



**BIRZEIT UNIVERSITY**

**Faculty of Graduate Studies**

**Water and Environmental Engineering Masters Program**

**MSc. Thesis**

**Strategy Development for Condensate Water  
Recovery from Air Conditioning in Palestine**

تطوير استراتيجية لاستخدام المياه الناتجة عن تكاثف الهواء داخل

المكيفات الهوائية في فلسطين

**Master's Thesis Submitted By**

**Lubna SIAM**

**Student number**

**1075340**

**Supervised by**

**Dr. Issam A. Al-Khatib**

**MAY, 2013**



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*This thesis was submitted in partial fulfillment of the requirements for the Master's Degree in Water and Environmental Engineering from the Faculty of Graduate Studies, at Birzeit University, Palestine.*

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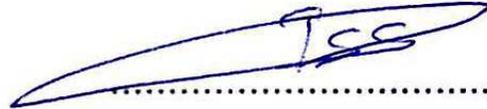
**Lubna SIAM**

This thesis was prepared under the main supervision of Dr. Issam A. Al-Khatib and has been approved by all members of the examination committee.

## Examination Committee:

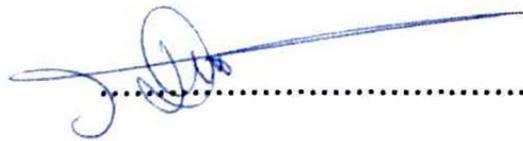
**Dr. Issam A. Al-Khatib**

Supervisor



**Dr. Nidal Mahmoud**

Member



**Dr. Mazen Hamed**

Member



The findings, interpretations and the conclusions expressed in this study do not necessarily express the views of Birzeit University, the views of the individual members of the MSc. Committee or the views of their respective employers.

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## ABSTRACT

As the need for water is increasing in Palestine, and the available water resources are barely meeting the current quality of life and economy. Air conditioning condensate water could be explored as an alternative water source, which could be considered within the global calculations of the water supply. Recovering of the air conditioning condensate water has been recently developed as a new technology which efficiently contributed to the water resources management. The objective of this study is to better understand the potential for recovery of condensate water from air conditioning systems. In addition, this study also evaluated this water source in terms of quality and quantity.

Generally, it was found that the condensate water is at good water quality, which conforms to the Palestinian standards for reused water for irrigation, except for the turbidity measurements. Therefore, if uses for drinking purposes, it might create some concerns linked to taste and color. Reflecting the heavy metals occurrence in the collected condensate water, no particular risk was concluded for the drinking water and the reused irrigation standards comparison. From a single unit capacity high quantity of water was observed at approximately 258.9 L and 453.0 L per month in Ramallah and Jericho cities respectively. This research had outlook an overview about the quantity of water generally generated in Palestine, through the market survey for the units of conditioning system sold in the year 2011. The calculated water volume resulted that the total estimated water generated from the new installed units in the year 2012 is around 46,330 cubic meter. This quantity should draw the attention to the decision and policy makers to put in place strict technical guidelines to be followed the local level.

## الخلاصة

بما ان الطلب على المياه في ازدياد في فلسطين, والموارد المائية المتاحة غير كافية و بالكاد تخدم المستوى المعيشي والاقتصادي. لذلك فإن المياه الناتجة عن المكيفات الهوائية يمكن ان تعتبر كمصدر بديل يؤخذ بعين الاعتبار في حسابات المياه المزودة. ان تطوير تكنولوجيا اعادة استخدام المياه الناتجة عن المكيفات قد تساهم بشكل فعال في إدارة الموارد المائية المتاحة.

الهدف من هذه الدراسة هو فهم أفضل للإمكانيات استخدام الماء المتكثف من أنظمة تكييف الهواء. وبالإضافة إلى ذلك، فإن هذه الدراسة أيضا تقييم هذا المصدر المائي من حيث النوعية والكمية.

بشكل عام، وجد أن نوعية المياه المتكاثفة في جودة جيدة، تتفق مع المعايير الفلسطينية للمياه المعاد استخدامها لأغراض الري، باستثناء قياسات التعكر. لذلك، إذا استخدمت هذه المياه لأغراض الشرب من المحتمل ان تخلق بعض التخوفات للمستخدم بما يخص الطعم واللون.

بالنسبة لقياسات المعادن الثقيلة في المياه المتكاثفة التي تم جمعها، لم يكن هنالك أي خطر على وجه الخصوص لمياه الشرب وإعادة استخدامها للري مقارنة بالمعايير الفلسطينية.

من وحدة تكييف واحدة لوحظ إنتاج كمية عالية من المياه، 258.9 لتر و 453.0 لتر شهريا في مدينتي رام الله و أريحا على التوالي.

كان هذا البحث لمحة عامة عن توقعات كمية المياه الناتجة عموما في فلسطين من المكيفات الهوائية، من خلال مسح للسوق الفلسطيني للوحدات التي تم بيعها في العام 2011. إن إجمالي المياه التقديرية المتولدة من الوحدات الجديدة فقط في عام 2012 حوالي 46330 متر مكعب. يجب أن تلفت هذه الكمية نظر صانعي القرارات و السياسات لوضع مبادئ توجيهية ينبغي اتباعها على المستوى المحلي.

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**LIST OF ABBREVIATIONS**

km <sup>2</sup>	Square Kilometer
km	Kilometer
mm/yr	Millimeter per year
MSL	Mean sea level
PCBS	Palestinian Central Bureau of Statistics
M/SEC	Meter per second
L	Liters
L/c/d	Liters per capita per day
Mcm/yr	Million cubic meters per year
Mcm	Million cubic meters
mm	Millimeter
m	Meter
AWVP	Atmospheric water vapor processing
IAQ	Indoor air quality
HVAC	Heating, ventilating, and air conditioning
AC	Air Conditioner
NWQMS	National water quality management strategy
PSI	Palestinian Standards Institute
PWA	Palestinian Water Authority
WHO	World Health Organization

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## CHAPTER ONE INTRODUCTION

### 1.1 Overview

In Palestine, the need for water is increasing with the current political situation, population growth, and high rate of urbanization. The depletion of fresh water resources keeps continuing as the demand for irrigation, industrial and municipal water keeps escalating. In Palestine, the available present conventional water resources are hardly sufficient to be maintained for the current quality of Palestinians' life and economy. Moreover, it is considered to be one of the countries with the scarcest renewable water resources per capita due to several constraints. The majority of the supplied fresh water in Palestine, come from scarce groundwater resources. This places the future population and its associated water demands, under severe pressure with these limited groundwater reserves (Al-Salaymeh et al., 2011). Exploring alternative sources of water play a vital role in water supply, when fresh water including the surface and the ground water become limited. Therefore, saving, reusing/recycling/recovering and developing new water technologies will improve the water resources management. Condensate water harvesting is one of the main approaches that could enhance efficiently the water management that contributes in stabling the Palestinian convoluted context.

