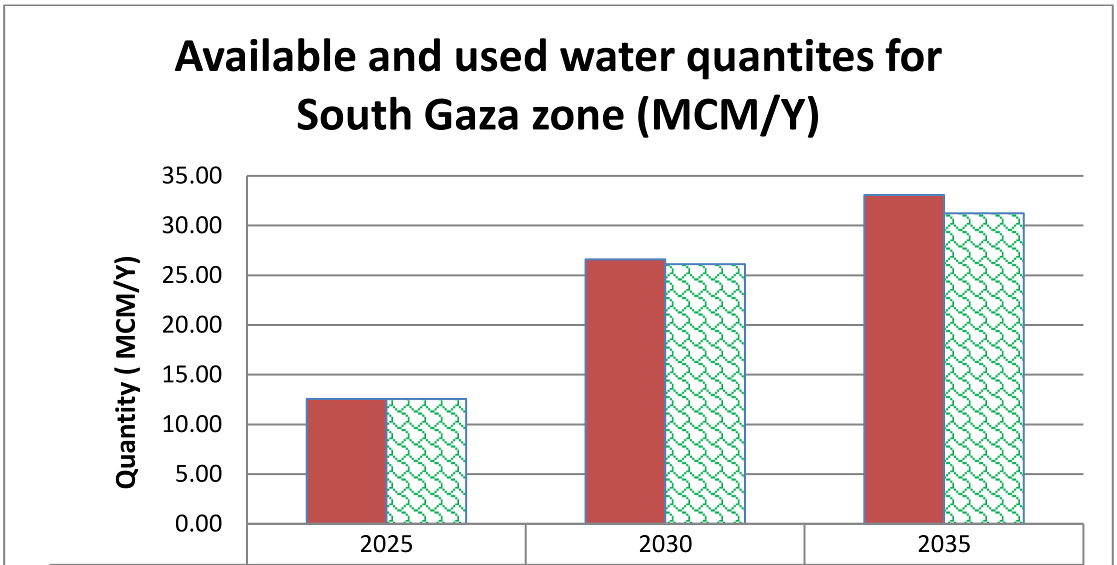
From the figure, there is full use of quantities in 2025, and according to the needs, there is a shortage of 2.53 MCM by 2025. While there are surplus quantities for years 2030 & 2035 with percentages usage from the availability equal of 68.6% & 65.1 %, respectively.

From the view of the researcher, the implementation of the study results will be gradually and no need to supply the shortage of quantities.

5.4.5.3 South Gaza Zone

As wastewater sector planners, KhWWTP will serve Khan Yonis Governorate only up to 2025 and will Rafah will be added after that. The plant will be started by 2019 with initial capacity 26,000 m3/d. So the upgrade should be starting soon to accommodate Khan Younis wastewater up to 2025 and both Khan Younis and Rafah after that which will be assumed in the research.

Fig(5.24) shows that there is full use of quantities in 2025, and according to the needs, there is a shortage of 5.96 MCM by 2025. For the year 2030, there is a usage for most quantities with 98.2% from the available. While there is a minor surplus quantity for 2035 with percentages usage from the availability equal of 94.4%.



	2025	2030	2035
Available Qtys	12.57	26.61	33.08
Used Qtys	12.57	26.13	31.24

Figure 5.24: Available and used water quantities for South Gaza zone

From the view of the researcher, the implementation of the study results will be gradually and no need to supply the shortage of quantities.

Chapter 6
Conclusions and Recommendations

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Conclusions and Recommendations

6.1 Conclusions

The conclusions include:

- The study reviews the water and wastewater sectors and explores the planned improvements.
- The actual quantities of collected wastewater exceeded the expected that resulted from the water consumption quantitates. In other means, there are unfamiliar quantities arrived the wastewater networks. This is a result of the uncontrolled water sources.
- The study shows potential improvements for the treated wastewater in the light of seawater desalination and the presence of regional WWTPs.
- The study shows potential significant improvements for the treated wastewater salinity, which make the ability to plant sensitive salinity horticultural crops.
- The future wastewater quantities were estimated for all areas. It is mentioned to say that the quantities will increase in an accelerated manner and the expansions for the treatment plants will be compatible with this increase.
- The agricultural needs from the horticultural crops were estimated.
- To achieve the self-sufficiency from the horticultural cops, the study proposed gross areas around 81,481 and 113,894 Dunums with 46.9% as phase one and 65.6% as phase two from the agricultural areas for 2025 and for years 2030 & 2035, respectively. While the remaining for the other agricultural purposes.
- The distribution was made according to areas renowned for the targeted crops. And then according to the availability of agricultural areas and treated wastewater. To meet the crops needs, the net cultivated areas will be 76,545 & 87,878 & 100,890 dunums for years 2025, 2030 & 2035 , respectively .
- The treated effluents will be used by 96.4%, 78.77 % and 73.71% from the produced treated wastewater for the years 2025, 2030 and 2035, respectively.

