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Assessment and Management of Non-Revenue Water in Gaza City

M.Sc. Thesis By

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إقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Assessment and Management of Non-Revenue Water in Gaza City

تقييم وإدارة المياه الغير محاسب عليها في مدينة غزة

أقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل أو أي جزء منها لم يقدم من قبل الآخرين لنيل درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

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Abstract

Different official parties related to water sector estimate the Gaza water system efficiency, but in the calculation steps remarked absence of a comprehensive water balance structure as International Water Association recommended, many terms not touched like unbilled authorized consumption and physical and commercial losses. Until cooperation between water sector regulator council and Gaza municipality led to building a water balance but many of its components are estimated.

Increasing the water system efficiency is directly related to decreasing non-revenue water, NRW volume is significant enough in order to start a comprehensive assessment and management of the water system of Gaza city.

The water balance top-down approach established by International Water Association is suitable for Gaza water distribution system, the followed methodology starts by reviewing related literatures, then illustrate definitions and make calculation of non-revenue water terms, the data includes system input volume, billed authorized, un-billed authorized, physical loses and commercial loses

It was found that the NRW is about 33.5% of the system input volume and the water losses is 30.8%, this results reflect the gab of the historical calculation and estimation of Gaza system efficiency.

It is recommended to make a regular monitoring of the water balance component and the percentage of NRW also execute the sustainable management plan, to ensure the permanent decreasing of loses and increasing the system efficiency until reaching the break point between investment and losses cost.

Abstract - Arabic

تقوم عدة جهات ذات العلاقة بقطاع المياه بتقدير كفاءة نظام توزيع المياه في مدينة غزة, و لكن لوحظ عدم إعتمادها على تحليل هيكل شامل للميزان المائي كما هو متعارف عليه دوليا و الذي إستحدث في السنوات الأخيرة عن طريق مؤسسة المياه العالمية لتوحيد آليه إحتساب كفائة أنظمة التوزيع في كافة أنحاء العالم, جميع طرق الإحتساب كانت تفتقر لمكونات الميزان المائي وتعتمد فقط على إحتساب إجمالي المياه الغير محاسب عليها من خلال كميات المياه المفوترة مطروحة من إجمالي الإنتاج دون معالجة القيم و دون النظر للمكونات الأخرى للنظام المائي. إستمر ذلك حتى أول تعاون بين بلدية غزة و مجلس تنظيم قطاع المياه و تم إنشاء ميزان مائي للمدينة حسب توصيات مؤسسة المياه العالمية و كانت القيم تعتمد على تخمين لبعض مكونات الميزان المائي في البداية مثل كميات المياه المصرح بها الغير مفوترة و الإستهلاك الغير مصرح به و الفاقد التجاري و الفاقد الفيزيائي لنظام التوزيع.

و كما هو معروف انه كلما قلت كمية المياه الغير محاسب عليها فإن كفاءة نظام التوزيع تزداد، و حاليا كمية المياه الغير محاسب عليها ذات قيمة لحد يجعل من الأهمية البدأ بتقييم و إدارة مكوناتها.

تعد طريقة نظام الميزان المائي التي وضعتها مؤسسة المياه العالمية مناسبة لنظام توزيع المياه في مدينة غزة, و تعتمد منهجية العمل على مراجعة الدراسات السابقة ذات العلاقة و من ثم إستعراض تعريفات مكونات النظام المائي مرورا بإحتساب قيمة البنود المختلفة وفق تصنيفاتها و هي كميات المياه الداخلة للنظام و كميات المياه المصرح بها المفوترة و كميات المياه المصرح بها غير المفوترة و كميات الفاقد التجاري و الفاقد الفيزيائي.

تبين ان كمية المياه الغير محاسب عليها تمثل حوالي 33.5% من كمية المياه الداخلة للنظام و كميات الفاقد الكلي للمياه في النظام حوالي 30.8%, هذه النتائج تظهر ان هناك فجوة في آلية إحتساب كفاءة نظام التوزيع مقارنة مع القيم السابقة.

و يوصى بالمتابعة الدورية لمكونات الميزان المائي و إدارتها بشكل مستدام لتخفيض قيم الفاقد ورفع كفاءة النظام لحين الوصول لأفضل قيمة إقتصادية بين تكاليف الإستثمار في النظام لتقليل الفاقد و المقابل المادي للكميات المفقودة.

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Quran Karim

بسم الله الرحمن الرحيم

" وَمَن يَتَّقِ اللَّهَ يَجْعَل لَّهُ مَخْرَجًا وَيَرْزُقْهُ مِنْ حَيْثُ لَا يَحْتَسِبُ وَمَن يَتَوَكَّلْ عَلَى اللَّهِ فَهُوَ حَسْبُهُ إِنَّ اللَّهَ بَالِغُ أَمْرِهِ قَدْ جَعَلَ اللَّهُ لِكُلِّ شَيْءٍ قَدْراً "

الطلاق: [2 - 3]

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Finally, special thanks to my family, friends, for their support and encouragement which gave me the strength to continue.

Dedication

This thesis is dedicated:

To my mother my spirit for their illimitable support,

To my father my leader in life for his continuously stimulation forward,

To my wife my kind friend for her great understanding and supporting me in work and learn,

To my sister my other half,

To my brother the support,

To my son, Nabil and my daughter, Ragda my two eyes.

To the great martyrs and prisoners who burned themselves to lighten our way.

To all with warm regards

List of Abbreviations

AWWA	**American Water and Wastewater Association**
BABE	**Burst and Background Estimation**
CMWU	**Costal Municipality Water Utility**
FM	**Flow Meter**
HZM	**Hour Zone Measurement**
IWA	**International Water Association**
MNF	**Minimum Night Flow**
SWDP	**Seawater Desalination Plant**
WB	**Water Balance**
PVC	**Polyvinyl Chloride**
PWA	**Palestinian Water Authority**
MOG	**Municipality Of Gaza**
NRW	**Non-Revenue Water**
RWH	**Rain Water Harvesting**
UFW	**Unaccounted for water**
UPVC	**Unplasticized Polyvinyl Chloride**
WW	**Wastewater**

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Chapter 1

Introduction

Chapter 1
Introduction

1.1 Background

Available data for any city water distribution system in the world shows that the system never completely tight, and have an amount of water lost due to several reasons such as pipes material, joints, fittings, workmanship, workable pressure. etc.). difference between amount of water inter the system and amount of authorized consumption called water losses, the water loss volume must fall in an acceptable range, that determined by service provider by balancing the price of lost water and the cost of investment to upgrade networks to decrease the lost volumes, the upgrading process must stop when the investment will cost more than lost volumes prices, this point called "economical point".

Many international associations proposed methods to calculate water lost volumes from distribution systems, but the most use one is the water balance principle using the top-down approach which proposed by IWA, this method focus in calculating non-revenue water which equal the amount of water lost from the system volume adding to it the amount of unbilled authorized consumptions.

In Palestine PWA in its status reports illustrate the distribution system efficiency for main cities in Gaza Strip and West Bank, also the WSRC publish the first report for water service providers performance indicators in 2010, the WSRC in its last report (WSRC, 2017) illustrate the NRW values for many city in Palestine started with west bank like Azaria 47%, Al Shayoukh 12%, Betounia 18%, Jenin 44%, Nablus 30%, Qalqelia 29%, Tolkarem 50%, Beit-lahim 36%, some cities of Gaza strip as Beit-Hanon 45%, Dier-Balah 40%, Khanyounis 27%, Jabalya 43%. Also the report mentioned that the Gaza city NRW value about 35%.

1.2 Problem Statement

In Gaza city the total water supplied to municipal network is about 30.40 Mm^3 in the year 2018 as stated in MOG reports (Water-MoG, 2016) and classified as follow:

- 23.75 Million m^3 from 79 municipal water wells.
- 6.65 Million m^3 from Mekorot water.

Also the (PWA 2017) stated in its report that the system efficiency about 61% in the city, that's mean about 39% of input water consumed as losses, the defined volume of losses significant enough in order to start real assessment of non-revenue water (UNRWA) that starts by defining its components that include different pattern of losses then establishing an effective management plans to save available and future strategic resources as sea water desalination.

Non-revenue water assessment and management in the Gaza City for water distribution system affect the sustainability of the water sector behavior in the city and indirectly the scarcity of fresh water in the aquifer by save the existing and proposed resources.

1.3 Aim of Study

To assess the current situation of non-revenue water then developing a management plan for Gaza City in order to increase water distribution system efficiency and defining non-revenue water components.

1.4 Objectives

1. Identifying the current NRW assessment approaches and management guidelines adopted by Gaza Municipality.
2. Determining the type of losses and categorize it.
3. Comparing different methods for computing each loss category and selecting the most appropriate to calculate the NRW in the distribution system.
4. Preparing a management plan for NRW in order to decrease NRW as possible in a sustained pattern in the future.

1.5 Thesis Structure

This thesis contains the following five chapters:

- Chapter one: contains the introduction that dealt with a general background about the NRW and the effort carried by international association to identify and standardizing the term and some national cities values for NRW, also it dealt with losses problem, the aim of the study, objectives to be achieved.

- Chapter two: titled with literature review describes the water distribution system, NRW assessment methods, also describe water balance term and focus specially on losses, finally it illustrate international values of NRW and some national literatures.
- Chapter three: describes the proposed methodology of the thesis and the proposed structure of the work.
- Chapter four: describe the study area as a geographic location also some data related to water sector like the available sources in the city, and describe the neighborhoods of the city and its characteristics and available consumptions pattern.
- Chapter five: list all results of analyzing data also the final water balance and calculated water system efficiency, finally it finished with a proposed management plan for the current situation.
- Chapter six: recommendation and conclusion focus on important results which concluded and some summarized recommended points.

Chapter 2
Literature Review

Chapter 2
Literature Review

2.1 Introduction

Water distribution systems are one of the most important and costly assets of water service provider utilities that collecting water from different sources then pumping it to end users with acceptable quality and quantity. However, not all water that is put into the distribution system gets to its intended destination due to many types of water losses.

Not all leaks and losses are a product of deteriorated water infrastructure and leaky pipes. Also commercial losses and illegal use of water, joined with a low tariff system or inappropriate metering and billing strategy and policy.

All types of losses can often be reduced by developing a management program, management, and water conservation program deemed to decrease losses and leaks and enhance the water network. these management plans and programs to save and restoring a potentially massive lost resource.

2.2. Characteristics of A Good Distribution System:

- Adequate water pressure at the consumer's connections for a particular rate of flow (i.e., pressures must great enough to sufficiently meet consumer needs).
- Pressures must be great enough sufficiently fit civil defense for firefighting.
- Also, pressures should not be exceeded recommended values too much because a very high-pressure head increases operational cost and increases leakages too.
    - Note: In tall buildings, it is important to provide booster pumps to raise the water to last floors.
- The purity of the distributed water must ensure. This achieved by ensuring that the water distribution system is completely water-tight and no in or out flow from joints.
- Maintenance and repair practices of the water distribution system should be easy, standard and economy.

- Alternative sources and redirection of water to supply customers during breakdown periods of a pipeline are also necessary.
- The distribution system should be designed to be flexible and shouldn’t if one pipe bursts, puts a large area without water. If a specific location of pipe is under repair and has been burst, the water to the population living in the remaining area of this pipeline should be available from another direction.
- During the maintenance process, it should not cause any obstacles to traffic on roads. In other words, the pipelines mustn't install and laid under main roads and highways unless it's the only solution and try to install it under foot paths.

2.3. Assessment Methods of Non-Revenue Water

Non-Revenue Water assessment is the first step towards setting a management plan and an NRW strategy (Kingdom et al., 2006).

The main target of the assessment process is to determine the amount of NRW components in the system (Puust et al., 2010). In the past the assessment process depending on the estimation procedure than the scientific calculated process (Liemberger et al., 2004). Before about ten years ago a large effort started by IWA and another international organization to set new methods and procedures in assess and manage the non-revenue water to improve final results. As noticed by (Vermersch et al., 2008).

(Puust et al., 2010), in their review paper, concluded that “mainly two main methods to determine and asses water losses and leaks;(1) TOP-DOWN approach mainly depending on water balance concept, and (2) BOTTOM-UP approach that depend mainly on 24 Hour Zone Measurement (HZM), or Minimum Night Flow (MNF) analysis

2.3.1. Top-down approach

IWA Water Loss Task Force was the first institution that interfaces a water balance structurer in its nowadays structure as a standard approach to internationally used in NRW calculations (table 2.1-Chapter two). Also, the IWA defines the terms used in the water balance clearly (Farley et al., 2003).

Because its compatibility to different countries water systems in developed and developing countries an international acceptance gained from a lot of utilities all over the world includes the AWWA and World Bank (Taha et al., 2016).

Ranhill and USAID in 2008 sponsored a handbook for NRW assessment and management standards procedures, the handbook illustrates four main steps to constrict a comprehensive water balance:

1. water input volume enters the distribution system.
2. Calculate authorized consumption:
   - Billed authorized consumption: total volume billed by customers to water utility
   - Unbilled authorized consumption: total volume provided with no direct charges to operate some types of public services; (metered and not metered)
3. Commercial losses (apparent):
   - Illegal use of water.
   - Meter inaccuracies issues
   - Data handling errors
4. Physical losses (real):
   - Leaks on different pipes categories (mains or distribution) as bursts
   - Leaks from water tanks
   - Leaks from house connections before customer's meters.

(AO Lambert et al., 2010) guide researchers by concluded that metered unbilled authorized consumption and unmetered unbilled authorized consumption range from 0.5% to 1.25% from the water that input the water system, on the other hand, the commercial loss mainly the unauthorized consumption range from 0.25% to 1% , and it may estimate as utility experience.

(Mutikanga et al., 2011) stated that the meter inaccuracies can be determined depending meters service time and by flow tests of a presentative sample of customers meter, also data handling error can be estimated using a historical billing data in water utilities records for a certain period finally the commercial losses is a sum of its above components.

2.3.2. Bottom-up approach:

Mainly the Bottom-up approach focus in determining the real (physical) losses by using a 24 Hour Zone Measurement analysis or Minimum Night Flow analysis, the MNF used more because HZM will be used implicitly when applying MNF analysis (Puust et al., 2010).