### 1.2 Statement of the Problem

As the present water supplies in the Palestinian region are neither adequate to provide acceptable decent living standards for the Palestinians, nor sufficient to facilitate development of their economic status. The need for exploring new sustainable water sources started to be at great importance, where new techniques should be tested and developed at every level. In the

meanwhile, cooling systems generate significant condensate water volume, which is most of the time connected to the drainage system and wastes. This source of water is considered to be significant and under-utilized, which at least could be collected and used to serve landscape irrigation purposes. It is predictable, reliable, and high quality, and occurs during summer months when irrigation needs are high.

### **1.3 Research Questions**

The research aims at answering the following questions related to the condensate water harvesting:

- How much water is being generated from air conditioning systems?
- How much water condensate is wasted?
- What is the quality of the generated condensate water?
- Why people are not considering the generated water as an alternative source of water?
- What are the use possibilities of this water, and what adjustments are needed?

### **1.4 Research Objectives**

The main purpose of this research is to better understand the potential for recovery of condensate water from air conditioning systems. The research also aims at investigation on this water source by assessing the qualities and measuring the quantities of the generated condensate water. The specific objectives of this research are to:

- 1) Assessing the chemical and microbial water quality parameters in the condensate water generated in the two cities of Ramallah and Jericho.

- 2) Assess the relation between the condensate water quantity and the condition system specifications.
- 3) Estimate the yearly condensate water generated by the supplied air condition systems in Palestine.
- 4) Better understand the perception of users' knowledge, behavior and attitudes regarding the use and the management of the condensate water as a new water source.
- 5) Propose a technical adjustment that could be taken into consideration to collect the generated condensate water.

### **1.5 Significance of the Study**

This research will be considered as a significant attempt in assessing quantity and quality of the condensate water generated in Palestine. This study will contribute in enhancing the knowledge of the users' on water conservation, water usage efficiency and thus environmental sustainability. The results of this research will provide some insight and information for further research for water scientists. The study provides a scientific discussion concerning water quality issues and intends to provide useful information on common methodologies that could be adopted to use the condensate water.

### **1.6 Approach and Methodology**

The overall research method used in this study is based on an interdisciplinary and integrated approach comprises of a combination of directions. This research is both desk-based and field-based. Scholarly articles consist of literature studies of published material and data from in the area of interest were reviewed and considered as secondary source of information. In particular, in regards to the condensate water assessments, water quality assessments and standards and the

generated water quantities by cooling systems. In addition, the primary source of data on condensate water quality and quantity was collected through sampling campaign in the two cities of Ramallah and Jericho in the summer time. Semi-structured Interviews were also carried out with the main suppliers in the air conditioning system as an aid to reveal essential primary data. Research data was sourced, collected and collated accordingly. A questionnaire survey was conducted towards 85 users, to restate selected results and to provide the additional safety aspect of air condition users' perception to the discussion of water conservation.

### **1.7 Thesis Outline**

This thesis is composed of six chapters. Chapter One presents general introduction to the content and structure of the research, including the statement of the problem, research questions and objectives and research assumptions and limitations. Chapter Two offers information describing the study area of Ramallah and Jericho cities. Chapter Three, the literature review, discusses condensate water consideration in terms of quality and quantity, presentation of condensate water management plans, water quality standards, and previous initiatives capturing air-conditioning condensate. Chapter four explains the approach and methodology adopted in this research from the main objective of the research the data collection and analysis process. Chapter Five provides the results and analysis of the gathered information, whereas chapter six draws the conclusion and final recommendation of this research.

## CHAPTER TWO

## STUDY AREA

This chapter presents the research's targeted area study. In this chapter, necessary information related to Jericho City and Ramallah governorate, was gathered and discussed. Based on the Palestinian Central Bureau of statistics, Palestinian Water Authority and World health organization, records and recent studies, along with scientific articles, the presented information was articulated as: Location, climate (rainfall, temperature, humidity..etc.), topography and drainage, land use, wastewater situation, demography and population and water resources, supply and demand.

### **2.1 West Bank Location**

The West Bank is an area of 5800 km<sup>2</sup>, 130 km from north to south and between 40 and 65 km from east to west that is, from 31° 30' N to 32° 30' N and from 35° E to 35° 30' E, figure 2.1 shows the location map for the West Bank. According to the recent studies, the West Bank holds a population of approximately 2,649,020 persons (PCBS, 2012).

The West Bank climate is highly influenced by the Mediterranean climate with dry, hot summers and cool, wet winters climate becomes more arid to the east and south. The western winds are moist as they come from the Mediterranean Sea. In the northern parts, these winds moves freely and give the areas a marine influence on the climate. In the southern parts, the terrain is hillier and serves as a barrier to the moist air. This leaves the winds reaching the southern parts drier. The rain season is between October and April and the highest rainfall month is January (Eklund, 2010).

The mean annual temperature is around 15-17°C degrees in the highlands around Hebron and Ramallah, 17-18°C degrees around Bethlehem, Jerusalem and Nablus (Eklund,2010).

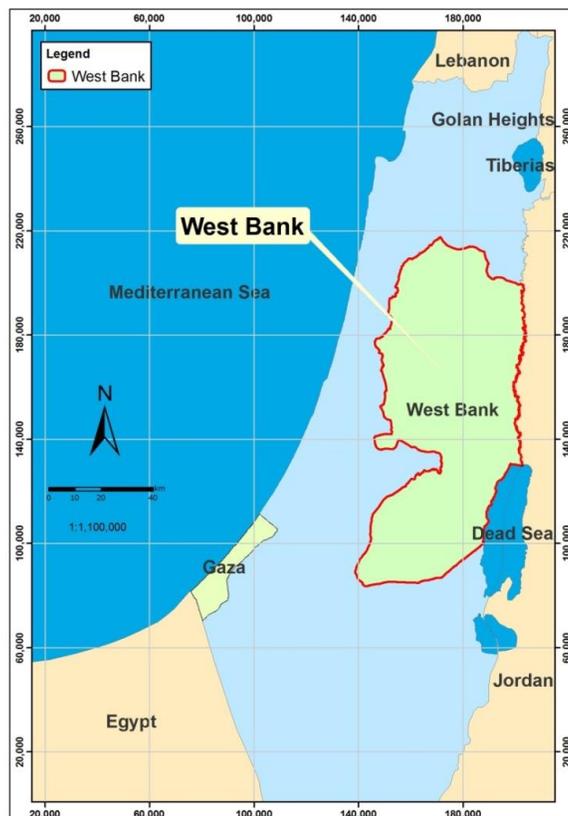


Figure 2.1: Location map for the West Bank (PU-AMI, 2011)

In the Jordan Valley and around Jericho, the mean annual temperature is 24-25 degrees. In the south, climate is affected by the Negev Desert to the west and the Arabian Desert to the east. Sand storms with hot winds containing sand and dust are common during spring and early summer (Eklund, 2010).

The rainfall on the central Highlands averages 700 mm/yr and becomes less than 100mm/yr at the Dead Sea. The distribution of rainfall is strongly influenced by the topography, with higher rainfall in the hills and mountains (Abdul-Hamid, 2008). The terrain of the West Bank is hilly with the

lowest point at -408 meters below Mean Sea Level (MSL) at the Dead Sea and the highest point at Tall Asur with 1022 meters above MSL. In terms of geomorphology, the West Bank can be divided into four major areas, Nablus Mountains, Jerusalem Mountains, Hebron Mountains and the Jordan Valley (Eklund, 2010).