6.2 Recommendations

- Called the related authorities upon to take the actions to reserve the agricultural lands without changes.
- Study the ability to irrigated new crops including the non-restricted irrigation crops with the remaining treated wastewater quantities.
- Study the water seasonal consumptions for crops and determine the peak water consumption.
- Study the expected contents of boron in the treated effluents resulted from the domestic seawater desalination projects and identifying the additional treatment units for boron removal where needed.
- Study the effect of improved domestic water quality on the farmers' water consumption behavior.
- Evaluate the effect of improved water supply on soil and plant yield.
- Awareness program should be executed for the farmers concerning the irrigation with the treated effluents. In addition, motivations actions may be applied for the landowner in the targeted areas.
- Controlling the industrial wastewater quality to prevent any degradation in the wastewater treatment.

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Annexes

Annex 1-a

Guidelines for the safe use of wastewater in agriculture [a]

Category	Reuse conditions	Exposed group	Intestinal nematode[b] (arithmetic mean no. eggs per litre)[c]	Faecal coliforms (geometric mean no. per 100ml)[c]	Wastewater treatment expected to achieve the required microbiological guideline
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[d]	Workers, consumers, public	≤ 1	≤ 1000	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[e]	Workers	≤1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and faecal coliform removal
C	Localized irrigation of crops in category B if exposure to workers and the public does not occur	None	Not applicable	Not applicable	Pretreatment as required by irrigation technology, but not less than primary sedimentation

a In specific cases, local epidemiological, socio-cultural and environmental factors should be taken into account and the guidelines modified accordingly.

b Ascaris and Trichuris species and hookworms.

c During the irrigation period.

d A more stringent guideline (200 faecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may cone into direct contact.

e In the case of fruit trees, irrigation should cease two weeks before fruit is picket, and no fruit should be picked off the ground. Sprinkler irrigation should be used.

Annex 1-b
Palestinian standards for reuse of treated wastewater

'Standards for reuse of treated wastewater – EQA, 2014'

Quality Parameter (mg/l except otherwise indicated)	Seawater Outfall	Recharging the aquifer by filtration	Industrial crops, Grains, Landscape	Fodder Irrigation		Gardens, Playgrounds, Recreational	Trees	
				dry	Wet		Citrus & Almonds	Olives
BOD_5	40	20	60	60	45	40	45	45
COD	100	50	120	120	90	80	90	90
DO	> 1	> 2	> 0.5	> 0.5	> 0.5	> 0.5	> 0.5	> 0.5
TDS	–	1000	1500	1200	1200	1500	1000	1500
TSS	60	50	50	50	40	30	40	40
pH	9-6	7.5-6	5.5−7.5	7.5-5.5	7.5-5.5	7.5-5.5	7.5-5.5	7.5-5.5
Color (PCU)	Free	Free	Free	Free	Free	Free	Free	Free
Fat Oil &Grease	8	0	5	5	5	5	5	5
Phenol	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
MBAS	25	5	15	15	15	15	15	15
NO_3	45	30	50	50	50	50	50	50
Total kjedahl Nitrogen(TKN)	50	25	100	100	100	45	100	100
P -PO_4	10	15	30	30	30	30	30	30
Cl^-	-	350	500	500	500	500	400	600
SO_4	300	300	500	500	500	500	500	500
Na	-	200	200	200	200	200	200	200
Mg	-	60	60	60	60	60	60	60
Ca	-	200	400	400	400	400	400	400
SAR	6	6	9	9	9	10	9	9
Al	2	2	5	5	5	5	5	5
As	0.05	0.05	0.1	0.1	0.1	0.1	0.1	0.1
Cu	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Fe	5	5	5	5	5	5	5	5
Mn	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Ni	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Quality Parameter (mg/l except otherwise indicated)	Seawater Outfall	Recharging the aquifer by filtration	Industrial crops, Grains, Landscape	Fodder Irrigation		Gardens, Playgrounds, Recreational	Trees	
				dry	Wet		Citrus & Almonds	Olives
Pb	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Se	0.02	0.05	0.02	0.02	0.02	0.02	0.02	0.02
Cd	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Zn	5	5	2	2	2	2	2	2
CN	0.1	0.1	0.05	0.05	0.05	0.05	0.05	0.05
Cr	0.02	0.05	0.1	0.1	0.1	0.1	0.1	0.1
Hg	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Co	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
B	1	1	2	2	2	2	2	2
Faecal Coliform (CFU/100ml)	500	200	200	200	200	200	200	200
E.coli (CFU/100ml)	Free	Free	Free	Free	Free	Free	Free	Free
Pathogens	Free	Free	Free	Free	Free	Free	Free	Free
الأميبا و الجارديا (Cyst/L)	Free	Free	Free	Free	Free	Free	Free	Free
الديدان الحلقية النيماتودا (Eggs/L)	<1	<1	<1	<1	<1	<1	<1	<1

Annex 2
Water consumption, UFW, and coverage of wastewater networks for all municipalities

" Water Sector Regulatory Council (WSRC) "