After install a flow meter to a district area the minimum flow recorded is represent the MNF for this area , Minimum Night Flow that determine usually after midnight when major water users are inactive, recommended period to execute the test of MNF range between 02: 00 am and 04: 00 am (Farley et al., 2003).

Minimum Night finally determining the leaks in the MNF period done by subtracting night water consumption from MNF value.

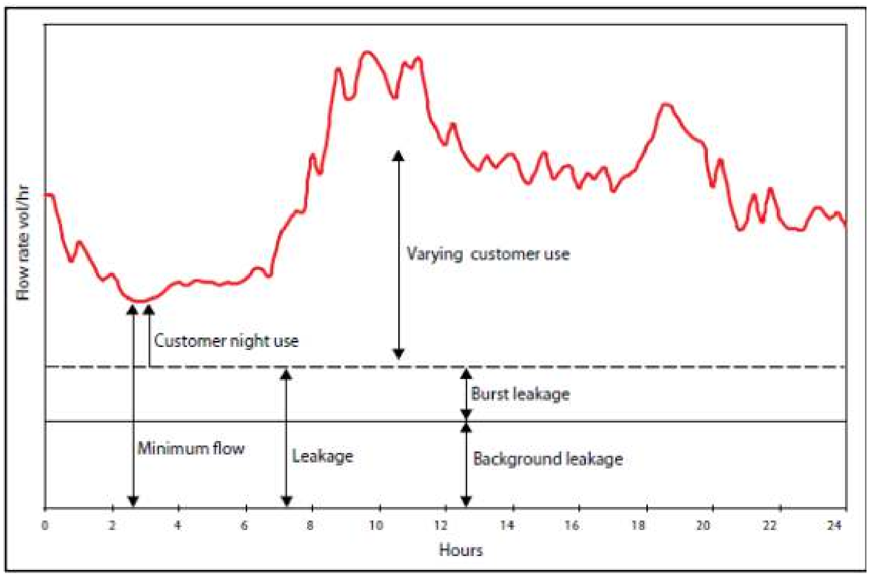


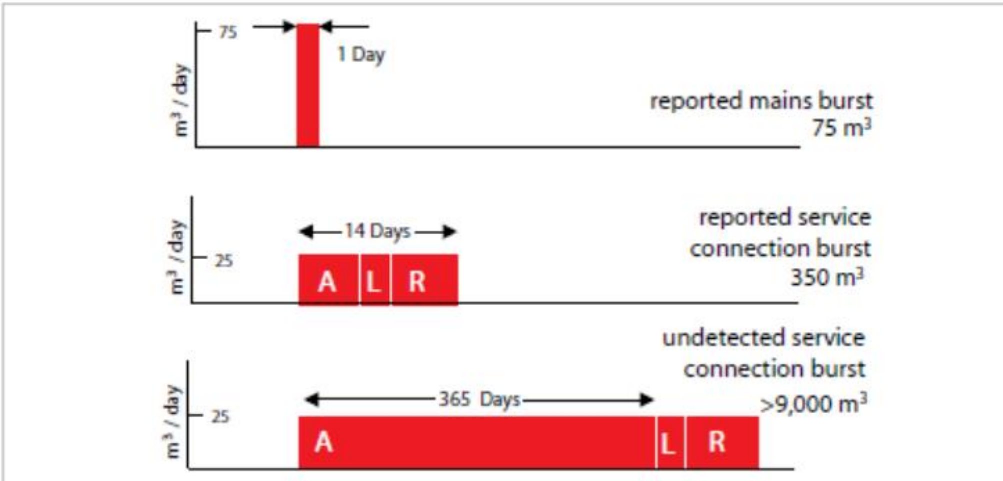
Figure (2.1): Typical 24-hour flow profile indicating MNF.

Source: R.anbill. and USAID

2.3.3. Component base analysis

(Taha et al., 2016) stated that Lambert in the 1990s developed a concept called Burst And Background Estimates (BABE), he describes BABE term as the physical losses that contain leakage and pipe bursts depending on flow rates and average run-times.

Therefore, to conduct such analysis, real losses in the network is categorized into four categories; (1) Background leakage at joints and fittings; (2) Reported leaks and bursts (high flow rates with short duration) (3) Unreported leaks and bursts (moderate flow rates with duration depending on the method of active leakage control) and (4) Hidden loss or excess losses; flow rates too low to be detected by sonic detection devices.



A: Awareness Time; L: Locating Time; R: Repairing Time.

Figure (2.2): Leak run time and volume of water loss

Source: Ranhill and USAID (2008)

2.3.4. Synergetic approach

(Taha et al., 2016) and (Puust et al., 2010) recommended in the literature that combined the two above approaches will increase the accuracy level in asses water losses and NRW and enhance results.

but not in all cases the combination of two approaches can be used because some field issues can stop this procedure.

2.3.5. Establishing water balance

To standardized the results of the NRW assessment, IWA proposed a standard procedure for calculating the water balance, so it can be used by both developed and developing countries and depend on the top-down approach.

Accordingly, WB can be quantified as explained in the following steps (M. Farley et al., 2005).

- Step 1: Determining water input volume enter distribution system.

- Step 2: Calculate authorized consumption:
    1. Billed Metered Consumption
    2. Billed Unmetered Consumption
    3. Unbilled Metered Consumption
    4. Unbilled Unmetered Consumption
- Step 3: Commercial losses (apparent):
    1. Unauthorized Consumption
    2. Customer Metering Inaccuracies and Data Handling Errors
- Step 4 Calculate Physical losses (real):
    1. Leaks on different pipes categories (mains or distribution) as bursts
    2. Leaks from water tanks
    3. Leaks from house connections before customer's meters.
    4. Leaks response time and maintenance can be divided into these stages as follow:
        - awareness,
        - location and
        - repair and estimates will have to be made for each of them.

2.4 Water Balance and Non-Revenue Water

A deep understanding of water system is the first step in building a water balance by calculating and estimating all its components to set priorities which will need urgent intervention. This process helps utility directors to understand the values, sources, and cost of non-revenue water.

A proposed structure of water balance in a comprehensive shape was firstly created by The International Water Association (IWA), this water balance proposed to used internationally as standard between all water utilities in assessment their water system efficiency (Figure 2.2). (M. Farley et al., 2008)

Table (2.1): Water balance components and structure

System input volume	1. Authorized consumption	1.1. Billed Authorized Consumption	1.1.1. Billed Metered Consumption
			1.1.2. Billed Unmetered Consumption

		1.2. Unbilled authorized consumption	1.2.1. Unbilled Metered Consumption
			1.2.2. Unbilled Unmetered Consumption
	2. Water losses	2.1. Commercial losses	2.1.1. Unauthorized Consumption
			2.1.2. Customer meter inaccuracies and data handling errors
		2.2. Physical Losses	2.2.1. Leakage on transmission and distribution mains
			2.2.2. Leakage and overflows from the utility storage tanks

Non-revenue water (UNRWA) is equal to the total volume of water entering the water supply network system from a water sources (the 'System Input Volume') minus the total billed amount of water that residential, commercial, industrial, public places and other types are authorized to use (the 'Authorized Consumption').

NRW = System Input Volume - Billed Authorized Consumption

This equation assumes that:

- System input volume has been corrected for any problems or errors.
- The billed metered consumption period for customer billing records is compatible with the System Input Volume period.

Utility managers should use the water balance to calculate every element and verify wherever water losses are occurring. They'll then priorities and implement the needed and specified policy changes and operational practices. NRW parts cover the whole water utility provide a system from the water treatment plant outlet meters to the client meters, which implies that managing NRW is that the responsibility of the whole operations department. Water utilities usually founded an 'NRW team', with unsatisfying results as everybody else within the company leaves NRW management to the present team. an NRW reduction strategy should embrace all staff with every department's responsibilities outlined in detail. (M. Farley et al., 2008)

Water loss happens in all water systems - only the amounts of loss varies. This relies on the characteristics of the pipe network and different factors, the water company's operational practice, and also the level of technology and experience applied to control it. The amount lost varies wide from country to country, and between regions of every country. The elements of water loss, and their relative significance, also vary between countries. One of the cornerstones of a water loss strategy is therefore to understand the relative significance of each of the elements, guaranteeing that everyone is measured or calculable as accurately as attainable, so priorities are often set via a series of action plans.

The expressions ‘water loss’ and 'non-revenue water' (UNRWA) are currently internationally accepted and have replaced expressions like ‘unaccounted-for water’ (UFW) that are less consistent and which do inter-country comparisons tougher (M. Farley, 2003).

Below descriptions of every component in the IWA reference manual (M. Farley, 2003):

- System Input Volume: is the annual volume input to that amount of the water network convey system.
- Authorized Consumption: is that the annual volume of metered and non-metered water taken by registered customers, the water provider, and others who are implicitly or explicitly authorized to do so (e.g. water used in government offices or fire hydrants). It includes exported water and also the leaks and overflows after the point of consumer flowmeter.
- Non-Revenue Water (UNRWA): is that the distinction between System Input Volume and Billed Authorized Consumption. NRW consists of Unbilled Authorized Consumption (usually a minor part of the water balance) and Water Losses.
- Water Losses: is the difference between System Input Volume and Authorized Consumption. It consists of Commercial Losses and Physical Losses
- Commercial Losses, sometimes referred to as ‘apparent losses’, consist of Unauthorized Consumption and all types of metering inaccuracies
- Physical Losses, also may be referred to ‘real losses’, are the yearly amounts lost through all types of leakage, bursts and overflows on trunks, service reservoirs and house connections, up to the point of consumer flowmeters.

Water loss = water produced – water billed or consumed

It is important to differentiate between water loss and leakage. The International Water Association has defined water loss as:

Water loss = ‘real’ losses + ‘apparent’ losses

The expression ‘real losses’ has replaced the expression ‘physical losses’. ‘Apparent' losses have replaced ‘non-physical’ losses, and ‘management’ losses. Real losses comprise leakage from pipes, joints, and fittings, from leakage through service reservoir floors and walls, and from reservoir overflows. Real losses can be severe and may go undetected for months or even years.

The volume lost will depend largely on the characteristics of the pipe network and the leak detection and repair policy practiced by the company, i.e.;

- the pressure within the network.
- the frequency and typical flow rates of latest leaks and bursts.
- the proportions of latest leaks that are ‘reported’.
- the "awareness" time (how quickly the loss is noticed).
- the “location” time (how quickly every new leak is located).
- the repair time (how quickly it's repaired or shut off).
- the extent of “background” leaks (undetectable tiny leaks).

There is an enormous distinction in volume lost from leaks within the different elements of the distribution network.

Leakage is typically the key part of water loss in developed countries, however this is often not the case in developing or partly developed countries, wherever illegal connections, meter error, or accounting errors are usually additional significant.

As stated in (M. Farley, 2003) : the major point in setting a technique in order to mismanage the NRW is to understand deeply the definition of NRW and its components also all factors that affecting NRW value. Secondly steps and procedures is established to start to calculate the NRW and to related affecting factors and prioritizing it finally a comprehensive plan of solutions can set and priorities to start implementation the proposed management plan

Farley in his study stated that there is some question must have answered before developing a management strategy, this question about the properties of the system and operation technique, and tools proposed to use to solve the faced problems:

- How much water is being lost?
- Where is it being lost from?

- Why is it being lost?
- What strategies can be introduced to reduce losses and improve performance?
- How can we maintain the strategy and sustain the achievements gained?

Table (2.2): Typical questions for developing a management strategy

Question	Task
1. How much water is being lost? - Measure Components	Water balance - Improved estimation/measurement techniques. - Meter calibration policy - Meter checks. - Identify improvements to recording procedures.
2. Where is it being lost from? - Quantify Leakage - Quantify Apparent Losses	Network Audit - Leakage studies (reservoirs, transmission mains, distribution network) - Operational/customer investigations
3. Why is it being lost? - Conduct Network And Operational Audit	Review of network operating practices - Investigate: historical reasons , poor practices, quality management procedures, poor materials/ infrastructure, local/political influences, cultural/social/financial factors.
4. How to improve performance? - Design A Strategy And Action Plans	Upgrading and strategy development - Update records systems - Introduce zoning - Introduce leakage monitoring - Address causes of apparent losses - Initiate leak detection/repair policy - design short/medium/long term action plans
5. How to maintain the strategy?	Policy change, training and O&M **Training:** - improve awareness - increase motivation - transfer skills - introduce best practice/technology **O&M:** - Community involvement - Water conservation and demand management programmers Action plan recommendations O&M procedures

Source: (M. Farley, 2003)

The parts of NRW can be determined by conducting a water balance. This is often supported the measuring or estimation of water produced, imported, exported, consumed or lost – the calculation ought to balance.

The water balance calculation provides a guide to what proportion is lost as leakage from the network (physical 'real' losses), and how much is due to commercial 'apparent' or 'non-physical losses'.

Because of the wide diversity of formats and definitions used for water balance calculations internationally (often within the same country), there has been an urgent need for common international terminology.

Drawing on the best practice from several countries, IWA Task Forces on Water Losses and have created a global best apply approach for water balance calculations, as well as definitions of its parts, and for comparing performance between utility operators. IWA approach to developing an NRW strategy, a water balance calculation, and an international measure of performance - the international leakage index (Liemberger et al.).

2.5. Causes of Water Losses

Leakage is typically the most important component of water loss in developed countries, however, this cannot continually the case in developing or partly developed countries, wherever unauthorized connections, meter error, or an accounting error are usually more important (Farley et al., 2003).The other parts of total water loss are non-physical losses, e.g. meter under registration, illegal connections and illegal and unknown use (M. Farley et al., 2001)

2.5.1 Pressure

In several water network systems, while total consumption and the total loss of water is notable, data for the potential effect of pressure upon consumption is unfortunately short to be as a result creates difficulty to assess and compare the demand and loss of water in its spatial distribution.

Pressurized water networks lead to rising the leakage when the pressure becomes higher, but if the pressure is too low to will lead to a shortage in supply water to customers, this also leads to unequal distribution of water so the areas with high elevation it will be drought and the lower areas will supply well.

To solve these issues water utilities, make pressure zones, by zoning the network into smaller parts with similar elevations, also zoning can provide flexible metering and managing these small parts.