The main land use in the West bank is mainly considered to be agricultural, around 54.8% of the mass area consisted of arable land, pastures, crops and other agricultural areas. The main waters in the West Bank are the Dead Sea and the Jordan River, both also having shorelines in Israel and Jordan. Palestinian built-up areas take up 5% of the area while 4% of the West Bank area consists of Israeli settlements, outposts and military areas (Eklund, 2010).

## **2.2 Jericho City**

Jericho City is located in the West Bank, near the Jordan River as shown in figure 2.2. The city is leveled at -250 meters below Mean Sea Level (MSL), to be marked as the lowest living city on earth. Jericho is considered as not oldest city in the world, with the oldest continuously occupied settlements. The desert climate is dominant in Jericho, to be considered as an oasis since it is watered by many springs. This characteristic makes it an important agricultural area, especially for fruits and vegetables (HWE, 2010).

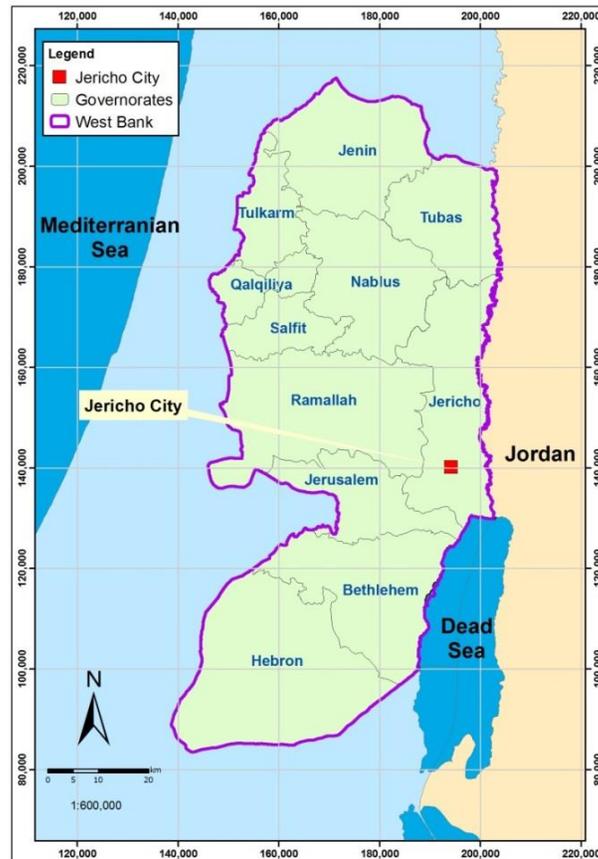


Figure 2.2: Location map for the Jericho City (PU-AMI, 2011)

## 2.2.1 Climate

The climate of Jericho is classified as arid which has hot summer and warm winter with very rare frost incidents.

### 2.2.1.1 Rainfall

The rainfall is mostly concentrated between December and March (PCBS, 2010). In general, the distribution of rainfall is strongly influenced by the topography, with higher rainfall in the hills and mountains (HWE, 2010). The average quantity rainfall was recorded by the Palestinian Meteorological Department, with over 80 rainfall stations distributed geographically from the

northern to the southern parts of the West Bank. The main findings of the time series indicate that the annual quantity of rainfall in Jericho governorate in 2010 was 124.2 mm (PCBS, 2010).

### **2.2.1.2 Temperature**

Since the Jericho city is the lowest in the West Bank, it has the highest temperatures compared to other governorates. The mean annual temperature is 25.6 °C, as stated by the PCBS in 2010, and the maximum annual average temperature is 32.3°C whereas the minimum annual average temperature is 19.5°C (PCBS, 2010). The month of January is considered to the coldest month with the minimum temperature.

### **2.2.1.3 Humidity**

The average annual relative humidity in the Jericho was 43% in 2010, according to the reports statistics measured in 2010 by the PCBS, the humidity in Jericho reaches its highest rates during the months of January and February, whereas the annual mean of relative humidity decreased in May to reach 38% (PCBS, 2010).

### **2.2.1.4 Wind**

The average daily wind speed in the district is around 4.5 m/sec throughout the year, the daily wind direction changes from a northwestern at night to southern in the early morning (PCBS, 2010).

## **2.2.2 Topography and Drainage**

The topography of the city of Jericho shows continuous decrease in elevation from about – 150 meters below Mean Sea Level (MSL) in the East to almost – 300 meters below Mean Sea Level

(MSL) in the West (HWE, 2010). There are six main wadis cross the Jericho region, mainly Wadi Al-Mallaha, Wadi Al-Auja, Wadi Abu Ubeida, Wadi An-Nuw'ema, Wadi Al-Qilt and Wadi Al-Ghazal. Wadi Al-Mallaharuns northsouth, while the remaining five wadis run eastwest. Wadi Al-Auja and Al-Qilt have permanent water flow while the rest are intermittent. Figure 2.3 shows the drainage wadis in the Jericho area (HWE, 2007).

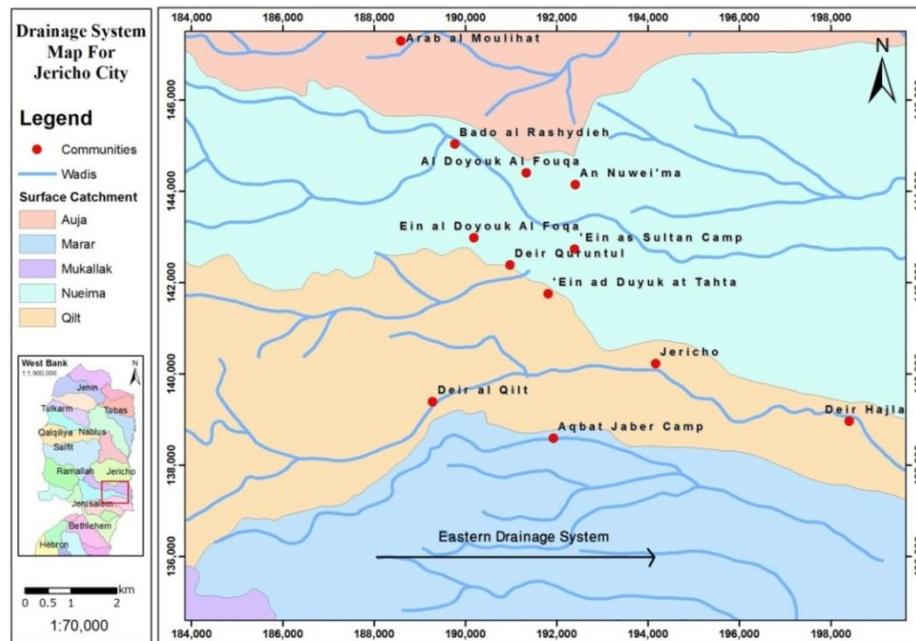


Figure 2.3: Drainage systems in Jericho City (PU-AMI, 2011)

### 2.2.3 Land Use

The Jericho City within its municipality master plan, covers an area of approximately 45 km<sup>2</sup>. This makes up about 0.8 % of the West Bank and 0.740% of the Palestinian territories (Gaza Strip and West Bank) (PCBS, 2008). There are different land use classes within the city boundaries, this includes Palestinian built up areas, Israeli settlements, cultivated areas, forests, nature reserves and Industrial areas. There are about seven Palestinian built up areas in the City; Jericho City, Al Nuei'meh, EinDuyuk Al Foqa, EinDuyuk Al Tahta, DierQruntul, DierHijlaand Dier Al Qilt. In

addition, there are two refugee camps, AqbatJaber and Ein as Sultan Camps, and five Israeli settlements. Figures 2.4 and 2.5 shows the built up areas and the land use maps in Jericho.