Area	S.N	Municpility	Popoulation (2017)	Counsumption l/c/d	UFW %	Average consumption l/c/d	Average UFW %	Coverage of wastewater network (%)	Average Coverage of wastewater network (%)
North Gaza	1	Um Al-Nnaser أم النصر	4,737	112	23%	102.29	37.94%	77%	91.48%
	2	Beit Hanun بيت حَانُون	52,237	122	45%			82%	
	3	Beit Lahiya بيت لاهْيا	89,838	96	32%			94%	
	4	Jabalya جَبَاليا	222,166	100	39%			93%	
Gaza	5	Gaza غزّة	631,215	92	35%	92.00	35.00%	89%	89.00%
Middle	6	Juhor ad Dik جُحْر الدِيك	4,586	56	32%	87.34	36.89%	0%	83.74%
	7	Al Mughraqa المُغْراقَه	11,458	60	60%			82%	
	8	Madinat Ezahra مدينة الزهراء	5,338	169	26%			84%	
	9	An Nuseirat النُصَيْرات	86,598	93	36%			81%	
	10	Al Bureij البُرَيْج	43,515	85	31%			93%	
	11	Al Maghazi المَغَازِي	27,827	86	41%			93%	
	12	Az Zawayda الزَوايْدَة	23,841	100	25%			93%	
	13	Deir al Balah دِير البَلَح	82,117	80	40%			89%	
	14	Al Musaddar المُصَدَّر	2,587	131	58%			41%	
	15	Wadi as Salqa وادِي السَلْقَا	6,715	66	38%			0%	
Khan Younis	16	Al Qarara القَرَارَة	29,004	94	35%	86.40	27.82%	0%	56.74%
	17	Khan Yunis خانيونس	246,307	82	27%			80%	
	18	Bani Suheila بَنِي سُهيلا	41,439	90	33%			32%	
	19	A'basan al Jadida عَبَسَان الجَدِيدَة	9,290	104	20%			0%	
	20	A'basan al Kabira عَبَسَان الكَبِيرَة	26,767	88	27%			0%	
	21	Khuza'a خُزَاعَة	11,388	121	16%			0%	
	22	Al Fukhkhari الفُخَّارِي	6,443	104	29%			0%	
Rafah	23	Al-Nnaser النصر	8,984	118	20%	79.87	31.47%	0%	84.15%
	24	Al Shokat الشَوكَة	16,445	70	31%			18%	
	25	Rafah رَفَح	208,449	79	32%			93%	

Annex 3
Intermediate Wastewater Treatment Plants Test Results
" Environmental Record (EQA,2017) "

Beit Lahia WWTP

Date	Influent				Effluent			
	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TDS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TDS (mg/l)
22/01/2017	480	1050	530	N.A	75	165	65	N.A
19/02/2017	340	800	365	N.A	80	180	70	N.A
05/03/2017	400	900	435	1762	100	425	70	1450
02/04/2017	380	822	410	N.A	85	185	55	N.A
14/05/2017	440	1050	345	N.A	150	345	85	N.A
18/06/2017	325	730	765	N.A	120	275	85	N.A
16/07/2017	420	925	445	N.A	120	260	85	N.A
20/08/2017	400	870	425	N.A	145	325	110	N.A
17/09/2017	350	805	380	N.A	100	235	75	N.A
15/10/2017	440	1000	480	N.A	100	240	80	N.A
12/11/2017	445	1000	490	N.A	90	225	70	N.A
24/12/2017	380	800	420	1732	80	200	60	1606
Average	400	896	458	1747	104	255	76	1528

Gaza WWTP

Date	Influent				Effluent			
	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TDS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TDS (mg/l)
10/08/2016	480	1056	240	3896	250	600	125	2908
17/10/2016	475	1045	208	2896	245	588	80	2692
19/03/2017	490	1078	228	N.A	150	360	120	N.A
09/04/2017	620	1364	N.A	2131	330	792	N.A	2163
Average	516	1136	225	2974	244	585	108	2588

Rafah WWTP

Date	Influent				Effluent			
	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TDS (mg/l)	BOD (mg/l)	COD (mg/l)	TSS (mg/l)	TDS (mg/l)
24/01/2017	580	1250	610	3603	120	300	100	3238
21/02/2017	600	1320	640	2496	145	335	110	2150
21/3/2017	580	1235	655	2694	110	270	85	3056
19/4/2017	550	1220	580	3097	240	500	150	3072
23/05/2017	600	1345	765	2176	155	355	145	2803
20/06/2017	540	1180	575	1920	185	410	105	3168
18/07/2017	600	1250	635	2905	190	425	125	3116
22/08/2017	600	1350	640	2976	160	335	115	3027
18/09/2017	505	1110	550	2924	150	320	110	3078
17/10/2017	700	1420	755	3027	220	450	140	3059
21/11/2017	480	1120	525	2924	175	390	160	3104
12/12/2017	560	1260	605	2745	175	400	135	2745
Average	575	1255	628	2791	169	374	123	2968