The leaks from water networks are directly proportional to the square root of the pressure in the pipes as indicated by the following relationship as stated by (Wallingford, 2003)

leakage and pressure relation

$$L \propto \sqrt{P} \quad \text{-------------(2)}$$

Where:

L=leakage in a distribution system

P= water system pressure

As leakage also bursts rates of pipes are related directly to pressure in the system. The strength of the relationship and the quantification of it is not as well understood as the relationship between flow rate and pressure. but there is a fact with evidence shows that the burst of pipes rate is very sensitive to the working pressure and statistics show that the relationship is more than linear with pressure. So it suggested that it could be a cubic relation between bursts rate and pressure.(Farley et al., 2003)

The pressure is varying in the water network system due to several reasons like the sudden close of pipes and the change in customers' demands, as noticed that the demand starts to increase until peak then vary with time to reach a minimum in the last hour of night

As a result, at minimum night flow (MNF) there is higher pressure and at peaks are less there is lower pressure (Obradovié, 2000)

As mentioned above frequent starts and stops of booster pumps, operation on control valves as sudden close may induce water hammer are also some of the causes to be mentioned for pipe breakage and water loss through leakage. Also locations of water tanks also have a great effect on workable pressure. 'Distribution Losses" is the sum of losses from four different parts of the distribution system; trunk mains, service reservoirs, distribution mains and communication pipes.

The composition between individual companies and supply zones are widely variable, as are the different of pressure values which are known to significantly affect leaks also (Mehren et al., 1891)

The level height of the water tanks depends on both (1) distance of the tank away from the targeted area and the level of the highest point to be supplied with water. (Abebaw, 2015)

The critical location in the distribution system is located at the highest elevation and the lowest elevation, variable speed pumps are good at this procedure by lowing its speed when pumping to the lowest point zone and installing pressure control valves, on the other hand, can increase pump speed when feeding the highest point zone. Pressure reducing valves (PRVs) throttle automatically to prevent the downstream hydraulic grade from exceeding set value and are used in situations where high downstream pressures could cause damage (Walskiet al., 2003).

2.5.2. Ages of pipes

Although there are not any scientifically based criteria for outlining the useful life for water mains, there has been a growing concern that a lot of older urban water distributions are deteriorating that as a result huge rehabilitation is needed to switch mains older than some predetermined number of years in age or "useful life". Pipe age and material are necessary factors contributive to the burst chance of pipes that as a result cause plenty of water loss. However, as this data is usually not offered particularly for aged pipes, it's typically estimated using the history of urban development. Reports from undertakings collected by the WRC, and proof from elsewhere recommend that leak rate from Mains are of the order of 100 to 2 00 l/hr. per km for newer mains and 150 to 3001/hr. per km for older mains. assumptive an average of 100 connections per km these figures would represent 1.0 to 3.0 1/hr per connection (Twort et al., 1994)

Although age is taken into account as an indicator for the break rate of mains, some studies have shown that it’s not the main determinant factor for main water break rates. Poor design, deterioration of pipe material and unexpected load condition will also result in a pipe burst.

2.5.3. Effects of corrosions

Corrosion is the problem that appears because pipes are in direct contact with moist soil a rounding it. The water that surrounding soil may cause problems that will affect the material of pipes in the water distribution system. The main cause of the breaks occurs at points where the wall of the pipe has been deteriorated due to corrosion of steel pipes. Corrosion of the wall surfaces of cast-iron or steel pipes can, under some conditions, be a big problem. Therefore, ductile-iron or steel pipelines placed in aggressive soils must be protected by coatings with corrosive resistant materials. The characteristics of the soil where a pipe is placed affect the rates of corrosion speed. (Liu et al., 2013).

2.5.4. Meter error

(Carpenter et al., 2003) mentioned in his study, as pipes ages affect the physical losses in the water system, flowmeter ages affected the commercial losses also. Due to mechanical parts deterioration occurred over time and by water quality under-registration of customer consumption is recorded.

Many developing countries try to reduce this problem by using flowmeters replacement policies and strategies in their projects programs, the National Reports stated that changing flowmeters periods in ranges from five to ten years, many customers due to insufficient work pressure in the networks due to the intermittent supply scheme their consumptions pass flow meters and doesn't restore correctly because the flow rates is less than Q minimum recommended by manufacturer.

As example the (WHO, 2000) stated in its report that the countries in Africa served its domestic customers of water and installing flowmeters for more than 78% of them but the replacement procedure is done for 8.8% of them every year, as a result under registration of them consumption is recorded due to its flow meter exceeded its meters recommended service time.

The domestic water has a reading errors because of two major reasons, (1) meter exceeded its recommended service time and its internal parts are deteriorated, (2) also low flow entered the meters. In addition to that low regular maintenance for customer’s meters will great the error values as described at (Twort et al., 1994).

The software must be developed or upgraded to provide alerts to the utility meter managers if there is any noted under register reading compared by a historical past reading to inform the customer make the needed maintenance for his flow meter.

2.5.5. Estimating loss from discovered leaks

Documentation reports important to make for any leaking water from discovered bursts to calculate this amount and record the volume of water lost due to making a real estimation for the physical losses. Three methods are suggested (from ‘’Leak Detection Productivity ‘’) by Douglas S.Greeley (State of California, 1992)

- Use a container of known volume.
- Use a hose and a meter.
- Calculate losses using modified orifice and friction formula.

The first method, sometimes known as the bucket and stop watch method is as simple as its name. Hold a container against the leak for a predetermined time. Time is recorded by a stopwatch. Measures the water captured with a measuring cup or other containers of known volume and then converts time and volume to l/min.

The second method requires connecting a hose to the leak and directing the flow through a meter. The third method is the simplest to perform in the field but requires calculation. This method is often helpful for large leaks where the flow is too great to measure and the main must be valve off. It requires that the size and shape of the hole shall be measured and the line pressure will be determined. A pressure gauge or a hand held blade pedometer could be used to determine the pressure of the water coming from the leak or a nearby fire hydrant. This method also uses some assumptions regarding the shape of the hole that may introduce error.

For losses from such items as pipes or broken taps, Greeley assumes an orifice coefficient of 0.80 and calculates flow in gallons per minute from the formula:

Equation follow for estimation of a leak from transmission mains

$$Q = \frac{(43767)}{1400} \times A \times \sqrt{P} \qquad \text{---------- (3)}$$

Where, Q= flow in gallons per minute

A= the cross-sectional area of the leak in square inches and

P= the pressure in pounds per square inch.

1. **Calculating Leak Rates for circular holes in distribution mains:**

A leak loss for circular holes under different pressure is estimated by Douglas S. Greeley formula as:

Equation 4 estimations of leaks from circular holes

$$Q = (30{,}394) \times A \times \sqrt{P} \quad \text{---------- (4)}$$

Where:
A is the cross-sectional area of the leak in square inches and
P is the pressure in pounds per square inch.

2. Calculating Leaks Losses for joints and cracks under different pressure

For leaks emitted from joints and cracked service pipes, an orifice coefficient of 0.60 is used in the following equation

Equation 5 estimations of leaks from Cracks and Joints

$$Q = (22.796) \times A \times \sqrt{P} \quad \text{---------- (5)}$$

Where "A" is the area in square inches and "P" is the pressure in pounds per square inch.

2.6 International NRW Values

During the 1990s, there have been significant advances in instrumentation for more effective leak detection and location – notably in metering and logging of flows, pressures and leak noises. Improvements in the understanding of pressure: leakage relationships, and in component analysis of Real Losses, and the factors which influence them, have been made. Increasingly, attempts are made to define the economic level of leakage for individual systems. Yet, despite some encouraging success stories, most water supply systems worldwide continue to experience high levels of water losses, most of which are almost certainly higher than their economic level.

The IWA Task Forces on water losses (AO Lambert et al., 1999; A Lambert et al., 2000) have recently produced an International "best practice" standard for defining and calculating components of water balance, and selecting the most appropriate performance indicators for different components of non-revenue water and water losses.

This international report commences with the IWA standard water balance and definitions, as the basic but essential first steps in management of water losses. Next, the assessment and management of unbilled authorized consumption – which is part of non-revenue water, but not part of water losses in the IWA definitions – is considered. Then follows the assessment and management of components of apparent losses. Volumes of unbilled authorized consumption and apparent losses represent water actually used to some purpose, but not paid for; in contrast, real losses represent a loss of water resources, at least part of which may be recovered by well-directed leakage management activities.

(AO Lambert, 2002) shows some international NRW values in different cities like Malaysia 36.4%, Italy 35%, Finland 19%, France 20%, Hong Kong 30.5%, Murcia 9.7%, Norway 40% USA 21%, Taiwan Province 23.1%.

2.7 National NRW Literatures

(Tayef, 2017) illustrated in his paper that the annual cost of water loss worldwide is estimated about 14 billion US dollars. In some low-income countries, water losses account for 50-60% of productive water, and the global loss rate is 35%. (Kingdom, et al., 2006) If we consider the amount of water loss in Palestine in 2015, it is 32.81% of produced water. The percentage of non-revenue water of the Gaza Strip for the same year is about 39%. Statistics show that the percentage of water loss in 2015 in Khan Younis was 40% (ie 3.4 million cubic meters). If we know that the average price per water cubic meter in Khan Younis is one NIS, we can estimate the annual water losses of 5.78 million NIS. Hence the importance of the study, that the current measures to reduce non revenue water is weak. Therefore, the objective of the study was to analyze the state que of water loss, to define and determine the water balance base line, to present the non-revenue water management plan adopted by the municipality of Khan Younis for the years 2015 and 2016 and to show the strengths and weaknesses of its management plan.

(Abu Merai et al., 2013) stated that the main outcomes of the study are that; farmers use the domestic network illegally for irrigation purposes leading to high percentage of unaccounted for water. This leads to higher water consumption per capita in Beit Lahya which apparently exceeds 230 l/c/d according to water well production in year 2010 equal (6.098 MCM) and the unaccounted for water more than 60% in semi urban quarters where green houses are the main agricultural practice. The difference between supply and demand indicates that the farmers use illegal connections to irrigate the adjacent agricultural areas. The overall system efficiency for water distribution is 42.0% and 55.7% for summer and winter periods, respectively. The quarters with intensive agriculture show high percentage of unaccounted for water (73%), while the urban quarters unaccounted for water is 24%. Therefore new policy and regulations concerning water resources management should be implemented for the semi urban areas in the Gaza Strip.

(Abdullah, 2012) illustrate that non-revenue water which should ideally be less than or equal to 30%. In the case of dair-balah equal 50%, followed by Jabalya 45%, while khanyounes 35% and rafah 28%.

(Alsharif et al., 2008) stated that his study can be a useful tool to assess the relative efficiencies of water supply systems and to establish benchmarks with which to measure progress in the management of water resources. Frontier efficiency models measure the efficiency of water use in the Palestinian Territories (West Bank and the Gaza Strip). At the municipality level, sufficient data for the years 1999–2002 were available to estimate efficiency and stability scores. The Gaza Strip efficiency scores were considerably lower than those of the West Bank. Water losses were the major source of the inefficiency as indicated by the large slacks of this input. The relative sizes of the municipalities affect efficiency scores little. Palestinian policy makers should focus on rebuilding the infrastructure of the water networks, beginning with the most DEA inefficient municipalities in order to minimize water losses.

(Gray et al., 2007) talk about Gaza Strip water destribution system and illustrate that the water infrastructure in the Gaza Strip is in an even worse state than that in the West Bank, and losses through pipe leakage are assumed to be considerable. Losses were higher than 50% in 1995 when control over resources and infrastructure was handed over to the Palestinians, and given the repeated missile bombardments of Gaza during the Intifada, this situation has not improved, despite high investment from donors.

Also (Gray et al., 2007) stated that in the West Bank the water situation shown that the average age of water networks is around 19 years. Thus water loss is high, averaging 28% in PWA systems, and ranging from around 31% to as high as 52% in municipalities. Taking water losses into account, the PWA estimated in 2003 that the actual average consumption rate per person did not exceed 50 L/day. (Mimi et al., 2004) providing information about Ramallah city and stated that many of the Palestinian localities still lack the existence of water networks while many others suffer from the poor conditions and high losses in their networks that reach up to 50% of the input into the supply system. Specaially in Rmallah district the water supply network consists of pipes connected in rings as a circulation system. At the end of 1995, the total length of the distribution system including all the different size of pipes was about 750 km. The water losses in the supply network are high and were estimated to be approximately 25% for the year 2000 which means a loss of approximately 2.6 million cubic metres.

(Jaradat, 2010) illustrated that more than 90% of the Gaza Strip population is connected to the municipal drinking water network while the other 10% of the rural areas is dependent on private wells, the overall loss of water in the Gaza Strip through the system is estimated at 45% of which 35% is due to physical losses and 10% is due to unregistered connections.

Chapter 3
Methodology

Chapter 3
Methodology

The following steps are describing the methodology starting from a literature review then data collection ending with results and management plan as follow:

3.1 Review for Available Literature

Reviewing related articles and reports for the subject in general, and searching for any previous studies or for similar situation cities by reviewing types of water distribution systems, and determining the important characteristics to having a good distribution system.

Also in the literature illustrated the international assessment methods of non-revenue water by listing them top-down approach, bottom-up approach and synergetic approach, in this study a comparison made in this chapter in order to select the most appropriate one to the water distribution system of Gaza city. Also addressing water balance, NRW terms and related terms clearly by reviewing the main references related as IWA handbook manual to deep understanding of the consumption and losses categorize.

In this chapter illustrate main causes of water losses as pressure, age of pipes, meter inaccuracy and effect of corrosion, also illustrated some NRW values for international developed and developing cities to clear the vision on where is the level that other cities reached in the NRW management, finally focusing on many literatures dealing with Palestinian and Gaza Strip network efficiency and presents some results of their literatures.

3.2 Study Area Description

This chapter illustrate Gaza city as a geographic location, its neighborhoods distributions and characteristics, also it describes the water sector in general and the losses values depending on the related utilities reports also it specially illustrate the distribution network in each neighborhood ages and diameters and the general condition of it, this data will supported by maps and tables.

This work will have done by using historical reports from the PWA and MOG.