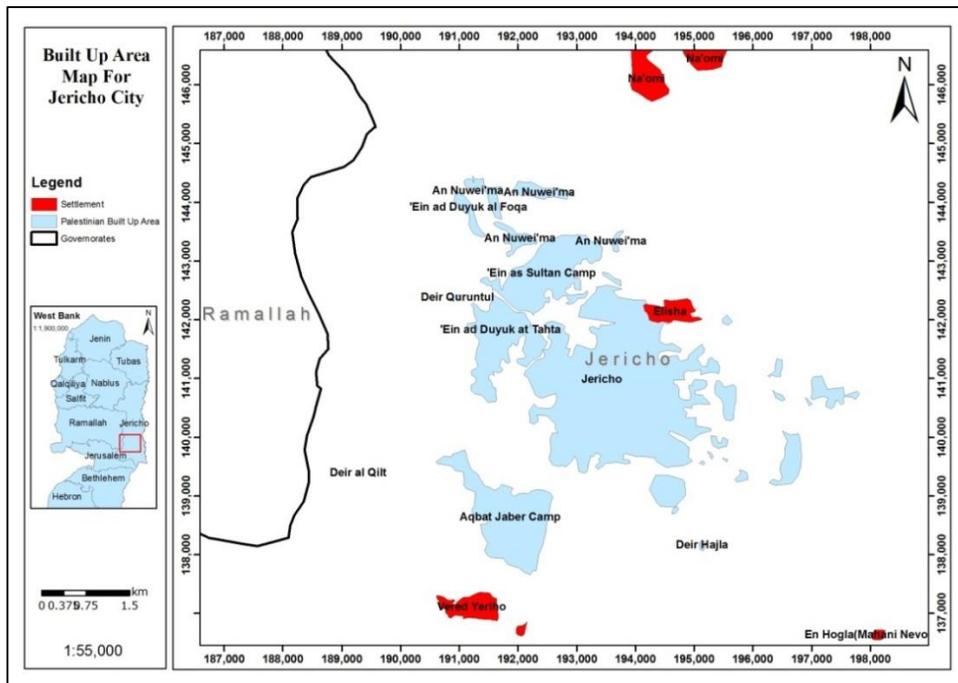


Figure 2.4: Built up area of Jericho City (PU-AMI, 2011)

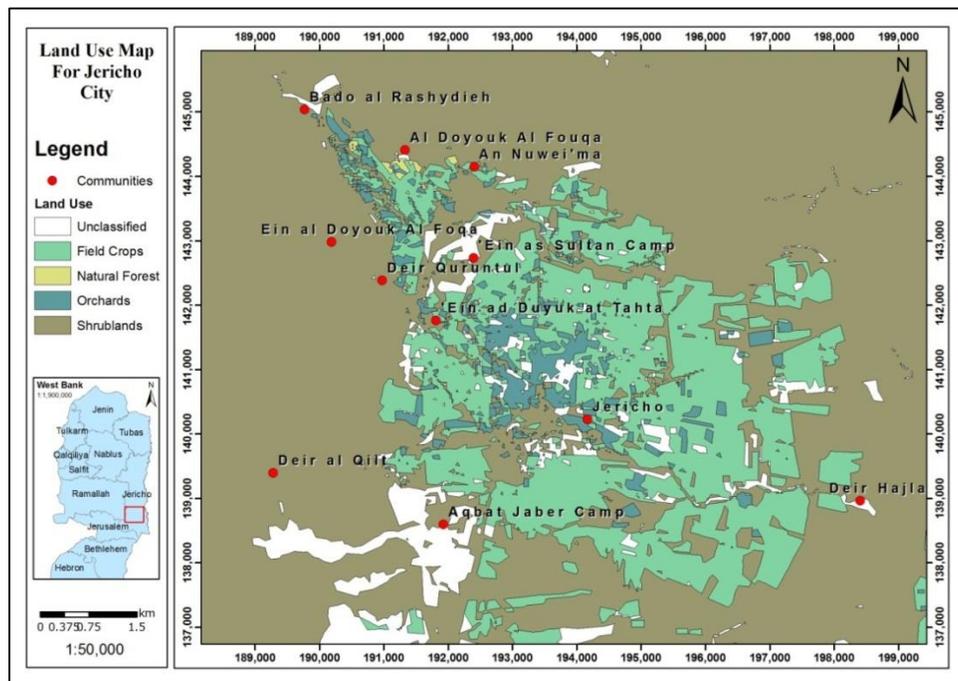


Figure 2.5: Land use map of Jericho City (PU-AMI, 2011)

### 2.2.4 Demography and Population

The Jericho District has a relatively low population density, in comparison to other regions in the West Bank. This is due mainly to the large Israeli designated closed military areas, military bases, nature reserves and the Israeli settlements located there (HWE, 2010). The population of the city of Jericho alone is 20,826 and 4,549 housing unit as per the census of 2012. The average size of the governorate households is 5.5 and the population natural increase rate is 3% persons (PCBS, 2012).

### 2.2.5 Ground Aquifers

As shown in figure 2.6, the City of Jericho lies over the Western Aquifer Basin, which included several aquifer systems; Lower Cenomanian Aquifer System, Upper Cenomanian-Turonian Aquifer System, Tertiary Aquifer System, Quaternary Aquifer System (HWE, 2010).