Annex 4
Calculating the expected future salinity for the water supply

- **Beit Hanoun Municipality:**

Reservoirs Names	Wells names	ID	Measured TDS Con. (mg/l)									Expected TDS Con. (mg/l)		
			2009	2010	2011	2012	2013	2014	2015	2016	2017	2025	2030	2035
ST-26 Reservoir	بئر الصناعية	C/76	1432	1414	*N.A*	1277	1246	1271	1241	1240	1123	890.825	724.8	558.8
	بئر الاوقاف	C/79A	1432	1469	*N.A*	1488	1643	1705	1705	1693	1612	1982.35	2147	2312
	بئر العزبة	C/127 A	542.5	554	*N.A*	563	616	619	606	563	562	624.98	644.5	664
	بئر الندي	C/137	469	477	*N.A*	459	423	*N.A*	429	425	490	425.813	414.3	402.8
	بئر الشوا	C/52	*N.A*	*N.A*	*N.A*	*N.A*	*N.A*	1469	*N.A*	1244	1488	1300.93	1248	1194
	بئر أم النصر الرئيسي	A-210	235	292	*N.A*	295	319	301	353	*N.A*	454	577.25	681.9	786.6
Avg. for ST-26												967.024	976.8	986.5
C-155 Reservoir	بئر ابو غزالة	C/128	819	861	*N.A*	878	880	903	900	869	887	937.708	963.7	989.8
	بئر خديجة	C/155 A	1004	1066	*N.A*	1252	1143	1180	1173	1119	1146	1301.08	1372	1444
	بئر الصلاح	C/167	*N.A*	*N.A*	*N.A*	1021	1057	1103	1104	1060	1102	1198.83	1258	1317
	بئر عايدة	C/20	992	974	*N.A*	1034	1068	1101	1107	1036	1089	1209.98	1278	1346
Avg. for C-155												1161.9	1218	1274

- **Beit Lahia Municipality:**

Reservoirs Names	Wells names	ID	Measured TDS Con. (mg/l)									Expected TDS Con. (mg/l)		
			2009	2010	2011	2012	2013	2014	2015	2016	2017	2025	2030	2035
BL-T01 Reservoir	بئر الشيخ زايد	A-205	555	571	608	680	691	686	740	706	735	942.25	1059	1175
	بئر المنتزه	A-211	*N.A*	477	468	529	539	596	615	647	688	937.7	1098	1258
	بئر فاطمة العلي	E-176	*N.A*	*N.A*	612	670	673	671	702	659	*N.A*	773	820	867
	بئر الشوا	E-6	567	572	593	619	633	603	642	630	695	771	835	899
Avg. for BL-T01												855.987	952.8	1050
ST-27 Reservoirr	بئر غبن	A-180	727	795	804	846	879	856	898	918	939	1133.58	1251	1369
	بئر المشروع	A-185	735	730	758	820	827	819	898	886	949	1145.93	1280	1413
	بئر السيفا	A-231	*N.A*	*N.A*	*N.A*	*N.A*	632	853	789	667	*N.A*	778.3	798.8	819
	بئر العطاطرة	D/67	430	471	498	534	541	681	492	451	471	555.383	575.3	595
	بئر أصلان	D/84	622	600	637	696	676	658	699	665	671	753.75	793.5	833
	بئر السلاطين الجديد	D/73	*N.A*	485	527	707	1041	1217	1668	1959	2573	Should be closed		
Avg. for ST-27												873.386	939.7	1006

- **<u>Jabalia Municipality:</u>**

Reservoirs Names	Wells names	ID	Measured TDS Con. (mg/l)									Expected TDS Con. (mg/l)		
			2009	2010	2011	2012	2013	2014	2015	2016	2017	2025	2030	2035
Tika Reservoir	بئر الزهور	D-75	615	585	602	671	818	870	952	1094	1099	1684.5	2048	2412
	بئر المروة	D-77	735	862	932	818	913	873	802	813	868	882.2	897.2	912
	بئر الخزان	E-90	*N.A*	1066	1091	1058	1143	1121	1141	1143	1117	1226.2	1276	1327
	بئر العلاوين	Al Alaween	*N.A*	*N.A*	*N.A*	*N.A*	*N.A*	*N.A*	808	837	899	1257.5	1485	1713
Avg. for Tika												1262.6	1427	1591
Q-82 Reservoirr	بئر الوكالة 1	E-11A	664	640	*N.A*	688	693	*N.A*	716	733	740	831.425	888.9	946
	بئر الوكالة 2	E-11C	549	551	*N.A*	539	540	544	556	549	549	550.668	552.2	554
	بئر العمري	E-171	1177	1171	1200	1283	1208	1252	1241	1215	1241	1308.32	1345	1381
	بئر الوكالة 6	E-177	*N.A*	*N.A*	*N.A*	735	732	769	773	785	782	881.275	938.1	995
	بئر الهسي	Q-72	744	728	761	849	792	848	861	857	*N.A*	1052.05	1151	1250
	بئر الزين	Q-82	810	789	825	942	903	931	941	945	949	1141.75	1246	1349
	بئر البوسنة	R-350	*N.A*	986	1049	998	1039	1122	1182	1250	1240	1575.25	1779	1982
	بئر الفاتح	R-351	859	919	909	1008	1037	1064	1116	1151	1165	1502.83	1702	1901
Avg. for Q-82												1105.45	1200	1295