3.3 Comparing methods for computing losses volumes to select the most appropriate one

- **Top-down approach**

(Farley et al., 2003) stated that IWA Water Loss Task Force was the first institution that interfaces the top-down approach also called a water balance structurer and nowadays it is selected as a standard approach to internationally executing NRW calculations. Also, the IWA defines the terms used in the water balance clearly.

This approach depending on divide the losses to both commercial losses that includes unauthorized consumption, meter inaccuracy and data handling error, on the other hand a physical loss that includes disappeared leakage from joints and connections, leaks due to breaks in pipes and over flow from storage tanks.

This approach also tries to breakdown the authorized consumption to calculating them in a comprehensive manner to both billed and unbilled consumptions, each of this category also divided to sub category both metered and unmetered consumptions.

In Gaza water distribution system, pumping pattern is intermittent due to energy shortage and other concerns, and the top-down approach is good for this situation because it is not depending on monitoring the flow in a continuous certain period.

- **Other techniques (bottom-up, component analysis, synergetic approaches)**

After a careful study of the above titled approaches, and illustrated description in the chapter of literature review, found that this approaches focusing on determining volumes of physical losses by calculating the MNF depending on 24 HZM, this terms need a water distribution system with a steady state supplying pattern 24/24 hour, because the user consumption should be saturated in the mid night when the major of users inactive else some night users is active and some modification made to eliminate the inactive users values, on the other hand a district meters must be setting in the different distribution zones, and this is not achievable in the field due to the level of uncertainty in some pipes connections between zones, so it may lead to huge errors in results, especially in the very old distribution networks.

Concluded from above that the top-down approach also called water balance principle is the most suitable approach to calculate the NRW values for Gaza city distribution system as a case study and it will give a good result, by taking into account different consumption categories and sub categories in authorized and lost volumes.

After select the most appropriate method for Gaza city, a next step will be executed as follows

3.4 Data Collection and Analysis

Any data without confidential sources mustn't be used, because it may lead to inaccurate results due to its high probability of error, but not in all cases, in some cases searching internet for statistical data from previous studies sites can be effective, Field measurements are highly required in order to check accuracy of data or to proof of others that are logic.

The work was done on three levels:

1. Collecting data based on previous filed works and knowledge and it will mainly collect from related utilities.
2. Collecting data based on flow meters and recording the needed data.
3. Use some data from previous related literature.

The main parts of water balance based on the international water association (IWA) manual as follow:

- Part (1): System Input Volume
- Part (2): Authorized Consumption
- Part (3): Commercial (Apparent) losses
- Part (4): Physical (Real) losses

Table (3.1): Water balance structure as IWA standards

<table>
<tr><td rowspan="3">System Input Volume</td><td rowspan="3">Authorized Consumptions</td><td rowspan="2">Billed Authorized</td><td>Billed Metered</td><td rowspan="2">Revenue water</td></tr>
<tr><td>Billed Un-metered</td></tr>
<tr><td>Unbilled Authorized</td><td>Unbilled Metered</td><td>Non-Revenue Water</td></tr>
</table>

			Unbilled Un-metered	*(UNRWA)*
	Total losses	*Commercial (Apparent) Losses*	*Unauthorized consumption*	
			Meter inaccuracies	
		Physical (Real) Losses	*Leakage from transmissions and other lines*	
			Leakage at storage tanks	

- **Part (1): System Input Volume:**

This amount of water can determine as follows:

1. Readings from water wells flow meters.
2. Readings from the bulk meters of purchased water (Mekorot).
3. Monthly and annual reports of Gaza municipality.

- **Part (2): Authorized Consumption:**

The annual volume of metered and/or unmetered water taken by registered customers, the water supplier and others who are authorized to do so

Billed Metered

- This type of authorized consumption can take from the water utility directly, it is important to note that the municipality doesn't read the meter monthly so, the annual reading to decrease error was chosen.
- As a financial procedure water accounts divided into about 50 categories that describe the nature of the use of these accounts
- Dividing the financial categories of water accounts into the following (Domestic, Commercial, Industrial, Health centers, Educational centers, Religious and accounts discovered as Illegal and treated by printing a bill with an estimated consumption.
- Water volumes purchased from the contractor is another type of authorized billed metered consumption, this is recorded by the facility operator in the municipality at every filling time.

Billed Unmetered

- This type of consumption describes any consumption with fixed or variable fees without metering the amount of flow, this type is not available in Gaza Municipality

Unbilled Metered

- This type of authorized consumption follows under non-revenue water and include Jabalya Municipality consumption from the northern wells.
- As an agreement between the municipality of Gaza, water wells located in Jabalya feed their surrounding area.
- This amount of water will be determined by taking a regular reading of its lines flow meter and install one if required.

Unbilled Unmetered

- Unbilled unmetered consumption, traditionally including water that utility uses for operational purposes like:
    1. Planted streets median: A visit to the departments of parks that responsible for irrigation of the green areas in the municipality to collect data about the irrigation scheme.
    2. Cleaning sewerage system: The wastewater department has a special vehicle that used to clean and remove any clogging in the wastewater network.
       Daily work scheme also can be known as number of the vehicle in every staff, number of staff in the day, the volume capacity of the vehicle, the result can give us a calculated volume of water.
    3. Civil defense firefighting: Civil defense in every compound has used private water well in order to fill their tankers because of the water supply system depending on intermittent pattern and they can't fill in their tankers in dry times.

- **Part (4): Physical (Real) losses:**

Physical losses can be classified into main parts as follows:

1. Leakage from transmission and distribution mains: This type of leakage can be determined by information reached the municipality by peoples soon to turn off the water that makes chaos and disruption in the area

Maintenance staff report burst after any task done this information contains (address, fittings, description of work, nature of area "asphalt or tiles or natural ground").

Detailed information recorded for the burst so we can calculate the amount of water that wasted.

The intermittent supply pattern reduces these amount because in the dry days no wasted water gets out from the burst pipe, but it may lead to seep some contaminant enter the pipes.

Leakage of Mains = # of reported bursts X average leak flow rate X average leak duration ----------- (6)

2. leakage and overflows from the utility’s reservoirs and storage tanks: Overflow cannot be significant in Gaza municipality until now because only two reservoirs enter the service but in the coming few years much other water tanks will be operated, so reporting the overflow situations in a pre-defined way, make the estimation more precise. The overflow history can found from the operator, for any situation occurred previously but in general, this situation happened rarely because there are an altitude valve and measuring ruler and alarming system in the reservoir facility.
3. Underground leakage from the pipes joints, from connection places and in the deteriorated area in the pipe body, this amount of water will be calculated by taking the world average percentage of physical losses from previous literatures and then subtract the values of leakage from breaks pipes and leakage from overflow of tanks, this procedure will be carried due to the uncertainty, lack of information’s and practical constrains in this field.

- **Part (3): Commercial (Apparent) losses:**

Commercial losses can be divided into four elements, which are:

1. Customer meter inaccuracy.
2. Data handling error.
3. Treated illegal accounts.
4. Unauthorized Consumption.

Customer Meter Inaccuracies:

- (M. Farley et al., 2008) said that "inaccuracy recordings of the meter may under-register customers consumption due its internal parts exceed its service life proposed by the manufacturer, the under-registration may lead to decrease sales and revenue to the water utilities, some meters are over-registration".

- Over-registration may from the air flow in the intermittent supply system that applied in Gaza city and most of developing countries.
- Class and type of meter are important because meter class describes its accuracy and nature of use, also the standards of installation are important.
- The data collection process in this type of losses starts by sorting flow meters into a group related to (Installation Year) can be useful.
- A field test executed using test bench experiment to determine the percent of error relative to the installation year, a number of flow meters which tested are installed in a series, a flow equal to 100 litre pumped by the device with a different pressure at 3 bar and 5 bar, one of the flow meters represent a new calibrated meter , the remaining meters have a different service periods.
- Also previous studies used to double check the percentage of inaccuracies of the flow meters.

Data Handling Error:

- Data is taken in irregular times but an average of historical data billed to the customers then when taking a new read a correction made.

Consumption estimation error in (treated illegal accounts)

- Any discovered illegal connection treated by opening account number and start to printing a bill every month with an average consumption, this average consumption as described in the section of authorized billed metered is now known for the utility and can't described as illegal because they have a bill but didn't have a flow meter yet until finishing some administration measures.
- So the amount of water that used over the average can follow under commercial losses because it has the same nature of this type of losses as it effects the revenue directly.

Unauthorized Consumption

- This type of loss is difficult to discover, simply if it has known it will be treated and didn't dealed as illegal and will dealed as (Billed metered or treated illegally) as described in the above sections.

- A good procedure is to discard the volume of (Authorized consumption and Total Losses) from the input system volume.
- This step is good until reaching the balance of input and output volumes.

3.5 Management Plan

A non-revenue water management plan describes a proposed plan to how will be developing and monitoring water system, in order to enhance the metering and computing data of water balance components and to build intervention priorities for treat losses as much as possible until reaching the most economic point with the lowest investment and operational cost.

The proposed management plan should depend on fixed and substantial funding either through external grants or through self-financing, also one of the important part of the management plan is to propose a managerial modification to ensures that everyone relevant to non-revenue water taken his role in different management stages like data collection, analysis, and treatment.

The following steps in forming the proposed management plan:

3.4.1. Planning for the system input volume

1. This section will be deal with both type of sources water wells and trunk line of MEKOROT.
2. This component of water balance is very important because it directly affects the results of the non-revenue percentage and losses percentage.
3. A monitoring program will be proposed by design a proposed table also for sources flow meters also a preventive maintenance very important to ensure the accuracy of its readings.
4. In the routine process, monitoring the flow meters' readings are also important to detect any meter error or blunder errors, so a work procedure also proposed.
5. In the development process, a district electromagnetic flow meters will be proposed due and its location will be set depending on the understanding of each neighborhood distribution network, the selection of electromagnetic meters is due to its high accuracy and low friction losses generated, also with no mechanical parts, in order to determine each distribution zone needs and to determine the zones with high losses values to provide future data to the operator where the problem.

3.4.2. Determine the authorized consumption

1. The major consumption in this type is the metered billed authorized consumption, the researcher depends on the collected data to propose a plan to repair customer flow meters also proposed a modification for the reading scheme, the plan of flow meter repairing depends on dividing the flow meters into groups by installation and service period, then establishing a target group every period of time, depending on proposed size of grants expected to finance such activities also according to a previous practical experience of the researcher in this field.
2. Unbilled authorized consumption one of non-revenue water component, divided into metered and unmetered.
3. Metered unbilled authorized consumption represents water volume demanded without fees and doesn't make revenue to the utility and doesn't return operation cost, the work will start by determine the area and zones contain this type of consumption, also a will understanding of the network is important, some modifications will be proposed in the water wells manifold where flow meters of this type of consumption was set, also a capacity building will be proposed and regular and preventive maintenance table proposed.
4. Unmetered unbilled authorized consumption includes all water used in the operation and to provide public service like firefighting, sewerage cleaning and irrigate planted streets median and parks, this step will start by collecting data from related parties in the water utility like wastewater department, parks department and civil defense to specify there sources of water, also a proposed tables will be set to monitoring the volumes of water consumed to public service purpose, finally a list of location on streets median proposed to insert meters to determine the amount of water consumed.
5. To decrease the estimation part a flow meter must be planted in different areas in the network in cooperation with the sewerage department, parks department and other official bodies that used municipal water for public services.

3.4.3. Physical losses

1. Understanding the water network and the distribution of pipes according to its manufactured material and date of installation will help to make an investment action plan.

2. A description of each neighborhood distribution system illustrated in chapter 4, a specific location selected depending on practical experience of the water department staff to insert a pressure gauge to real-time monitoring the workable pressure on the system, also a list of deteriorated networks will have provided from MOG water department to take it on consideration when building a proposed project action plan later in this study.
3. This plan will focus in develop existing and deteriorated water networks or installing a digital and wireless transmitter pressure gauge also planted a flow meter in different areas to define each neighborhood water balance to create an efficient priority for development project selection.

3.4.4. Commercial losses

1. About 48,000 water account is registered in Gaza city, regular monitoring to these flowmeters is important and directly affects the water balance structure.
2. A volume of investment will determine in according to the current situation of these flow meters and the current procedures implemented by the operational utility to collect readings.
3. A proposed plan set by link the work with GIS, and proposed to use new technology to reduce the error on readings and to check the compatibility between the customers' accounts in the database with the houses in the field to ensure that all unauthorized customers is treated.

3.4.5. Managerial management

1. An important step is to create a body responsible for monitor the performance of a management plan for the above terms.
2. The new body or unit should include different parties related to the water sector include but not limited to operation and maintenance, financial, IT and legal advisor.

3.4.6. Projects action plan

As a result of studying and assessment of the NRW in the city, and understanding the distribution system in different neighborhoods and the type of pipes material and its situation, a list of project and activities list as a table of projects to developing and enhancing the efficiency of the distribution system and reducing the NRW, the list of projects as mentioned above need a fixed and substantial funding either through external grants or through self-financing, and this list is also set depending on practical understanding of the researcher that coming from his position as an engineer in the water department in the MOG.

This done by grouping each proposed development activity in every category in the water balance, then trying to quantify the amount of work and setting an execution time, finally suggest a rough budget for each project to determine the total budget for the proposed action plan.

Chapter 4
Study Area Description

Chapter 4
Study Area Description

Gaza is the largest city in Gaza Strip with a total area about 55.90 km^2, it has been inhabited since 3000 BC. In the 2018 population reached about 639,929 capita distributes in all city neighborhoods, as a result of population increase considerably in the last 3 decades, also demand to basic infrastructure services increased rapidly "fresh water, electricity and transportation".

Now citizens in Gaza strip were supplied with fresh water for drinking and cooking purposes from the private desalination plant to cover their families' essential requirement but they use municipal water for other uses.

Due to high stress on the aquifer, water salinity in Gaza strip aquifer became a recipe that cannot be ignored, most decision makers agreed about finding a strategic solution and decrease huge demand from the aquifer to reduce the intrusion of seawater on account of the fresh water. Palestinian water authority status report show that "The total water supply for domestic use in the Gaza Strip on 2016 was 98.094 Mm^3 classified as follows (PWA 2017):

- 81.580 Million m^3 from 273 municipal water wells.
- 2.627 Million m^3 from UNRWA wells.
- 9.967 Million m^3 from Mekorot.
- 3.919 Million m^3 from about 154 private desalination plants (Brackish and Seawater).