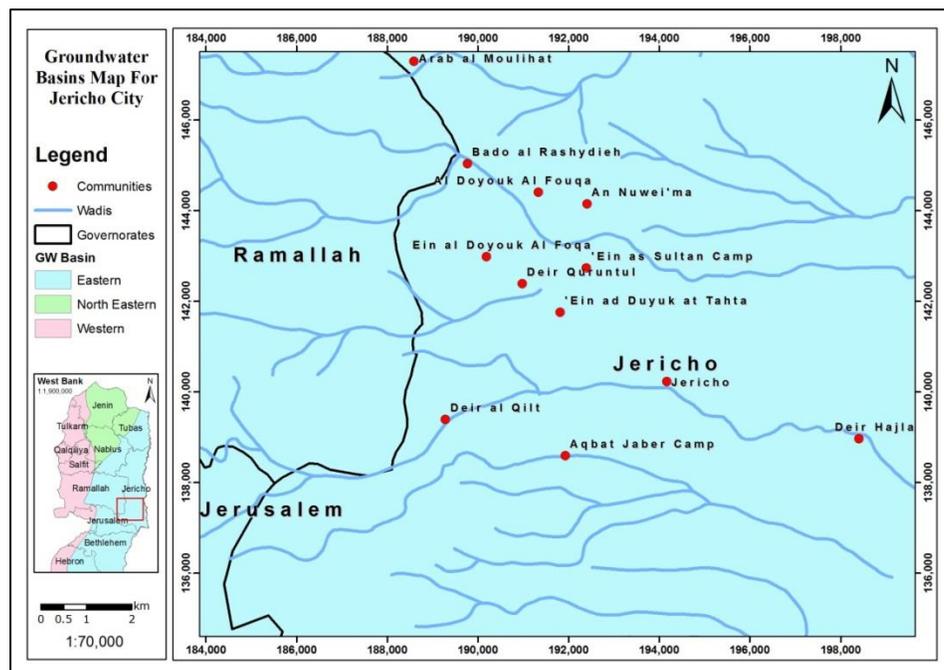


Figure 2.6 Groundwater Basins in Jericho (PU-AMI, 2011)

### **2.2.6 Water Demand**

In calculating the water demand for Jericho City, the World Health Organization standard for the amount of required water for drinking and other domestic uses per capita of 150 L/c/d is adopted (WHO, 2008). Considering the population consensus for 2012 was 20,826 inhabitants, the needed amount of water is about 1.14 Mcm/yr. According to the Municipality of Jericho calculations for the per capita daily allocation of water from the quantity of water supplied, which is about 1.8 Mcm/yr, with a population of about 20,826 leading to a daily allocation per capita of around 250 l/c/d. The Palestinians can supply the whole water quantity from their own resources from Ein Al Sultan Spring; 42% of its discharge goes to cover the domestic use (Jericho Municipality, 2011).

### **2.2.7 Water Supply**

The main water resources in the West Bank, and region as a whole, are groundwater aquifers. Wells and springs constitute the main sources of water in the West Bank. Surface water and seasonal small rivers running in the wadis can also be considered as additional water sources which are used mainly for agricultural purposes. The main available water resources for the Jericho city is the ground water. The main groundwater resources withdrawal is from springs (Jericho Municipality, 2011).

#### **2.2.7.1 Domestic and Agricultural Water Resources**

In Jericho, the main source of domestic water supply is the Ein Al Sultan spring, spring located to the east of Wadi Al-Qilt in Jericho city, it is related to the Upper Cenomanian-Turonian Aquifer. This spring is operated by the Jericho Municipality and Ein Al Sultan Water Association. This

spring is discharging annually about 5.5 Mcm, with percentages of 42% and 58% for domestic and agricultural uses respectively (Jericho Municipality, 2011).

#### **2.2.7.2 Wastewater Infrastructure**

Similar to other Governorates in the West Bank, the responsibility of wastewater management in the Jericho City is through the municipality. Wastewater collection networks are totally lacking in the City. Cesspits are the only commonly used method of wastewater disposal. Cesspits serve either a single house or sometimes a cluster of houses (Jericho Municipality, 2011).

### **2.3 Ramallah Governorate**

As shown in figure 2.7 the Ramallah District is located at the central are of the West Bank, it oversees Palestinian coastline on the West side.

It is bordered by the Jerusalem governorate in the south, the Nablus and Salfit governorates in the north, Jericho governorate in the east, and the 1948 borderline between Israel and West Bank from the west. Nowadays, Ramallah city is considered as the temporary capital of the coming Palestinian state due to its proximity to historical capital of Palestine, Jerusalem.

#### **2.3.1 Climate**

The Mediterranean type climate is mainly dominant in the area of Ramallah. In winter the area is subjected to short, cool, rainy season, and long, warm, dry summers.

### 2.3.1.1 Rainfall

Over the year, the rainfall is only limited between the months of December and April. The topography of is strongly influencing the distribution of the rainfall. . The annual quantity of rainfall in Ramallah governorate in 2010 was 502.1 mm (PCBS, 2010). The average annual rainfall is higher in the western part of the governorate than the eastern part. The average annual rainfall in the eastern part of the governorate varies from 200 to 450 mm, whereas in the western part of the governorate, the average annual rainfall varies from 350 to 550 mm. In the mountains the average annual rainfall heights vary from 550 to 700 mm (HWE, 2009).

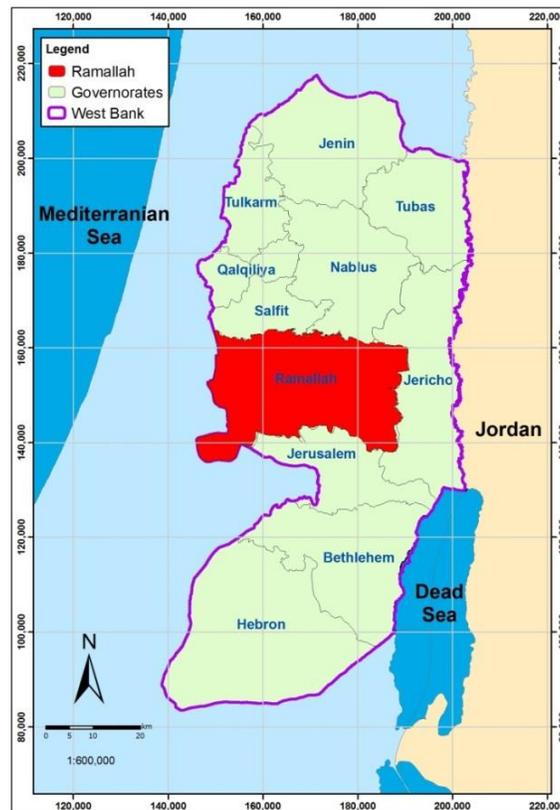


Figure 2.7 Location map for Ramallah Governorate (PU-AMI, 2011)

### **2.3.1.2 Temperature**

Ramallah has lower temperatures compared to other area; the mean annual temperature is 18.6 °C and the maximum annual average temperature is 23.1°C whereas the minimum annual average temperature is 15.4°C. The month of January is considered to be the coldest month with temperatures around 9°C, while August is the hottest month with temperatures between 26-31°C (PCBS, 2010).

### **2.3.1.3 Humidity**

The average annual relative humidity in the Ramallah reached 57%, where the highest rates were measured during the months of January and February. For the extreme maximum relative humidity, the highest value was 100% registered for (January – April) in Ramallah Station (PCBS, 2010).

### **2.3.1.4 Wind**

The yearly wind speed measured by the station locate in Ramallah in 2010 was 10.7 km/hour. According to the PCBS, 2008; the average daily wind speed was measured to be 16.0 km/hour in December, in the direction of the west-east direction. In summer, the direction of the wind is mainly northwestern and northeastern, it is hot and dry with an average wind speed of 18.6 km/hour in August (PCBS, 200810).