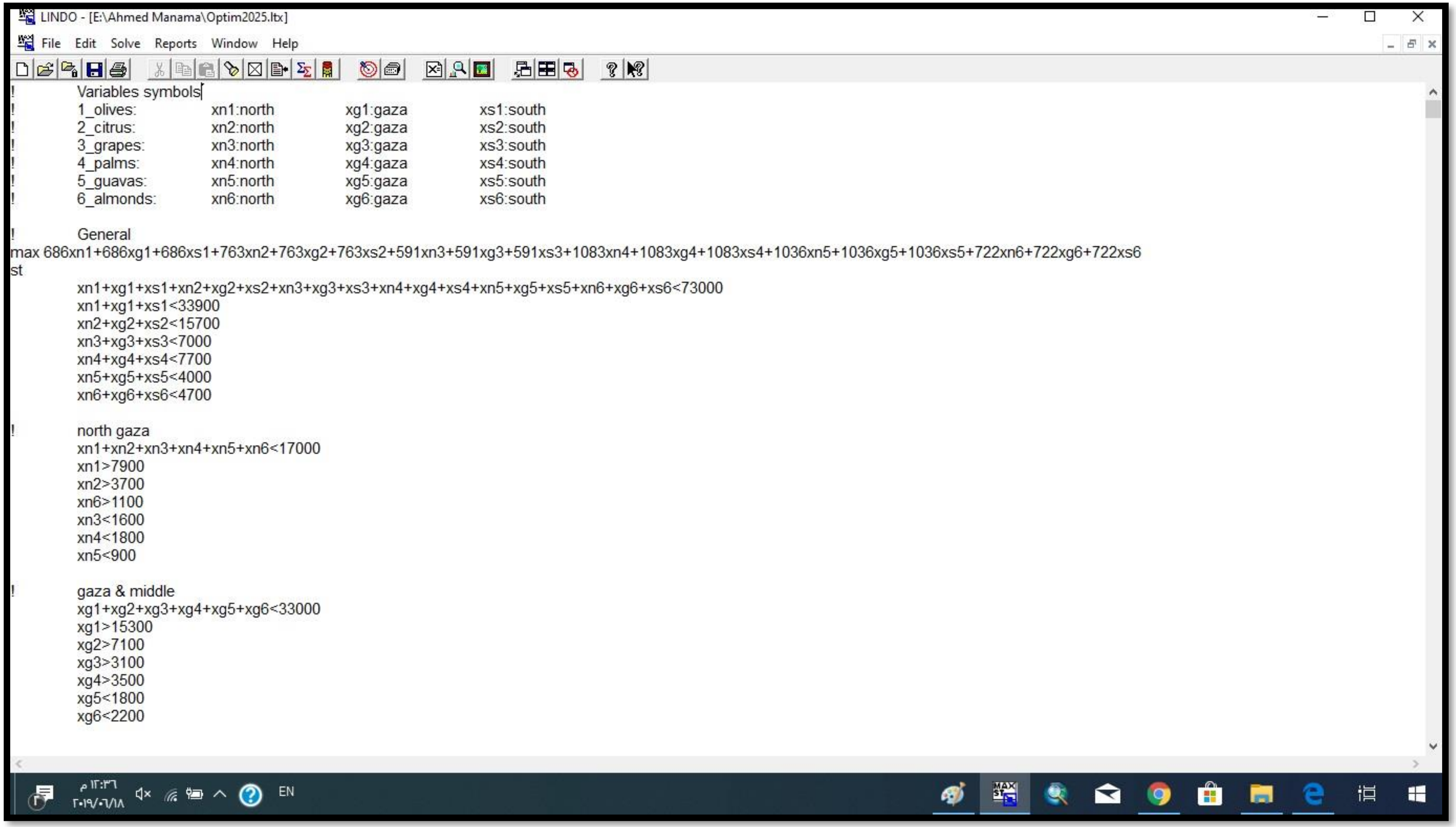
- **Jabalia Municipality: (Cont.)**

Reservoirs Names	Wells names	ID	Measured TDS Con. (mg/l)									Expected TDS Con. (mg/l)		
			2009	2010	2011	2012	2013	2014	2015	2016	2017	2025	2030	2035
ST-23 Reservoirr	بئر أبو شرخ الشرقي	D-2	806	828	782	843	855	864	850	828	846	896.883	923.3	950
	بئر أبو شرخ الغربي	D-60/1	980	911	951	900	739	895	900	848	846	718.325	649	580
	بئر ابو حصيرة	E-1	589	616	629	730	732	790	805	855	860	1176.08	1360	1545
	بئر الوكالة 3	E-11B	673	675	*N.A*	706	775	701	730	737	744	821.207	865.3	909
	بئر أبو طلال	E-156	744	720	736	784	732	792	776	769	831	881.317	929.9	978
	بئر الوكالة 4	E-164	541	516	*N.A*	551	552	487	541	567	575	588.725	609	629
	بئر الوكالة 5	E-168	609	627	*N.A*	719	683	741	763	782	787	988.35	1105	1222
	بئر اريجوني	E-181	*N.A*	*N.A*	*N.A*	780	799	849	806	785	782	805.775	795.1	784
	بئر يافا	E-182	*N.A*	*N.A*	*N.A*	*N.A*	689	688	693	660	689	655.8	641.8	628
	بئر البهتيمي	E-4	610	557	590	645	671	685	664	681	681	811.675	882	952
	بئر الخزان	E-90	*N.A*	1066	1091	1058	1143	1121	1141	1143	1117	1226.2	1276	1327
Avg. for ST-23												870.03	912.5	955