Particularly in Gaza city, the total water supplied to municipal networks is about 30.39 Mm^3 in the year 2018 and classified as follow:

- 23.75 Million m^3 from 79 municipal water wells.
- 6.64 Million m^3 from Mekorot water.

The Municipality produce about 135 Liter/capita/day and water department reported in 2016 (Water-MoG, 2016) that the water network efficiency was 67%.

The Municipality of Gaza has a water network with a total length about 715 km, which includes pipes (UPVC, steel and others), water facilities (wells, tanks, and boosters) and fittings (valves, tees, and others).

Water salinity in Gaza city different from one area to another, and the TDS ranges from less than 1000 ppm to more than 15,000 ppm, the general shape show that from the middle line of the city at Al Yarmouk Street to the west toward the Mediterranean coast, the water is more saline than the eastern part of the city, but sometimes there are irregular distribution for water quality depending on aquifer natural formation.(Water-MoG, 2016)

Source: www.openstreetmap.org

4.1 Gaza water Sources

Gaza city depending on two main sources water wells and mekorot that purchased from other part, two main compounds of wells form the half of city system input volume, one is located in the northern east of Gaza in Salah el deen street called al Safa wells, the other compound located inside Jabalya municipality boarders which located in the north of Gaza municipality boarders.

About 60 other local water wells distributed in neighborhoods of the city and connected to the distribution network directly to serve its local areas.

Mekorot line starts from the east of al Shejaea neighborhood to carry the water from its sources to Al Muntar Storage tank then to the distribution networks in the west of the city. The strategy of the MOG is to stop saline water wells in the west of the city in order to refresh the aquifer and feeded the western area with a good quality water instead.

4.2 Gaza Neighborhoods

(Gaza, 2019; Water-MoG, 2016) municipality of gaza published that Gaza city compined from 16 neighborhoods as follows:

#	Neighborhood name	Area (KM^2)	Destribution Network Describtion
1	Al Shejaea	5.65	• **Water Sources:** Al Safa wells, local municipal wells • **Main Pipes Material:** Steel,UPVC and HDPE • **Demand Pattern:** Domestic, agricultural and some industrial • **Location:** Center of the east of the city • **General status of its distribution networks:** At a medium condition and some of them exceeded its service age.
2	Al Tofah	2.84	• **Water Sources:** Al Safa wells, local municipal wells • **Main Pipes Material:** Steel,UPVC and HDPE • **Demand Pattern:** Domestic and agricultural • **Location:** Norther East of the city • **General status of its distribution networks:**

			At a medium condition and some of them exceeded service age, the eastern area need new networks, the western areas need a development
3	Sheikh Radwan	1.03	• **Water Sources:** Sheikh Radwan wells, local municipal wells • **Main Pipes Material:** Steel,UPVC and HDPE • **Demand Pattern:** Domestic, industrial and commercial • **Location:** Northern west of the city • **General status of its distribution networks:** At a good condition except the eastern part have a very deteriorated network.
4	Al Awda-Maqouse	0.71	• **Water Sources:** Sheikh Radwan wells only • **Main Pipes Material:** Steel,UPVC and HDPE • **Demand Pattern:** Domestic, commercial • **Location:** Northern west of the city • **General status of its distribution networks:** Need a replacement specially diameters of 3 inches.
5	Al Naser	2.04	• **Water Sources:** Sheikh Radwan wells, local municipal wells • **Main Pipes Material:** Steel,UPVC and HDPE • **Demand Pattern:** Domestic and commercial • **Location:** west of the city • **General status of its distribution networks:** At a good condition and most of them new UPVC.
6	Al Zayton	9.16	• **Water Sources:** Al Safa wells, local municipal wells, Mekorot • **Main Pipes Material:** Steel,UPVC, HDPE and some Asbestos • **Demand Pattern:** Domestic, agricultural and industrial • **Location:** East of the city • **General status of its distribution networks:** Most of them have deteriorated condition and some of them exceeded service age, the eastern area need

			new networks, the western areas need a development.
7	Sheikh Ejlen	2.23	• **Water Sources:** Mainly depending on mekorot, local municipal wells • **Main Pipes Material:** UPVC and HDPE • **Demand Pattern:** Domestic and agricultural/recreational • **Location:** Southern west of the city • **General status of its distribution networks:** New UPVC pipes.
8	Tal El Hawa	0.79	• **Water Sources:** Mainly depending on mekorot, local municipal wells • **Main Pipes Material:** UPVC and HDPE • **Demand Pattern:** Domestic and commercial • **Location:** Southern west of the city • **General status of its distribution networks:** Most of it have new UPVC pipes
9	Al Sabra	1.52	• **Water Sources:** Mainly depending on mekorot, local municipal wells • **Main Pipes Material:** Steel old pipes, UPVC and HDPE • **Demand Pattern:** Domestic and commercial • **Location:** Southern west of the city • **General status of its distribution networks:** Most of them have deteriorated condition and some of them exceeded service age.
10	North Remal	2.37	• **Water Sources:** Mainly depending on mekorot, local municipal wells • **Main Pipes Material:** Steel old pipes, UPVC and HDPE • **Demand Pattern:** Domestic and commercial • **Location:** Center of the west of the city

			• **General status of its distribution networks:** Have new UPVC
11	South Remal	2.77	• **Water Sources:** Mainly depending on mekorot, local municipal wells • **Main Pipes Material:** Steel old pipes, UPVC and HDPE • **Demand Pattern:** Domestic and commercial • **Location:** center of the west of the city • **General status of its distribution networks:** Have new UPVC
12	Old City	0.70	• **Water Sources:** Al Safa wells, local municipal wells • **Main Pipes Material:** Steel and HDPE • **Demand Pattern:** Domestic, commercial • **Location:** center of the city • **General status of its distribution networks:** Most of them have deteriorated condition and some of them exceeded service age.
13	Beach Camp	0.81	• **Water Sources:** Sheikh Radwan wells, local municipal wells • **Main Pipes Material:** Steel,UPVC and HDPE • **Demand Pattern:** Domestic • **Location:** west of the city • **General status of its distribution networks:** Most of them have deteriorated condition and some of them exceeded service age.
14	Blakhea	0.16	• **Water Sources:** Sheikh Radwan wells, local municipal wells • **Main Pipes Material:** Steel,UPVC and HDPE • **Demand Pattern:** Domestic • **Location:** west of the city • **General status of its distribution networks:** New U-PVC pipes

15	Al Daraj	2.43	• **Water Sources:** Al Safa wells • **Main Pipes Material:** Steel,UPVC and HDPE • **Demand Pattern:** Domestic, industrial and commercial • **Location:** center of the city • **General status of its distribution networks:** At a medium condition and some of them exceeded service age.
16	Area of Extended Boarders	11.78	• **Water Sources:** Al Safa wells, local municipal wells • **Main Pipes Material:** UPVC and HDPE • **Demand Pattern:** Domestic, agricultural and some industrial • **Location:** Southern of the city • **General status of its distribution networks:** Small distribution network and need a new networks.

Source: (Gaza, 2019)

Chapter 5

Results and Discussion

Chapter 5
Results and Discussion

This chapter illustrates data collected and measured from related parties also the results achieved and discussion, it mainly contains seven sections, the first describes the system input volume that combined the volume of waters from wells and the volume of water that purchased. The second dealt with authorized consumption and illustrate data collection and data analysis. The third dealt with water losses and data collection and analysis to use it in building the water balance. The fourth illustrate Gaza city water balance components and volumes calculated using different ways described earlier in the methodology, the fifth section shown the system efficiency and summarize the important numbers and percentage about the distribution system related to NRW, the sixths sections comparing the results with comparison with the old historical data collected by the related parties and determining where the gaps and finally the seventh section previewing a proposed management plan to sustainability monitoring and reducing the NRW values.

5.1 System Input Volume

5.1.1. Water wells

Represent the two-third of Gaza city sources of water, also the most stable source of water but in the last three decades face a sudden change in water quality due to sea water intrusion, table (4.1) below listed the volumes of water production that measured by water wells flow meters at 2018 as reported by the Water department annual report.

Table (5.1): Water wells monthly production

Month	Production (m^3)	Month	Production (m^3)
January	1,835,929	July	1,930,895
February	1,491,471	August	2,110,715
March	1,593,928	September	2,217,393
April	1,949,847	October	2,166,259
May	1,917,652	November	2,212,306
June	2,390,862	December	1,933,915
Total (m^3)		***23,751,172***	

5.1.2. Purchased water (Mekorot)

The delivered volume of Mekorot vary seasonally, the following table (5.2) illustrates the monthly volume and the total annual delivered volume.

Table (5.2): Mekorot water received monthly volume

Month	Received Quantity (m^3)	Month	Received Quantity (m^3)
January	585,500	July	447,200
February	512,100	August	537,700
March	458,700	September	655,300
April	527,500	October	636,300
May	490,400	November	668,800
June	477,400	December	647,900
Total (m^3)		***6,644,800***	

As shown in figure (5.1) below, the aquifer water wells represent about 78% of input volume to the water balance and the remain from purchased good quality water "Mekorot" as shown in figure 5.1 below.

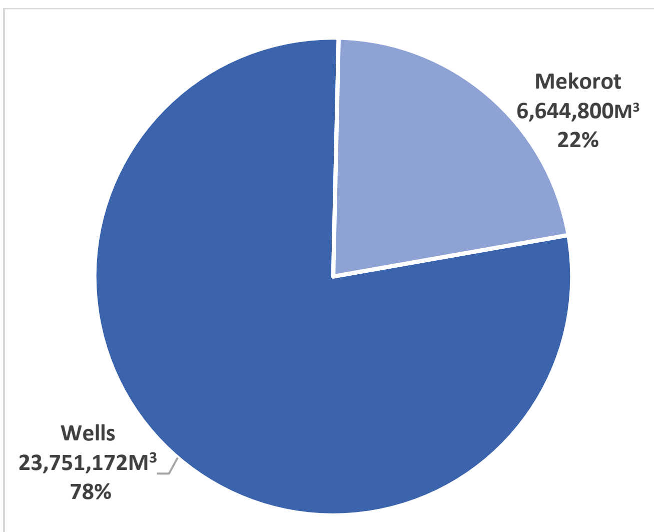


Figure (5.1): System input volumes

In the coming few years Gaza city planned to operate a desalinated seawater plant with daily productivity of 10,000 m^3, nowadays Gaza Seawater Desalination Plant (SWDP) is under construction.

5.2 Authorized Consumption

5.2.1. Billed authorized consumption

1. **Metered billed consumption**

   This category of consumption contains domestic, industrial, agricultural, commercial, educational centers, health centers, religious places, public-others and accounts that discovered as illegal then treated by opening an account and billed an estimated demand volume in the account bill.

The consumptions listed above in the metered billed category shown in table (5.3) as follows:

Table (5.3): Distribution of water volumes consumed in 2018

#	Category	Quantity of water Recorded
1	Domestic	17,580,480
2	Industrial	45,041
3	Agricultural	-
4	Commercial	1,522,638
5	Public – Educational	181,696
6	Public - Health Center	36,778
7	Public - Religious	87,493
8	Public - Others	432,495
9	Discovered as Illegal	296,856
Total		**20,183,477**

- Purchased from Contractors

Amount of water purchased from contractors to wash new water pipe networks and for testing new water tanks, total amount taken from the water department and equal to (14,955m^3).

2. **Unmetered billed**

This type of consumption describes any consumption with fixed or variable fees without metering the amount of water, this type not available in Gaza Municipality.

The below bar chart in figure 5.2 shows that about 96% of billed authorized consumption is classified under domestic use and the sum of all other billed consumption about 4% of authorized consumption.

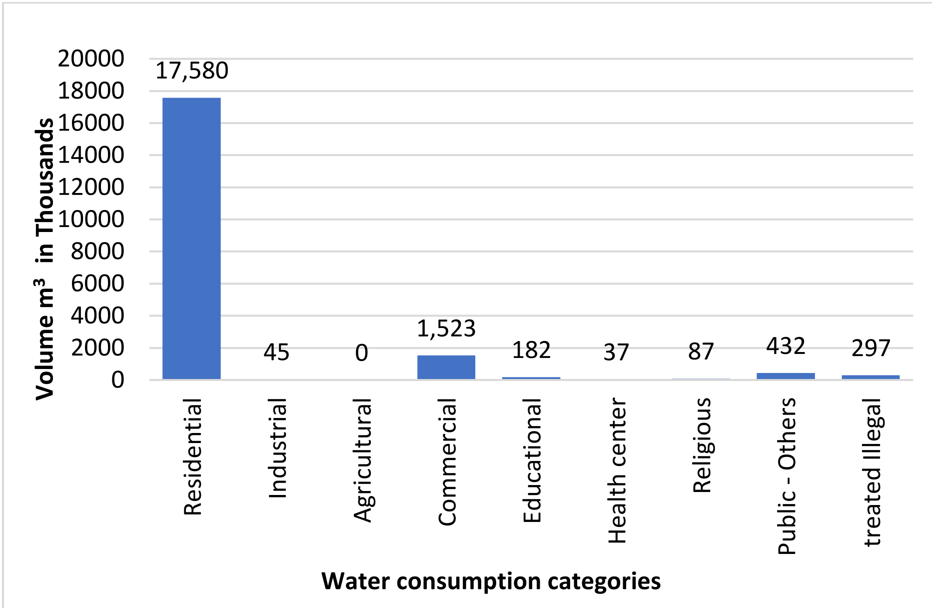


Figure (5.2) Billed authorized consumption

5.2.2. Unbilled authorized consumption

1. **Metered unbilled authorized**

Jabalya Municipality from Northern Wells

Gaza Municipality has six water wells in Jabalya Municipality called, Safa well No. 5, Sheikh Redwan No. 10, Sheikh Redwan No. 11, Sheikh Redwan No. 12, Sheikh Redwan No. 15 and Sheikh Redwan No. 16.

Safa Well No.5 feeding the eastern area of Shejaea neighborhood , the main line located at al Karama street and didn't have any online flow meters on its route after leave Jabalya Municipality borders , but water department make a frequently inspection in the route of the pipe using all available equipment before summer season determining some illegal connection, excavate above the illegal demand pipe and disconnect it , this process can be performed there due to the location of the main pipe route in a rural area and far from the city center with undeveloped roads.