## **2.3.2 Topography and Drainage**

There is a wide variation of the elevation difference in the topography of Ramallah. The highest point in the governorate is 1,022 m above sea level at Tal A'sur, whereas the lowest elevation is 100 m below sea level at the southeast corner of the governorate. The topography of Ramallah is

divided into three main parts: the eastern slopes, mountain crests and western slopes. The eastern slopes are located between the Jordan Valley and the Mountains and are characterized by steep slope forming wadis. Whereas, the Mountain crests forms a steep water divide line that separate the eastern and western slopes, with an elevation ranging between 750 and 800 meters above sea level. And the Western slopes are characterized by gentle slopes with an elevation ranging between 250-500 meters above sea level (HWE, 2009). There are two major drainage systems in the Ramallah region: The first system runs to the west towards the Mediterranean while the second one runs to the east towards the Jordan River as shown in 2.8. Figures 2.8 shows also the groundwater divide and the surface water divide do not coincide on the same line. As it can be seen for the surface water divide, Ramallah drains to the west while Al-Bireh drains to the east. As for the groundwater flow movement, both cities drain to the east. (HWE, 2009).

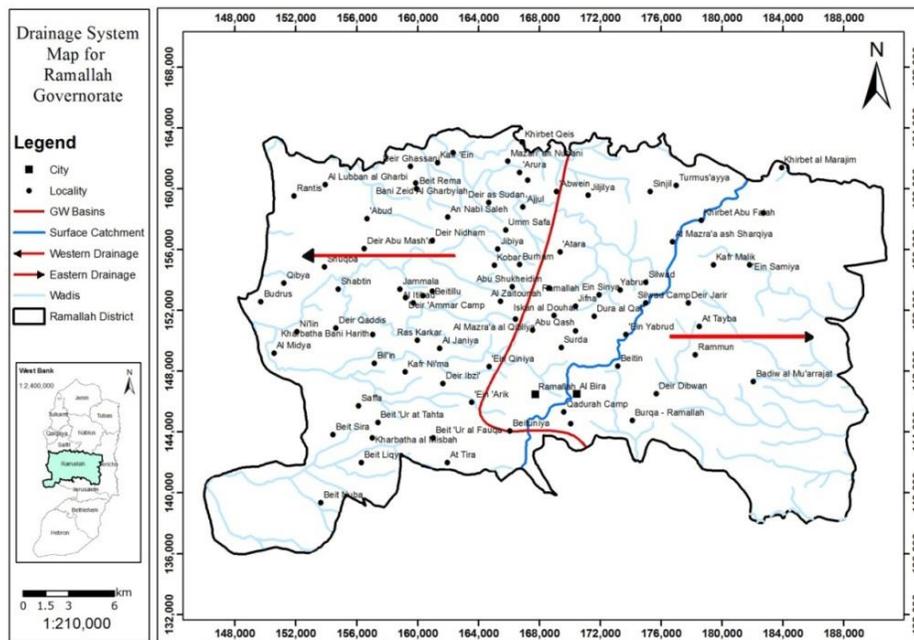


Figure 2.8: Drainage systems in Ramallah Governorate

### 2.3.3 Land Use

Ramallah governorate covers approximately 855 km<sup>2</sup>, comprising 15.1% of the West Bank and 14.2% of Palestine (Gaza Strip and West Bank) (HWE, 2009). The different land use classes within the Governorate boundaries, includes Palestinian built up areas, Israeli settlements, cultivated areas, forests, nature reserves and industrial areas. There are 24 Israeli settlements in the Ramallah governorate occupying approximately 30.27 km<sup>2</sup> of the district's land (3.54 % of the total district's land). The total cultivated area in Ramallah governorate covers approximately 184.9 km<sup>2</sup> (PCBS, 2008). Rain-fed agriculture is the most dominant farming pattern in the district, occupying approximately 184.4 km<sup>2</sup> while the rest is irrigated (see Figure 2.9).

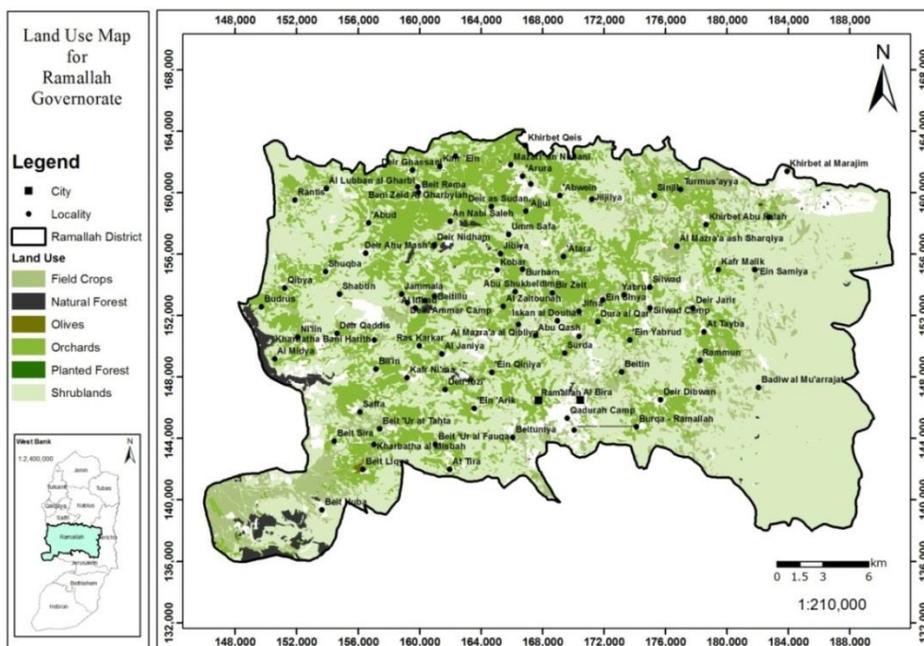


Figure 2.9: Land Use Map of Ramallah Governorate (PU-AMI, 2011)

There are about 80 Palestinian built up areas in the governorate. Ramallah, Al-Bireh, Silwad, Bani Zeid, Birzeit, Deir Dibwan and Bitunia are the only communities designated as municipalities. Village councils govern other built up areas. In addition, there are five refugee camps, Al-Amari,

Qaddura, Al-Jalazone, Silwad and DeirA'mmar. Figure 2.10 shows the built up areas in Ramallah governorate (HWE, 2009).