- **<u>Summary for North Governorate:</u>**

Municiplity	Res. ID	Source	Year 2025				Year 2030				Year 2035			
			Quantity (CM/d)	Weighted %	TDS Conc. (mg/l)	Weighted Conc. (mg/l)	Quantity (CM/d)	Weighted %	TDS Conc. (mg/l)	Weighted Conc. (mg/l)	Quantity (CM/d)	Weighted %	TDS Conc. (mg/l)	Weigh Con (mg/
Beit Hanon	ST-26	GCDP	1754	0.40	300	119.08	4207	0.73	300	218.77	4008	0.60	300	178.8
		G.water	2665	0.60	967	583.19	1562	0.27	976.8	264.47	2715	0.40	986.5	398.3
		Total	4419			702.27	5769			483.24	6723			577.
	C-155	GCDP	2146	0.26	300	77.48	8192	0.75	300	223.78	7516	0.57	300	170.4
		G.water	6163	0.74	1162	861.81	2790	0.25	1218	309.46	5713	0.43	1274	550.3
		Total	8309			939.29	10982			533.24	13229			720.7
Beit Lahia	BL-T01	GCDP	2996.5	0.33	300	98.43	8874.3	0.76	300	228.99	8047.8	0.61	300	181.7
		G.water	6136	0.67	856	575.13	2752	0.24	952.8	225.53	5236	0.39	1050	413.7
		Total	9132.5			673.56	11626.3			454.52	13283.8			595.4
	ST-27	GCDP	2949	0.30	300	88.59	11350	0.77	300	231.30	11891	0.64	300	193.0
		G.water	7038	0.70	873.4	615.49	3371	0.23	939.7	215.19	6588	0.36	1006	358.0
		Total	9987			704.07	14721			446.49	18479			551.7
Jabalia	Tika	GCDP	7788	0.56	300	168.73	14372	0.83	300	249.00	13433	0.71	300	212.0
		G.water	6059	0.44	1263	552.47	2944	0.17	1427	242.56	5572	0.29	1591	466.3
		Total	13847			721.20	17316			491.55	19005			678.4
	Q-82	GCDP	4295	0.33	300	100.19	11350	0.77	300	231.30	8502	0.54	300	163.4
		G.water	8565	0.67	1105	736.25	3371	0.23	1200	274.82	7107	0.46	1295	589.5
		Total	12860			836.44	14721			506.13	15609			752.9
	ST-23	GCDP	4	0.00	300	0.08	10392	0.56	300	168.66	5472	0.27	300	80.9
		G.water	14496	1.00	870	869.79	8093	0.44	912.5	399.51	14799	0.73	955	697.
		Total	14500			869.87	18485			568.16	20271			778.
Summary			73054.5			778.10	93620.3	0	0	497.62	106599.8			664.9