For Sheikh Redwan Wells No. (10, 11, 12, 15 and 16), Gaza Municipality put on-line two flow meters in the main line to monitor the amount of water collected from above five wells from Northern Area "Sheikh Radwan Well" no. (10, 11, 12, 15 and 16) as described in the figure below:

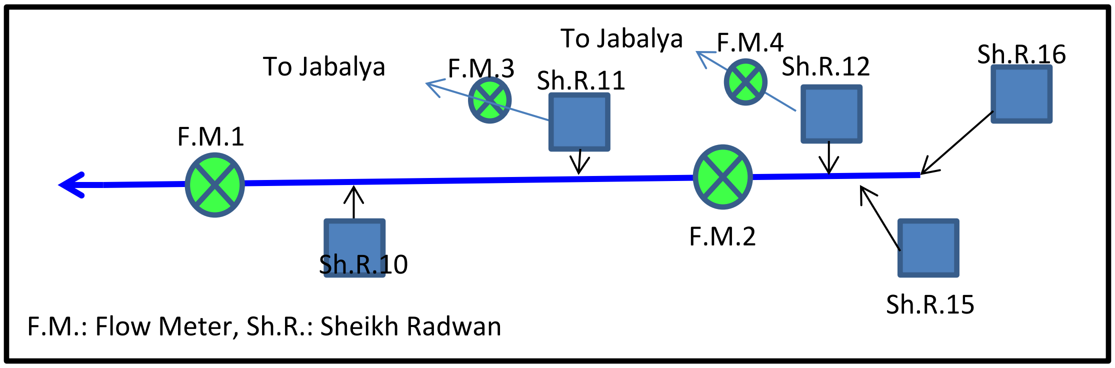


Figure (5.3): Schematic drawing for north well and its flowmeters distribution

Table (5.4): Water balance of north wells

#	Measure Point	Qty. (m^3)
1	Total Northern Wells Production	2,308,355
2	Production of wells. Sh.R. 12, 15, 16	*1,415,120*
3	FM 1	1,512,059
4	FM 2	921,000
5	FM 3	120,000
6	FM 4	72,000
7	Calculated Not Metered from Sh.R. 12, 15, 16	422,120
8	Calculated Not Metered from Sh.R. 11, 10	182,176
9	Calculated Not Metered Consumption of Jabalya Municipality	604,295
10	Metered to Jabalya from Sh.R. 12,11	192,000
11	**Total Consumption of Jabalya Municipality**	**796,295**

2. Unmetered Unbilled Authorized Consumption

- Unbilled unmetered consumption is any form of authorized consumption that is neither metered nor billed. This type includes consumptions such as planted Streets Median, cleaning Sewerage system, civil Defense firefighting.

- **Planted Streets Median:**

Many streets in Gaza city planted with different types of trees and grass a list of streets with planted median is shown in table 4.5 to determine the amount of water needed to its growth, the table shown their names and the daily consumption of water that determined from the department of parks management in the MOG.

Table (5.5): Illustrate planted streets average daily consumption.

Streets Names	Streets Arabic Names	Daily Consumption m^3
Sharldegul	شارل ديجول	2
Al quds	القدس	4
Eiz el deen al qassam	عز الدين القسام	2
Naser	النصر	2
Omar al mukhtar	عمر المختار	1
Al shuhada	الشهداء	5
Al wehda	الوحدة	1
Al thawra	الثورة	1.5
Al basaten	البساتين	2
Yousef al athama	يوسف العظمة	2
Khalel al wazer	خليل الوزير	2
Kamal naser	كمال ناصر	2
Mohamed al najar	محمد يوسف النجار	3
Omar ben al khatab	عمر بن الخطاب	2
Irrigation cargos	جتر "عربة" الري	15
المجموع	**المجموع**	**46.5**

- Daily Consumption ≈ 47 m^3
- Yearly Consumption ≈ 17200 m3

– **Cleaning Sewerage system:**

Mainly cleaning of the sewerage system depend on using pressurized water, to flush sands and solids particles from pipelines to manholes also to remove any clogging using a water jet nozzle, the wastewater (WW) department metered the amount of water needed by daily operational tasks as follows:

Table (5.6): Wastewater system cleaning

Item	Number	Description
Number of work shift	3	shift
WW cleaning cars in morning shift	3	car
WW cleaning cars in mid of day shift	1	car
WW cleaning cars in night shift	1	car
Capacity volume of WW cleaning cars	7	Cubic meter
Filling times of each	2	
Total daily filling (m^3)	70	m^3/day
Total yearly water used (m^3)	**25,550**	m^3/year

– **Civil Defense fire fighting**

Depends on private water wells and didn’t consume water from municipal network for firefighting purpose, so this category is neglected.

As discussed earlier, this type of water falls under NRW, because it doesn’t revenue a direct financial profit. A significant volume of Jabalya municipality about 800,000 m^3 demanded yearly and about 17,000 m^3 for planted medians in streets about 25,000 m^3 demanded from wastewater department to clean sewerage system and finally civil defense didn’t depend on municipal water in emergency situation due to its intermittent supply scheme and use a private water wells to fill its tanks mainly.

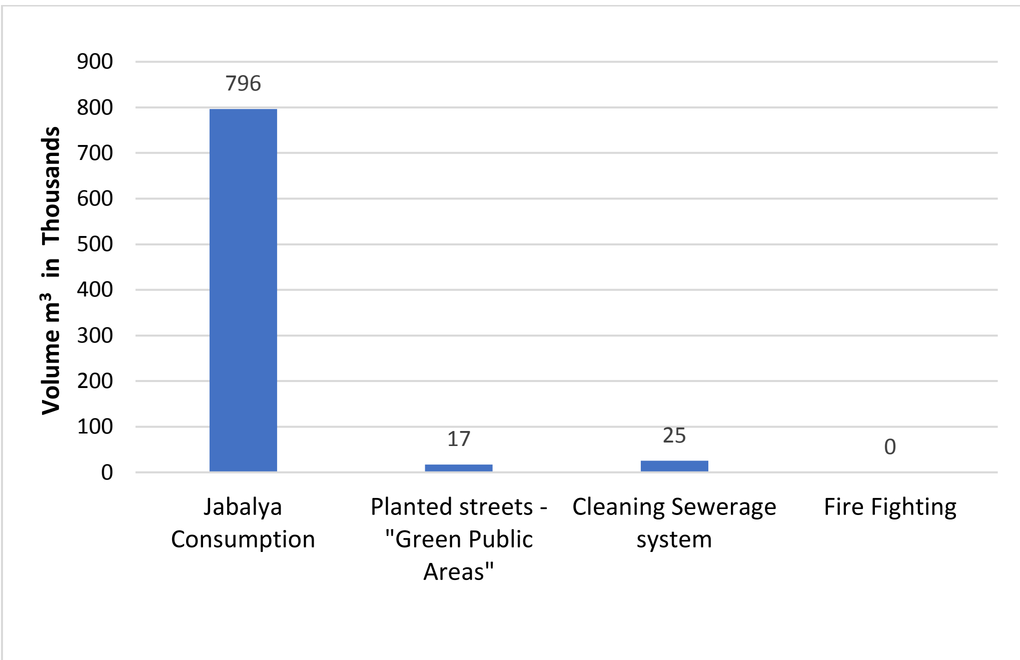


Figure (5.4) Unbilled authorized consumption

5.3 Water Losses

5.3.1. Physical losses

1. **Leakage on transmission and distribution mains due to breaks pipes**

The diameters of pipes maintained by the maintenance team in water department recorded, also the amount of water wasted known. A monthly record is listed in table 5.7 below illustrate the numbers of break pipes classified by its diameters, also an average flow from the beak pipes and the response time are estimated by the technician staff in the department.

Table (5.7): Distribution of bursts pipes over year 2018

Month / Pipe diameter	**1/2"**	**3/4"**	**1"**	**2"**	**3"**	**4"**	**6"-8"**	**10"-12"**	**others**
January	19	60	26	28	7	11	3	1	0
February	6	38	25	34	1	11	2	0	0
March	11	36	24	28	2	12	1	0	1
April	15	33	23	21	2	13	0	0	1
May	8	16	12	13	2	16	5	1	0
June	5	17	6	14	0	6	2	0	0
July	7	33	13	17	2	14	4	2	0
August	8	42	21	25	0	14	4	0	1
September	7	42	33	21	2	9	2	0	1
October	13	61	25	49	6	17	4	0	1
November	12	36	31	30	0	13	5	0	0
December	13	38	16	41	1	11	4	0	0
Total bursts Signs	**124**	**452**	**255**	**321**	**25**	**147**	**36**	**4**	**5**
Average flow in specific Diameter in (2-3) bar (M^3/hr)	**3**	**4**	**8**	**20**	**30**	**50**	**150**	**250**	**40**
Time From Known to Repair (days)	**6**	**6**	**4**	**4**	**2**	**1**	**0.5**	**0.5**	**4**
Total Leak Until Repair	**5356.8**	**26035**	**3917**	**12326**	**360**	**1764**	**648**	**120**	**960**
Total (M^3)	**51487**								

2. **Leakage and overflows from the utility storage tanks**

There are two balancing tanks in Gaza city already operated and two tanks under construction, from two years ago al muntar water tank operated and filled and emptied manually by careful monitoring from its operator man. In summer of 2018, civil defense water tank operated to feed southern west of Gaza but civil defense tank depends on altitude valve to fill mainly and monitored by an operation man.

- The total recorded overflow of tanks about 2 times
- The input average flow = 625 m^3/hr.

- Average response time = 0.25 hr.
- Total overflow volume from tanks = 312 m^3

3. **Underground leakage from joints and location of connections**

As mentioned in (Liemberger, 2003) that the real "physical" losses can range from 7% to 15% from the system input volume, so by taking this percentage as a benchmark can concluded that:

- Real losses (taken 10% as average) = 30,395,972*0.10 = 3,039,597 m^3
- Underground leakage = real losses – (breaks leak+overfloe leak)
- = 3,039,597-(51,487+312) = 2,987,798 m^3

The physical losses have three main components, leaks from pipes including breaks, over flows from tanks and the underground leakage as below:

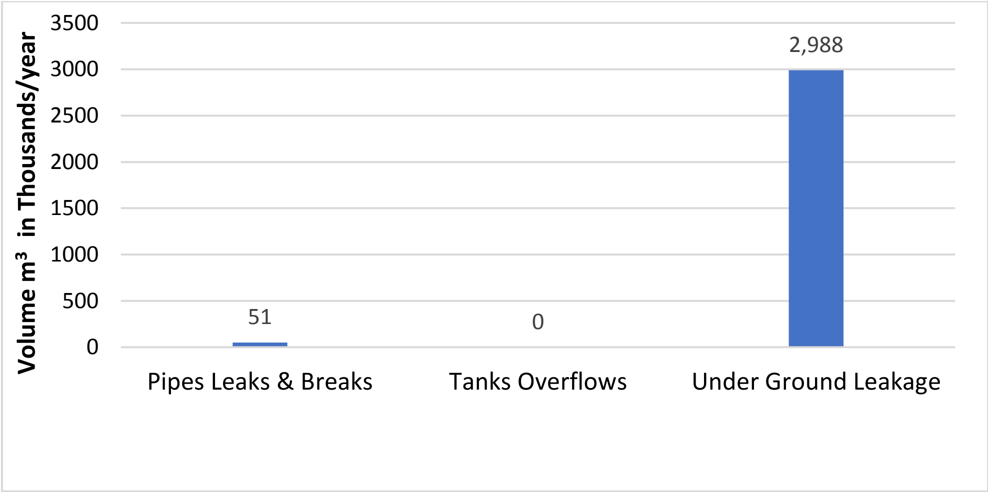


Figure (5.5) Physical losses

5.3.2. Commercial losses

1. **Meter Inaccuracies**

Any type of flow meter has an accuracy range depending on flow rate also the service period, most of meters installed in Gaza city is ARAD class C and in the product catalog the accuracy range from 2-5 % in normal operation range. Table 5.8 below shown water meter as groups classified according to its service period by years.

Table (5.8): Distribution of meters according to installation time

Flow Meter Service Period (Years)	Number
From 0 to 5	2,781
From 6 to 10	4,585
From 11 to 15	1,749
Older than 16	38,771

The following table shown test bench results by pumping 100 littre of water throw the flow meters with a different pressure values.

Table (5.9): Test bench results

Flow Meter No.	Flow Read No. 1	Flow Read No. 2	Accuracy %
At Pressure = 3			
1 (new)	21	20	1
2	36	28	8
3	89	77	12
4	42	36	6
5	64	54	10
6	78	64	14
At Pressure = 5			
1 (new)	39	39	0
2	46	39	7
3	95	76	19
4	34	26	8
5	70	57	13
6	89	71	18

- From the above data collected from the test bench for different five flow meter in addition to a new calibrated one, the average accuracy when the workable pressure equal 3 = 10%
- Also the average accuracy equal 13% when the workable pressure is 5 bar.

- Billed metered authorized customers yearly demand = 20,198,432 m^3
- The used value of error will taken as 15% because most of flow meters installed (about 38,780 meter) located in the group which have more than 16 years in service, and the tested fllow meters having a diffirent ages, so it gives a lower value.
- Volume lost as reading inaccuracy (by taken error equal 10%) = 3029765 m^3
- As a check meter in accuracy percent depending on meter age and type – range (2% - more than 15%) as in stated ARAD flow meters catalog.
- Also as a double check concluded from (Barfuss et al., 2011) it is good to take flow meter accuracy about 15% especially large for flow meters older than 20 years (Proposed service period) and falling in the table above in the fourth group (older than 16 years).

2. Data handling errors

In Gaza city, the flow meters reading taken in irregular period and an average consumption recorded in water bills, yearly records taken in this study to increase the time period to decrease the margin of error as possible and to ensure that as maximum times of real reading taken by the flow meter readers man.

5% of the total consumption taken to be in a safe side and to cover the above situation and to cover any blunder errors and any managerial problem in reading collecting system.