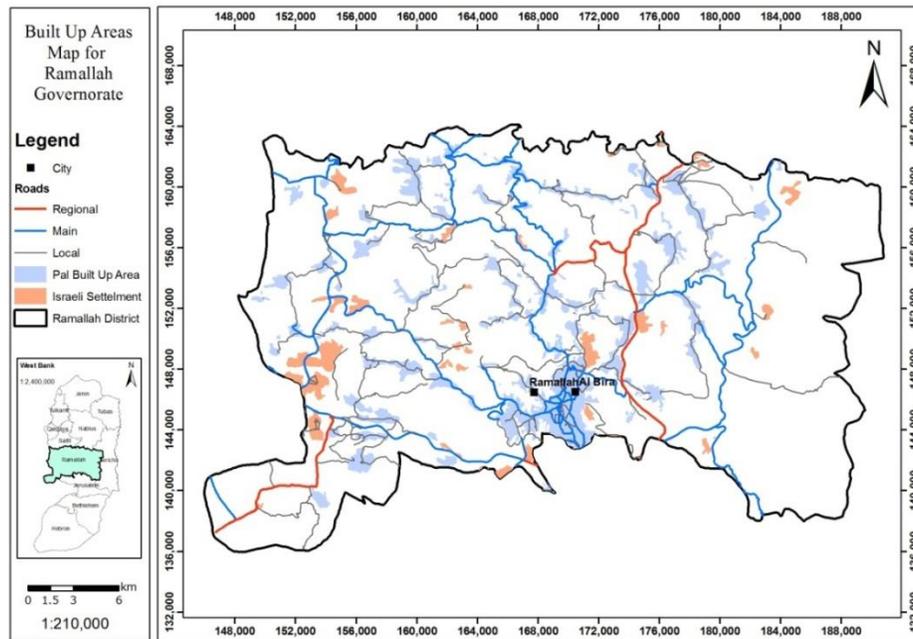


Figure 2.10: Built up areas Map of Ramallah Governorate (PU-AMI, 2011)

### 2.3.4 Demography and Population

The population of Ramallah governorate is approximately 319,418 persons (PCBS, 2012). The population of Ramallah governorate can be classified by type of locality, where 180,790 or 56.6% of the total governorate population live in urban areas, 120,101 or 37.6% of the total governorate population live in rural areas, 18,526 or 5.8% of the total governorate population live in camps. The total number of households in the governorate is 60,267, where 34,111 are located in the urban areas, 22,660 are in the rural areas, and 3,496 are in camps. The average size of the governorate households is 5.3 and the population natural increase rate is 3 % (PCBS, 2012).

### **2.3.5 Groundwater Aquifer Basins**

The West Bank lies over three main aquifer basins: Eastern, Northeastern and Western Basins. Ramallah governorate lies over the Eastern and Western Basins. The Eastern Aquifer Basin underlies the Eastern part of governorate. Its water flows towards the east and southeast. The Western Aquifer Basin underlies about 45% of the Ramallah governorate to the west and its water flows towards the west (HWE, 2009).

### **2.3.6 Water Demand and Consumption**

In calculating the water demand for Ramallah governorate, the World Health Organization standard for the amount of required water for drinking and other domestic uses per capita of 150 L/c/d is adopted (WHO, 2008). Considering the most recent population consensus for 2012 was 319,418 inhabitants, the needed amount of water is about 17.5 Mcm/yr. According to PWA supply reports and studies, the calculated the per capita daily allocation of water for Ramallah governorate from the quantity of domestic water supplied, which is about 16.6 Mcm/yr with a population of about 319,418 leading to a daily allocation per capita of 142.38 L/c/d. The deficit between the supply and demand quantities is 0.9 Mcm/yr. Palestinians can supply only about 18% (2.9 Mcm/yr) from their own resources; the rest are purchased from the Israeli water company 'Mekorot' (PWA, 2013). According to PWA, the actual water consumed for domestic sector is 12.5Mcm/yr, therefore the actual measured deficit due to water losses is, 4.2 Mcm/yr. This leads an actual daily allocation per capita of 107 L/c/d (PWA, 2013).

### **2.3.7 Water Supply**

The main available water resources for the Palestinians living in Ramallah, is the ground water, except for small- scale rainwater harvesting in rural areas (Abdul-Hamid, 2008). In addition to the

Groundwater resources which are mainly withdrawn from wells and springs, the Palestinians purchase water from the Israeli water company 'Mekorot' (PWA, 2013).

### **2.3.8 Domestic Water Resources**

In the Ramallah governorate, the sources of domestic water supply can be divided to; local resources (Palestinian wells and springs) and purchased water resources. According to PWA updated reports, about 18% (2.988 Mcm) of the water supplied yearly to the inhabitants are obtained from the local resources in the Ramallah governorate, mainly the Ein Samia groundwater wells. Whereas, 82% (13.612 Mcm) of the yearly supplied water is purchased from Mekorot (PWA, 2013).

### **2.3.9 Wastewater Infrastructure**

Wastewater is considered the most important threat to the groundwater quality in Ramallah governorate. There are few communities within the governorate that are served by sewerage collection system; 204, 7220 of the governorate population are not connected to any sewerage collection system (PCBS, 2011). According to HWE reports, 2006 it is highlighted that the rest majority of the Palestinian rural villages in the Ramallah governorate, are still using cesspits or septic tanks for wastewater disposal. Consequently, wastewater infiltrates from these cesspits to the groundwater aquifers. Whereas, septic tanks are evacuated by vacuum tankers, the content usually is discharged "with high contaminant concentrations of BOD, TSS, and Bacteria" to the nearby open environment (wadis, open lands), sewerage and irrigation systems, or even to solid waste disposal sites. (HWE, 2006)

**CHAPTER THREE****LITERATURE REVIEW**

This chapter reviews the literature on the recycled and reused water, condensate water consideration in terms of quality and quantity, condensate water collection methods in lined with baseline water footprint, presentation of condensate water management plans, water quality standards, and previous initiatives capturing air-conditioning condensate. Knowing the importance the condensate water generated by the cooling systems, unfortunately there is no wealth of literature on the topic.

**3.1 Introduction**

The current unstable political conditions are leading to scarcity of water resources in Palestine; where the Israeli Occupation is utilizing more than 85% of the groundwater resources in the West Bank and denied Palestinians access to their natural and historical water rights in the Jordan River (Aliewi et al., 2008). Access to water is a final status issue of key importance, Palestinians' water access is variable, and water is of dubious quality. Water pollution is a key challenge in the West Bank of Palestine, where the water quality is governed by many factors. The absence of wastewater collection systems and the spread of cesspits in the majority of the rural areas, are considered as the reasons of water contamination. In addition, the leachate from random solid waste dumping sites, the runoff from urban drainage, and the fertilizer and pesticide residues, are also contributing to the water contaminations (Al-Salaymeh et al., 2011).

As the Palestinian water sector situation has been reviewed thirteen years after the Oslo accords; one third of the Palestinian communities across the West Bank, comprising about 10% of the total population, still lacks proper water network supply services. Accessing springs, using harvesting

cisterns and water tankering are considered to as the typical used coping mechanisms for unconnected communities. Moreover, unserved communities pay very high expensive prices for often poor water quality. More specifically, the available domestic water for the Palestinians averages at 50 L/d per person, which is supplied in a very variable and discontinuous pattern. Quarter of the water connected Palestinian population are supplied with less than 50 L/d, with some water supply services providing as little as 10-15 L/d (World Bank, 2009). In lined with the world's consideration, the minimum quantity of 135 L/d per person is estimated as a minimum requirement for a country human health, economic and social development (Chenoweth, 2008).

The reality of the constrained water supply must be managed in both economic and political directions, therefore changing the demand and supply patterns might lead to a sustainable balance. The importance of saving every water drop and using water more efficiently should remain the top priority and major concern. This could be mitigated by initiating saving, reusing and recovering technical technologies.