Annex 5
'LINDO' Input & Output

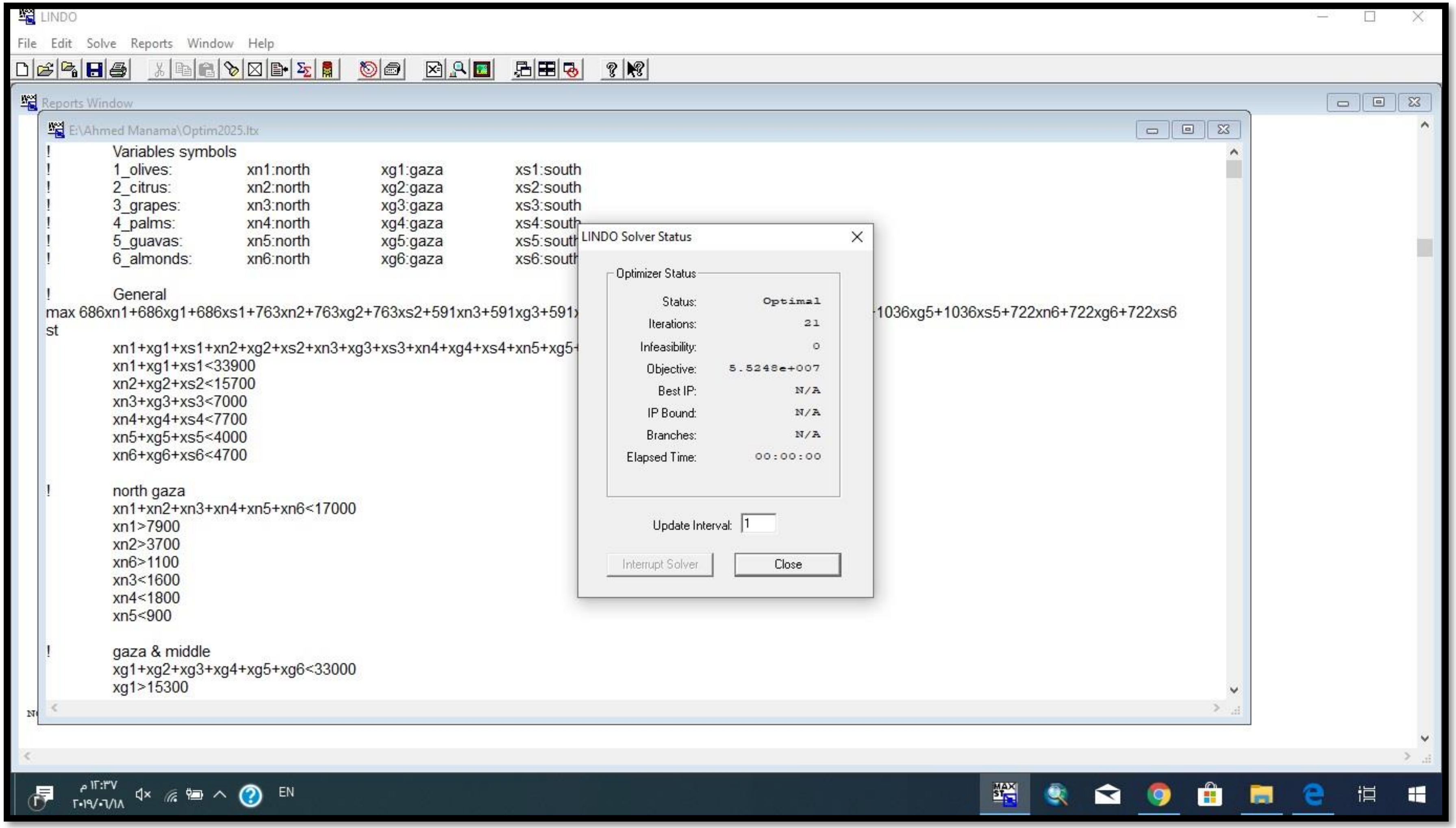


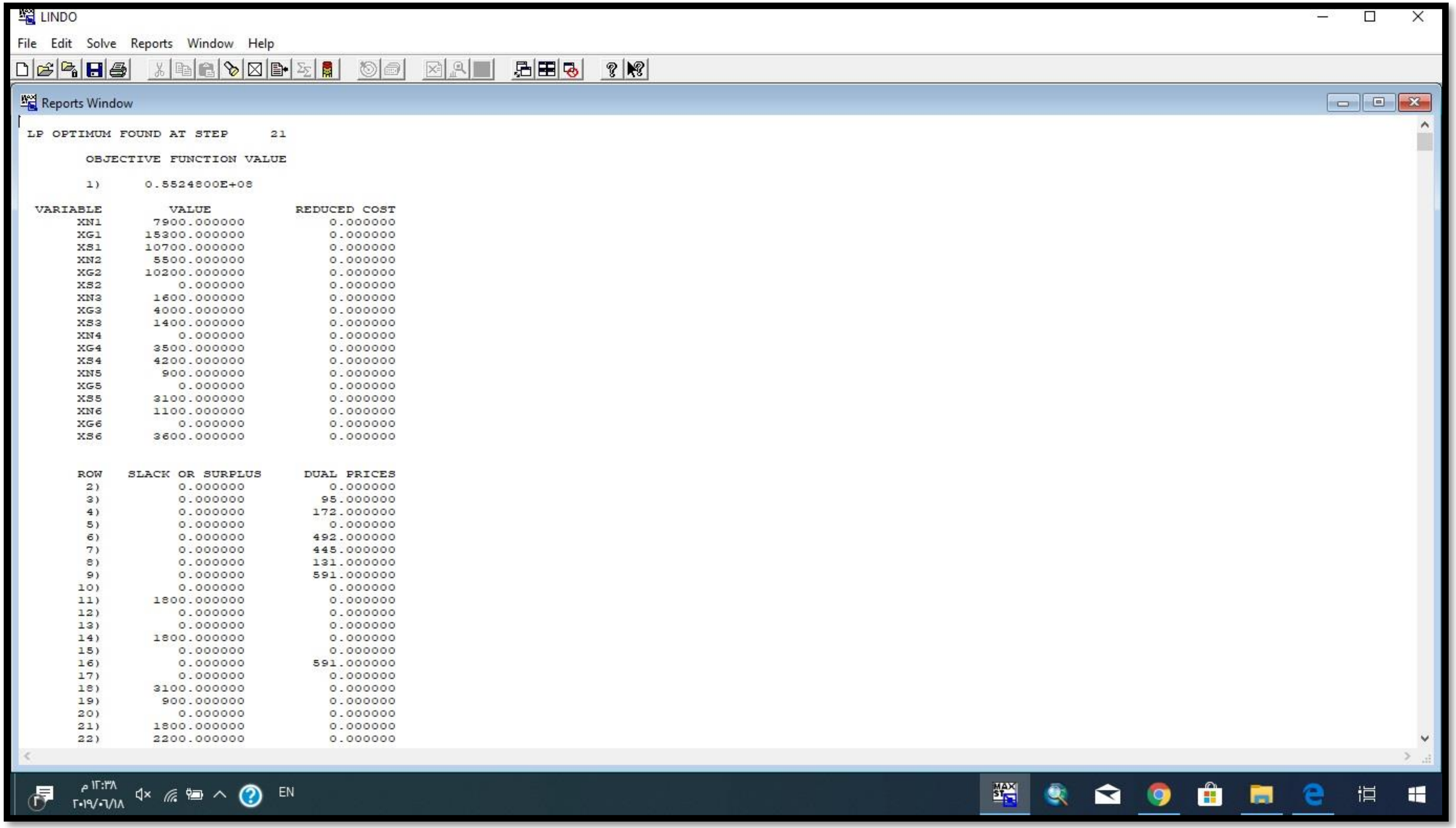

```
!          Variables symbols
!          1_olives:        xn1:north        xg1:gaza        xs1:south
!          2_citrus:        xn2:north        xg2:gaza        xs2:south
!          3_grapes:        xn3:north        xg3:gaza        xs3:south
!          4_palms:         xn4:north        xg4:gaza        xs4:south
!          5_guavas:        xn5:north        xg5:gaza        xs5:south
!          6_almonds:       xn6:north        xg6:gaza        xs6:south

!          General
max 686xn1+686xg1+686xs1+763xn2+763xg2+763xs2+591xn3+591xg3+591xs3+1083xn4+1083xg4+1083xs4+1036xn5+1036xg5+1036xs5+722xn6+722xg6+722xs6
st
           xn1+xg1+xs1+xn2+xg2+xs2+xn3+xg3+xs3+xn4+xg4+xs4+xn5+xg5+xs5+xn6+xg6+xs6<73000
           xn1+xg1+xs1<33900
           xn2+xg2+xs2<15700
           xn3+xg3+xs3<7000
           xn4+xg4+xs4<7700
           xn5+xg5+xs5<4000
           xn6+xg6+xs6<4700

!          north gaza
           xn1+xn2+xn3+xn4+xn5+xn6<17000
           xn1>7900
           xn2>3700
           xn6>1100
           xn3<1600
           xn4<1800
           xn5<900

!          gaza & middle
           xg1+xg2+xg3+xg4+xg5+xg6<33000
           xg1>15300
           xg2>7100
           xg3>3100
           xg4>3500
           xg5<1800
           xg6<2200
```