- Customers yearly demand = 20,198,432 m^3
- Data handling errors percent = 5%
- Volume lost as reading inaccuracy = 1,009,922 m^3

3. Consumption estimation error in (treated illegal accounts)

Any illegal use of water discovered by municipality related team treated in a long process, this process ends by opening a customer account "treated illegal account" to the customer then start to record monthly estimate consumption.

The consumption estimation process ends when the customer finishing his issue and pay for a new flow meter to the municipality and other related fees, before that the consumption estimated.

- Number of treated illegal accounts "with estimated consumption" = 2,528 customer
- Volume of water for treated illegal accounts = 296,856 m^3
- Percent of estimation inaccuracy = 25% from the estimated volumes registered in this type of consumption bills.
- error of water for treated illegal consumption (from 25%) = 74,214 m^3

4. Unauthorized Consumption

Unauthorized consumption is a deductive value found by subtracting total type of consumptions (authorized and losses) from the total system input volume.

Illegal Consumption = Input volume – (Authorized + Other Losses)

= 30,395,972 – (21,038,127 + 5,165,775)4

= 4,192,070 m^3

From the below bar chart, the meter inaccuracies about 32 % of the commercial losses, data handling error about 10% error in average estimation on illegal treated accounts about 1% and the remaining volume about 56% of commercial losses fall under illegal consumptions.

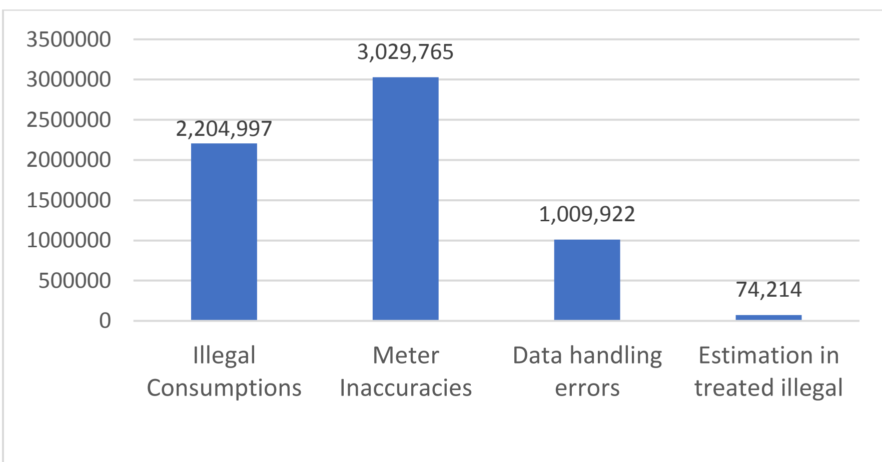


Figure (5.6): Commercial losses

5.4 Water Balance

As a result, the data collection and analysis the water balance can be filled to determine each component weight as below

Table (5.10): Calculated water balance for Gaza city water system for year 2018

system input volume	1. Authorized consumption 21,037,477	1.1. Billed Authorized Consumption 20,198,432	1.1.1. Billed Metered Consumption 20,198,432	Residential 17,580,480
				Industrial 45,041
				Agricultural NA
				Commercial 1,522,638
				Public - Educational 181,696
				Public - Health Center 36,778
				Public - Religious 87,493
				Public - Others 432,495
				treated Illegal accounts 296,856
				Purchased from Contractor 14,955
			1.1.2. Billed Unmetered Consumption 0	Monthly amount without Meter NA
		1.2. Unbilled authorized consumption 839,045	1.2.1. Unbilled Metered Consumption 796,295	Jabalya Consumption 796,295
			1.2.2. Unbilled Unmetered Consumption 42,750	Planted streets - "Green Public Areas" 17,200
				Cleaning Sewerage system 25,550
				Fire Fighting NA
	2. Water losses	2.1. Commercial losses	2.1.1. Unauthorized Consumption 2,204,997	Unauthorized Consumptions 2,204,997
			2.1.2. Customer meter inaccuracies, data handling errors and estimation error	Meter Inaccuracies 3,029,765
				Data handling errors 1,009,922
				Estimation error in (treated illegal accounts)

		6,318,898	4,113,901	74,214
		2.2. Physical Losses	2.2.1 Under Ground Leakage	2,987,798
			2.2.2. Leakage on transmission and distribution mains	51,487
			51,487	
			2.2.3. Leakage and overflows from the utility storage tanks	312
30,395,972	9,358,495	3,039,597	312	

5.5. System Efficiency

- System input volume "resources flow meters" = 30,395,972 m^3.
- Authorized consumption = 21,037,477 m^3.
- Billed authorized = 20,198,432 m^3.
- Unbilled authorized = 839,045 m^3
- Water losses = 9,358,495 m^3
- Physical losses = 3,039,597 m^3
- Commercial losses = 6,318,898 m^3
- Non-revenue water NRW (%) =

$$\frac{\text{System Input Volume} - \text{Billed Authourized Consumption}}{\text{System Input Volume}} X\ 100\% = 33.5\%$$

- Water losses (%) =

$$\frac{\text{System Input Volume} - \text{Authourized Consumption}}{\text{System Input Volume}} X\ 100\% = 30.8\%$$

- Physical losses = 10%
- Commercial losses = 20.8%
- Authorized consumption = 69.2%
- Billed Authorized consumption = 66.5%
- Unbilled authorized consumption = 2.7%

5.6. Comparison with Historical Data

Palestinian Water Authority status report (PWA 2017) that published in June 2018 stated that the system efficiency in Gaza equal 61%, so the Losses about 39%, but as shown in calculated water balance for year 2018 data, the water losses are about 30.8%, so there is an improvement in calculation procedure about 8.2% compared with 2015 results.

On the other hand, there is no official body try to calculate the non-revenue water until 2015 while Gaza Municipality in cooperation with Water Sector Regulator Council (WSRC) have published the first performance indicators for water and wastewater sectors and collect data related to water balance structure that recommended by International Water Association (IWA), as a result the non-revenue for Gaza municipality about 35.4% in 2017. So the enhancement of water balance calculation decrease water losses percentage about 8% and the non-revenue water percentage about 2% in a similar comparison period "2017-2018".

The following section illustrates the proposed management plan to make sustainable future management for non-revenue water and to decrease the losses as possible to reach the economic point between NRW cost and investment to reduce NRW.

5.7 Management Plan

This section illustrates the proposed management plan to make a sustainable NRW management and to make its value under control and its inner components understood and well defined for the water utility operators.

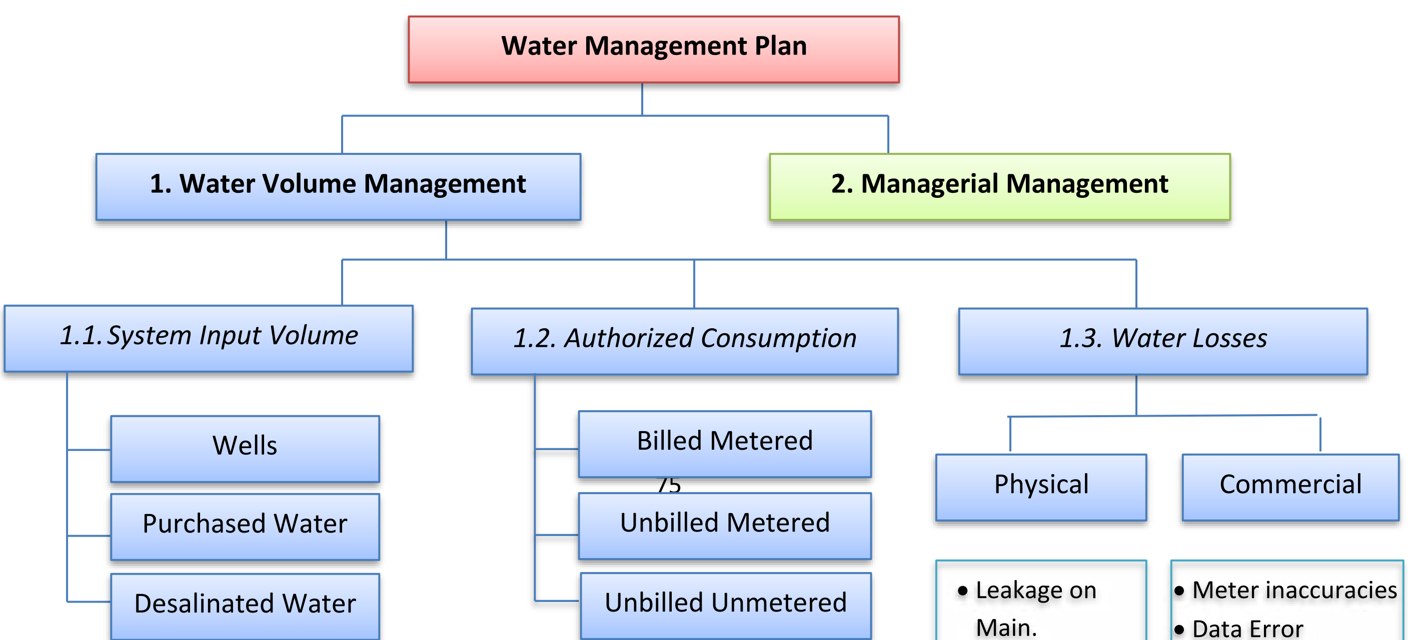


Figure (5.7): Management plan structure

5.7.1. System input volume (resources)

The input volume quantify any water enter the system to deliver to customers as municipal water include water wells, purchased water "Mekorot" and public desalination plants.

1. **Wells**

Revise wells flow meter monthly readings, in order to detect any errors, this step can start by programming an excel sheet to monitor production volume in each good facility as suggested below:

Table (5.11): Proposed table for monitoring water wells production

Well Name	Well Number	Monthly Production volume	Results (Cells Programmed with color coding as below)
Example: Well X	Remal No.X	15000	In Production Range
Example: Well Y	Remal No.Y	1000	Lower than production range
Example: Well Z	Remal No.Z	20000	Higher than production range

- Any over estimation or lower estimation can lead to an error in two levels, firstly it can higher than the input volume result on heightening NRW value. Secondly, it can be lower than the input volume and result in lowering the NRW value, in the two cases data given reached us to misleading results.
- Yearly preventive maintenance needed, Gaza municipality has about 69 in service water well.
    - Divide the inspection/maintenance visit into groups can distribute the load monthly, and make the work done effectively and efficiency.
    - About 6 wells needed to be inspected/monthly by flowmeter maintenance technicians, as well as Gaza municipality has a separated section that can deal with this issue.

- As a result of this step, a requirement sheet is established and the technicians defined all their needs, in the other hand a diagnose statues list for each well is established.

2. **Purchased water "Mekorot"**

As a political agreement, PWA reached about 650,000 m^3 of drinkable water, this water is purchased and pumped into Gaza municipality network.

Municipality of Gaza receives this amount and try to pump it to the area which suffering from saline water, this area concentrated in the western part of the city. The proposed management plan of mekorot as follow:

- Install district flow meters at different branches of mekorot.
- Try to analyze the data taken from flow meters in order to make priorities for NRW management.

5.7.2. Authorized consumption

1. **Billed authorized consumption**

   Metered billed consumption

- In the begging must make an urgent intervention to repair water metering system.
- Sorting flowmeter data historically as in table 5.8.
- Preparing a list of long term projects divided into four groups, each group has five projects, the group proposed execution period about 5 years and repeated typically every 5 years. as proposed bellow:

Table (5.12): Proposed plan for meter replacement

Cycle	Stages	Number of Targeted flow meter to repair	Proposed Period To Execute	Proposed Repair Budget (20$/F.M.)
No.X (Starts from flow meter installed older than 16 years)	Stage No. 1	5,000	1 Year	100,000
	Stage No. 2	5,000	1 Year	100,000
	Stage No. 3	5,000	1 Year	100,000
	Stage No. 4	5,000	1 Year	100,000
	Stage No. 5	5,000	1 Year	100,000
	Total for Cycle No.X	***25,000***	***5 Years***	***500,000$***

- This cycle takes about 5 years, the bulk number of inaccurate flow meter replaced and the cost of flow meter repair projects will drop significantly in the next cycle.
- This is a type of sustainability management.

- As a promotion offer for customers (any customer make a self-repair for his flow meter must reward a free 2 months from the municipality and marked as repaired in the database system).
- The municipality will take the old flow meter and guarantee the accuracy of readings without additional costs.
- Start a system for Pre-paid flow meter for a selected authorized category that use the water for business purpose and proposed in the western area in the city sorted by priority such as Tal El Hawa, Southern Al Remal, Northern Al Remal, Al Naser Area

This system proposed to apply for customers sorted with careers (commercial, and industrial), and for household customers tagged with private water wells.

2. Unbilled authorized consumption

Metered unbilled consumption

- This type of consumption relates to a formal agreement with Jabalya municipality from water wells located in its borders to feeds Jabalya customers around the wells.
- Its location mainly in two areas: Al Saftawe area and Bir Al Naja area.
- Flow meters must be installed in all the feeding pipes to Jabalya.
- A flow meter installed in every water well, two district meter also installed by the water department after well "12,15,16" and at the end of carrier line of all the North wells.
- Also, install a check valve after every flow meter in all north wells.
- Make annual maintenance for North water wells and for district meters.
- A capacity building for technician staff in the field of ultrasonic flow meters and electromagnetic flow meters.

Table (5.13): Proposed table to monitor the north wells

Description	***Monthly Data***
Flow Meter Readings	
FM 1	
FM 2	
FM 3	
FM 4	
Flow Meter Volume	
FM 1	
FM 2	

FM 3	
FM 4	
Well	
Sheikh Radwan well no. 10	
Sheikh Radwan well no.11	
Sheikh Radwan well no.12	
Sheikh Radwan well no.15	
Sheikh Radwan well no.16	
Total Northern Wells Production	
Production of Sheikh Radwan well no. (12,15,16)	
Illegal from 12,15,16	
Illegal from 11,10	
Authorized Un-billed Metered from 10,11	
Total Illegal Consumption of Jabalya Municipality	
Total Consumption of Jabalya Municipality	

Unmetered unbilled consumption

This type includes consumptions such as flushing of mains and sewers, street cleaning, firefighting, etc., traditionally including water the utility uses for operational purposes, Usually, it is a small component that is very often estimated from different parties that use this water. Unbilled unmetered consumption.