LINDO
File Edit Solve Reports Window Help
Reports Window
E:\Ahmed Manama\Optim2025.ltx
! Variables symbols
! 1_olives: xn1:north xg1:gaza xs1:south
! 2_citrus: xn2:north xg2:gaza xs2:south
! 3_grapes: xn3:north xg3:gaza xs3:south
! 4_palms: xn4:north xg4:gaza xs4:south
! 5_guavas: xn5:north xg5:gaza xs5:south
! 6_almonds: xn6:north xg6:gaza xs6:south
! General
max 686xn1+686xg1+686xs1+763xn2+763xg2+763xs2+591xn3+591xg3+591x
1036xg5+1036xs5+722xn6+722xg6+722xs6
st
xn1+xg1+xs1+xn2+xg2+xs2+xn3+xg3+xs3+xn4+xg4+xs4+xn5+xg5+
xn1+xg1+xs1<33900
xn2+xg2+xs2<15700
xn3+xg3+xs3<7000
xn4+xg4+xs4<7700
xn5+xg5+xs5<4000
xn6+xg6+xs6<4700
! north gaza
xn1+xn2+xn3+xn4+xn5+xn6<17000
xn1>7900
xn2>3700
xn6>1100
xn3<1600
xn4<1800
xn5<900
! gaza & middle
xg1+xg2+xg3+xg4+xg5+xg6<33000
xg1>15300
LINDO Solver Status
Optimizer Status
Status: Optimal
Iterations: 21
Infeasibility: 0
Objective: 5.5248e+007
Best IP: N/A
IP Bound: N/A
Branches: N/A
Elapsed Time: 00:00:00
Update Interval: 1
Interrupt Solver
Close
EN




```
LP OPTIMUM FOUND AT STEP      21

       OBJECTIVE FUNCTION VALUE

       1)      0.5524800E+08

 VARIABLE        VALUE          REDUCED COST
      XN1      7900.000000          0.000000
      XG1     15300.000000          0.000000
      XS1     10700.000000          0.000000
      XN2      5500.000000          0.000000
      XG2     10200.000000          0.000000
      XS2         0.000000          0.000000
      XN3      1600.000000          0.000000
      XG3      4000.000000          0.000000
      XS3      1400.000000          0.000000
      XN4         0.000000          0.000000
      XG4      3500.000000          0.000000
      XS4      4200.000000          0.000000
      XN5       900.000000          0.000000
      XG5         0.000000          0.000000
      XS5      3100.000000          0.000000
      XN6      1100.000000          0.000000
      XG6         0.000000          0.000000
      XS6      3600.000000          0.000000


      ROW   SLACK OR SURPLUS     DUAL PRICES
       2)         0.000000          0.000000
       3)         0.000000         95.000000
       4)         0.000000        172.000000
       5)         0.000000          0.000000
       6)         0.000000        492.000000
       7)         0.000000        445.000000
       8)         0.000000        131.000000
       9)         0.000000        591.000000
      10)         0.000000          0.000000
      11)      1800.000000          0.000000
      12)         0.000000          0.000000
      13)         0.000000          0.000000
      14)      1800.000000          0.000000
      15)         0.000000          0.000000
      16)         0.000000        591.000000
      17)         0.000000          0.000000
      18)      3100.000000          0.000000
      19)       900.000000          0.000000
      20)         0.000000          0.000000
      21)      1800.000000          0.000000
      22)      2200.000000          0.000000
```