Planted median of streets:

- Its amount of water can calculate by cooperation with the section in municipalities that responsible for irrigation process.
- Sitting up a list of street names that depend on municipal water for irrigation, then installing a 2" flow meter on its main line in order to calculate the amount of water demanded every month.
- The distribution team is responsible for collecting the readings every first day of the month.

Table (5.14): Proposed monitor volumes consumed for planted streets

#	Distribution Area	Street name	Reading 1	Reading 2	Volume	Notes
1	Naser Team	Street 1	XXX	YYY	ZZZ	-
		Street 2	XXX	YYY	ZZZ	-
		Street 3	XXX	YYY	ZZZ	-
2	Beach Camp Team	Street 1	XXX	YYY	ZZZ	-
		Street 2	XXX	YYY	ZZZ	-
		Street 3	XXX	YYY	ZZZ	-
3	Tal El Hawa Team	Street 1	XXX	YYY	ZZZ	-

		Street 2	XXX	YYY	ZZZ	-
		Street 3	XXX	YYY	ZZZ	-

Cleaning sewerage system

- Three defined points available for teams that cleaning the sewer system, these points can provide water about 24 hours in the day alternately.
- A flow meter installed in these points by water departments to manage this amount of water.
- A proposed table shown below can be used for collecting readings in order to calculate the amount of water used by this part of user as a public service.
- The distribution team is responsible for collecting the readings every first day of the month as follow:

Table (5.15): Proposed monitor volumes consumed for sewerage cleaning

#	Distribution Area	Collection point	Reading 1	Reading 2	Volume	Notes
1	Naser Team	Al SAFA Point	XXX	YYY	ZZZ	-
2	Beach Camp Team	Sheikh radwan well no. 7	XXX	YYY	ZZZ	-
3	Tal El Hawa Team	Well Barchelona No.5	XXX	YYY	ZZZ	-

Table (5.16) : Proposed streets to set flow meter for irrigation purpose

#	Street Name
1	Sharl Degol Street
2	Al Quds Street
3	Ez El Deen Al Qasam Street
4	Naser Street
5	Omer Muktar Street
6	Shuhada Street
7	Basaten Street
8	Yousef Athama Street
9	Kamal Naser Street
10	Mohamed Yousef Najar Street
11	Omer Ben Katab Street
12	Carried tanks for manual irrigation system by cargos

5.7.3. Water Losses

1. **Physical losses**

Defined as a volume of water lost by physical leak or bursts or overflow from the water system, physical losses divided to:

- Leakage on transmission and distribution mains.
- Leakage and overflows from the utility storage tanks.

Leakage on transmission and distribution mains

- Pressure management is one of the major components of a leakage management plan. Pressure level strongly influences burst repetition, preparing a pressure management plan for water network starts by building a good pressure monitoring system.
  - Firstly, setting up a digital pressure gauge at a critical point.
  - Secondly, connect the pressure gauge by a wireless network
  - Finally, connect the wireless network by a control room in the water department center.

Some proposed locations to set the digital gauge pressure on it are shown below

Table (5.17): Proposed pressure gauge location

#	Area	Proposed Pressure Control Points
	East of City	Al Safa Wells
		Abo Ably Well
		Bagdad Street –Heten School
		Al Beltage Street
		Al Halal Well
		South of Al Korba
		East of Al Mansoura
		Mekorot line 1 – Eastern Safad
		Mekorot line 2 – Western Safad
		Al Zahra Well
		Al Nafaq Area
		Al Wehda Street – Abo Ase
	Tal AL Hawa	Barchelona well
		Al Khor Intersection-mekorot
		Jamet Al Doal Street – Al Yazje Bakery
		Jaber Well
		Ansar Intersection
		Al Mena'a Roundabout
		Al Moror intersection
		Remal – Al Kanz Mosque
		Al Shuhada Street – Mustafa Hafez
		Al Sabra Area – Thalathene street – beside GEDCO.

#	Area	Proposed Pressure Control Points
		Asqola Intersection
	Shekh Redwan	Abo Eskandar Area
		Lower Shekh Redwan Bridge
		Upper Shekh Redwan Bridge
		Eastern Naser – East of Rantese hospital
		Parcel 65
		qarashale Area
		Naser – Al Dana building
		Nothern of AL qassam street
		Al Safa water tank
		Al shekh redwan water tank
		Shekh redwan healthcenter well
		Trunk line from North wells
	Beach Camp	Blakhea area
		Al Zeraa intersection
		Halema trunk line At Abo Ali Eyad street
		Al Majadla Area
		Hmaid Street
		Block 1 & 2

- Also, it's important to make a priority sorting for maintenance system, larger in diameter faster in maintenance.
- Urgent response for bursts signs in order to redirect water sources away from this area to decrease the amount of wastewater.
- Replacing all asbestos pipes with U-PVC or steel pipes.
- Assets management, by define areas with deteriorated water pipes, network and need urgent intervention, after data collection from the water department a list of a project proposed as bellow:

Table (5.18): Proposed pipes replacement locations

Area	Neighborhood	Proposed Length(m)
Replacing asbestos	All City	5,000
Al Seka Street	Zayton	1,300
Habosh area	Remal	2,500
Al Zeharna Jalaa Street	Remal	960
Ansar – Al Jazaer street	Remal	650
Beach Camp	Beach Camp	4000
Al Borham Area	Zayton	5,000
Sabra Area	Sabra	10,000
Abu Eskandar	Shekh Redwan	8,500

Area	Neighborhood	Proposed Length(m)
Deferent Areas	-	15,000

- This project proposed to decrease the amount of physical losses that compound from underground leaks and pipe bursts.
- Solving this problem also reflected positively in reducing maintenance cost lead to reduce the operational cost that directly related to the (water cubic meter " tariff ") so customers bill.
- Relating to an effective store system must ensure availability of materials and equipment when needed.

2. **Commercial losses:**

   Meter inaccuracies

Water distribution pattern in Gaza city fall under intermittent supply pattern, this lead to empty the distribution network from water and instead filled with air, in the next wet time while pumping water in a high pressure, the air forced to out from house connections mainly and any other air release valves installed in the pressurized zone, the foregoing results in:

- A faster rotation impeller in multi-jet flow meter leads to break parts or reducing the accuracy of the flow meter with time results in under-register in customer's bill.
- Over-register while metering air flow in customer's bill.

So, the municipality should follow some procedure to eliminate meter inaccuracies problem:

- Follow a fixed procedure for preventive maintenance for customer's flow meters by combining this with a proposed management plan in (Billed Metered Consumption) section.
- Make a long term plan in order to fix an air release valve in all needed points specially in the trunk lines.
- Supervising the installation of flow meters, and recommended to be installed by a special technician.
- Choosing the appropriate class of flow meters, a brief comparison below:

Table (5.19): Flow meter types description

Class Type	Brief Specification	Proposed work location

B	• Lower accuracy than C and D. • Sediments not greatly affect the meter.	• In low water quality areas and high TDS
C	• Acceptable accuracy falls between D and B. • Have good performance in water with a little amount of suspended solids.	• suitable in most situations, because of they more accurate than Class B meters • not expensive as Class D meters
D	• Highest accuracy than C and B • Affected by any suspended solids and sediments.	• Preferred in high-quality water. • Water tanks that feeding roof due to low static pressure and min. velocity.

Unauthorized consumptions

In fact, there is already a system in Gaza municipality to deal with this type of consumption, the action from the municipality starts with a legal procedure by notifying customer to install a flow meter. Then a service bill with estimated consumption issued monthly.

But many customers keep away from installing their own flow meter due to a high amount that will pay to the municipality by linking the meter installation with all other taxes like building organization fees, urban development fees, property taxes and others and didn't prefer to make anything and leave estimated consumption bill published monthly.

A proposed plan to inspect any unauthorized consumption executed every five years at least as follow:

- Dividing the city to 18 districts (neighborhood).
- Preparing a map linked with GIS to identify all buildings with customer's number, a smart phone (Tab) is proposed to use in this stage to eliminate using a map and to efficiently organize the work.
- Synchronization of data available to link field collected data with GIS database.
- The inspector can enter data and compare the mobile map with field to determine any building without at least a customer number and flow meter.
- Also, the inspector can enter the flow meter situation in the system to combining it with the proposed plan of maintain flow meter of authorized meter customers.
- A good advantage for this system is to let the inspector color coding the buildings to easing visual filtering of the map.

5.7.4. Managerial management for NRW

1. **Establishing NRW unit team**

- The team has a member from each related operational department, including production, distribution, finance, customer service and information technology "IT".
- The NRW unit should first set a utility-wide target for NRW reduction, taking into account the utility's other goals and policies and making it more compatible with NRW reduction.
- The cost of water lost is the value of the water lost through both physical and commercial losses.
- As NRW increases, the cost of water lost increases proportionally.
- The cost of NRW management is the cost of reducing NRW, including staff costs, equipment, transportation, and other factors. As NRW decreases, the cost of NRW management increases. Adding the two cost components together gives the total cost.
- The NRW management should be stopped when the management costs more than the price of water lost and this called as the economic point.

2. **Projects action plan**

As a summary of the proposed management plan illustrated in table 5.19 below shown the activities suggested to develop the system in order to increase its efficiency to reach a minimum NRW, also this proposed projects is a base structure to sustainable monitoring and development of the distribution system in the Gaza city.

Table (5.20): Projects action plan

Proj. #	Project description	Project main Component	Proposed execution period	Estimated Cost $
Development of Water Networks				
1	Replacing asbestos	U-PVC Pipes	4 months	500,000
2	Sheikh Redwan	U-PVC Pipes	4.5 months	250,000
3	Sabra Area	U-PVC Pipes	4 months	220,000
4	Al Remal	U-PVC Pipes	3 months	75,000
5	Beach Camp	U-PVC Pipes	3 months	85,000
6	Zayton	U-PVC Pipes	4 months	110,000
7	Shejaea	U-PVC Pipes	2 months	60,000
8	Parts of Jalaa Street	U-PVC Pipes	2 months	60,000
9	Deferent Areas	U-PVC Pipes	6 months	500,000
	Total			**1,860,000 $**
Pressure Management				
11	Pressure Gauge at Al Safa wells Main Lines and related areas in the east of the city.	Installing a pressure gauge and a monitoring room	6 months	200,000
12	Pressure Gauge at North wells Main Lines and related areas.	Installing a pressure gauge and connecting it to the monitoring room	4 months	150,000
13	Pressure Gauge at Mekorot Main Lines and related areas.	Installing a pressure gauge and connecting it to the monitoring room	6 months	150,000
14	Pressure Gauge at Different areas.	Installing a pressure gauge and connecting it to the monitoring room	6 months	150,000
	Total			**650,000 $**
Flow meters Management				
15	Repair 25,000 customers flow meters	Repair or replace flow meters	5 Year	500,000
16	Replace (40) wells flow meters	Replace flow meters	1 year	250,000
17	Install a District meters (12",10",8",6")	Install electromagnetic flow meters	6 months	250,000

Proj. #	Project description	Project main Component	Proposed execution period	Estimated Cost $
	Total			**1,000,000 $**
IT based Management				
18	Developing "NRW Management" program	It mainly used for: • Recording the flow meters readings for resources • Recording district flows meters readings. • Connected it to the digital pressure gauges that mentioned in the plan previously. • Input water balance components. • Warning for preventive maintenance. • Warning for any pressure or flow reading up normal.	1 year	100,000

Chapter 6

Conclusion and Recommendations

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6.1 Conclusion:

- Different official parties related to water sector calculate and present Gaza water system efficiency like PWA, CMWU. But in the calculation steps remarked absence of a comprehensive water balance structure as IWA recommended. PWA stated that the water losses about 39%, and the cooperation between water sector regulator council and Gaza municipality conclude that water losses equal 32.6% and NRW 35.4%.
- Water status of the study area was assessed as follows.
  - Billed authorized consumption includes meter inaccuracies due to exceeding its recommended life span is 20,198,432 m^3.
  - Metered unbilled authorized consumption, amount of water delivered by an agreement between Gaza and Jabalya municipalities, is equal 796,295 m^3.
  - Unmetered unbilled authorized consumption combined of any water used for public service like cleaning sewage system and irrigate planted streets, is equal 42,750 m^3.
  - Physical losses, combined from all types of wasted water physically due to pipe bursts and underground leakage is equal 3,039,597 m^3.

  Commercial losses also contain the illegal consumbtion, customer meter error and data handling errors, the category total water volume is equal 8,305,971 m^3.
- The top-down approach is recommended because of its more suitable to Gaza city water situation system, the total billed authorized consumption is 66.5%, the NRW 33.5%, the total water losses in the system is 30.8%, commercial losses are 27.3% and the physical losses is 10%.
- A sustainable management plan proposed, including three levels of management (regular data collection, monitoring collected data and developing collection tool or instrument).

6.2 Recommendations

- System input volume is a critical amount, and develop its measurement tools must have a top priority, electromagnetic flowmeters are good due to no mechanical parts and high accuracy in collected data.
- Star to replace sources flowmeters also customers as soon as possible, due to its effect in water balance calculations.
- An improvement to the billing system and readings of flowmeters is important, a new technology proposed to be used such as tablets that integrated with GIS maps, to reduce blunder errors, also a check to readings by prevent entering data when the reader spatial location far from the flow meter.
- It is also good for the municipality to categorize discovered illegal customers in the treatment process, to enhance average consumption booked in them new bills.
- Making a feasibility study for doing more efforts to treating illegal demand from the trunk lines and determine where is the economical point between (Investing to decrease NRW) and (the amount of water will be lost if no reaction has taken).
- Installing a district flow meters at least in two locations on Safa No.5 water well, located in the eastern of the city.
- Using water with low quality to clean sewerage system, also installing flow meters on all main lines used municipal water to irrigate planted streets.
- Installing a number of pressure gauge on the network as stated in the management plan in order to operate control efficiently and to decrease physical losses due to bursts.
- Use HDPE pipes for pipes equal or less than 2 inch diameters to reduce breaks, water losses and cost of maintenance, in which 70% of breaks within these diameters.
- Facilitate new customers from making new water account and don't link it with other financial issues, to encourage the people using water as authorized resources and keep them away from taking illegal connections.
- Building a cost calculation system and tariff structure.

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