### **3.2 Recycling and Reuse of Water**

Through water recycling or reuse techniques, several water sources that have been conventionally wasted, such as storm water, sewage effluent and grey water; can become a valuable resource. According to National Water Quality Management Strategy (NWQMS, 2006), developed by the Environment Protection and Heritage Council, the Natural Resource Management Ministerial Council and the Australian Health Ministers' Conference, there are two distinct advantages that can be considered through water recycling or reuse:

1. Provision of additional water sources for various purposes, including many that are provided by constrained freshwater resources (NWQMS, 2006).

2. Reduction of the discharge of wastewater into receiving environments. This aspect is considered as a vital driver for the water recycling concept, whereas it is often highlighted in the planning and development of recycled water schemes (sewage collection and treatment systems) (NWQMS, 2006).

Water recycle and reuse are considered as good environmental practices, considering that their implementation is highly dependent on the economics and hence can be challenging to implement (EPA, 2007). However, following the National Water Quality Management Strategy, in reduction of the wastewater discharge, can be developed and planned simply at the household level. Consequently, this research studies where this can be undertaken sufficiently by the engagement of potential users of conditioning systems. A development of condensate water recovery can be designed in lined with the second advantage of the National Water Quality Management Strategy. Where condensate water is mostly discharged as wastewater into the environment.

### **3.3 Atmospheric Water Harvesting**

Since the problem of water scarcity is severe in arid zones and many countries such as the Gulf States. Where, some of the Gulf countries rely seriously on water desalination technology to overcome the dearth of water resources. However, present desalination techniques consume a lot of energy that is mainly generated by burning fossil fuels, which is a depleting source and better is conserved for the future. Hence, several universities and research centers have been engaged over the past years in comprehensive studies on innovative ideas to get potable water. These experiments had been carried out by United Nations experts, to be applicable in particular for developing countries (Habebullah, 2008).

Atmospheric water harvesting or atmospheric water vapor processing (AWVP) has been experienced as an emerging technology in which the atmospheric water vapor is condensed and collected. Different techniques have been developed to extract the water vapor from the air, examining larger scale schemes. Experiments had been carried out in Sweden, Tanzania, Tunisia, France, Bahrain, Chile and Saudi Arabia. Some of the techniques were considered as being not economically feasible for large scales. Therefore in general, atmospheric water harvesting or atmospheric water vapor processing (AWVP) is relatively new technology for small-scale, locally managed water supplies (Habeebullah, 2008).

Three main approaches had been studied and considered in which the atmospheric water vapor might be collected:

1. Water collection on cold surfaces using either heat pump technology or radiative cooling devices.
2. Concentration of the vapor using desiccants and then release the vapor in a regeneration process.
3. Inducing convection currents in a tall tower structure pushing the humid air to cold high altitude zone where condensation takes place.

In general, the fresh water obtained from the three processes is expected to be soft and neutral water of good quality with very low contents of minerals and metals (Habeebullah, 2008). Not much attention had been given for obtaining fresh water by condensing the air moisture on the evaporator surface of a conventional heat pump. However, the high ambient temperature and humidity in areas in Gulf States, created a new motivation to apply the atmospheric water vapor processing techniques using conventional heat pump. Heat pumps are used to cool and dehumidify

a continuous air stream that is then distributed to open spaces where people gather around and perform their activities. This process of direct climate tuning can directly address the need of water conservation, where it can be extended to become a source of fresh water, in the case that water is a cost-free by-product (Habebullah, 2008).

### **3.4 Baseline Water Footprint and Condensate Water Collection**

The term “Water Footprint” was coined in 2002 by UNESCO-IHE as an indicator of water use that looks at both direct and indirect water use of a consumer or producer. As water is becoming a more scarce resource globally, GE Water and Process Technologies have developed a four-step framework for reducing water footprint, gaining cost efficiencies and realizing brand value. The baseline water footprint was framed as one of the main elements of this framework. The developed guidelines will direct the decision makers in identifying and emerging sustainability policies based on an effective water usage strategies. As a result, a water efficiency objective is set and will be met by applying a variety of tools and metrics proposed in this framework. This framework implies using a basic water balance, capturing all water-consuming elements with related direct and indirect costs. By using the water balance tool, a full picture of every water-consuming component will be provided (GE, 2008).

The water balance concept is comprised by six basic categories under which any on site water consuming entity should be considered: Inlet water pretreatment, cooling towers, boilers, processing (any water consuming facility as part of the production process), wastewater plant or water effluent, other (ash ponds in a power plant). For each scheme the operation unit, capture and diagram the water balance: registering all flows of water into and out of the operation, and verify a mass balance of both the water flow and the key chemical constituents within or added to the

water. The cooling towers are considered as one of the significant category under which “in and out” water quantities should be monitored, this ensures an accurate understanding of the operation, and that no significant flows are forgotten (GE,2008).

### **3.5 Recovery of the Air conditioning Condensate Water**

Air conditioning condensate water, can be considered as one of the water saving techniques, either at the individual household level, or at larger scale buildings. Air-conditioning systems have been used in many parts of the world (Wilson, 2008). The purpose of most systems is to provide thermal comfort and an acceptable indoor air quality (IAQ) for occupants. With the improvement of standard of living, occupants require more and more comfortable and healthful indoor environment (Kostiainen et al., 2008). Cooling systems rely on evaporator coils; condensate drains carry away the water, instead of wasting this source, capturing it would be an alternative to be studied (Wilson, 2008). Condensate water from air conditioning systems, is an untapped water source that can be recycled for cooling towers or outdoor irrigation. It should no longer be viewed as a waste product to be sent down sanitary sewer lines (Guz, 2005).

### **3.6 Air Condensate Recovery-Air-Conditioning**

Most of the modern constructions are heavily air conditioned with a variety of different equipment being used. Heating, Ventilating, and Air Conditioning (HVAC) equipment is used to create a conditioned indoor environment by consuming large amounts of energy to cool, filter, and dehumidify the air in these structures. In any air conditioning system functioning based on elevated outside dew point temperatures, condensate water will be generated at the chilled water heat exchanger (either in the air handler or fan coil) that must be disposed. The air-conditioning systems

are composed of various heat and mass transfer devices. Water and liquid desiccant are two liquids commonly used in air-handling processes, which contact humid air directly. Heat and mass transfer occur between air and water (or liquid desiccant) (Bryant et al., 2008).

The main function of the Air conditioning cooling systems depend basically on the evaporator coils in which refrigerant fluid changes from liquid to vapor, thus through this process the coils are cooled (Wilson, 2008). Air blowing past the coils cools off as it goes by, and moisture from the air condenses on the coils. In general, the fresh water obtained from the condensation recovery is expected to be soft and neutral water of good quality with very low contents of minerals and metals (Habebullah, 2008). Figure 3.1 is a schematic diagram that shows the internal design of the air conditioning unit and the mechanism of operation.

In large commercial building were cooling towers are consuming water through a continuous water loop. A water makeup for the cooling tower is needed, this might be used by the water condensate. The condensate can often redirected to feed into the cooling tower without being stored, because the condensate water generated in a building will never exceed the evaporative losses from the cooling tower (Wilson et al., 2008).

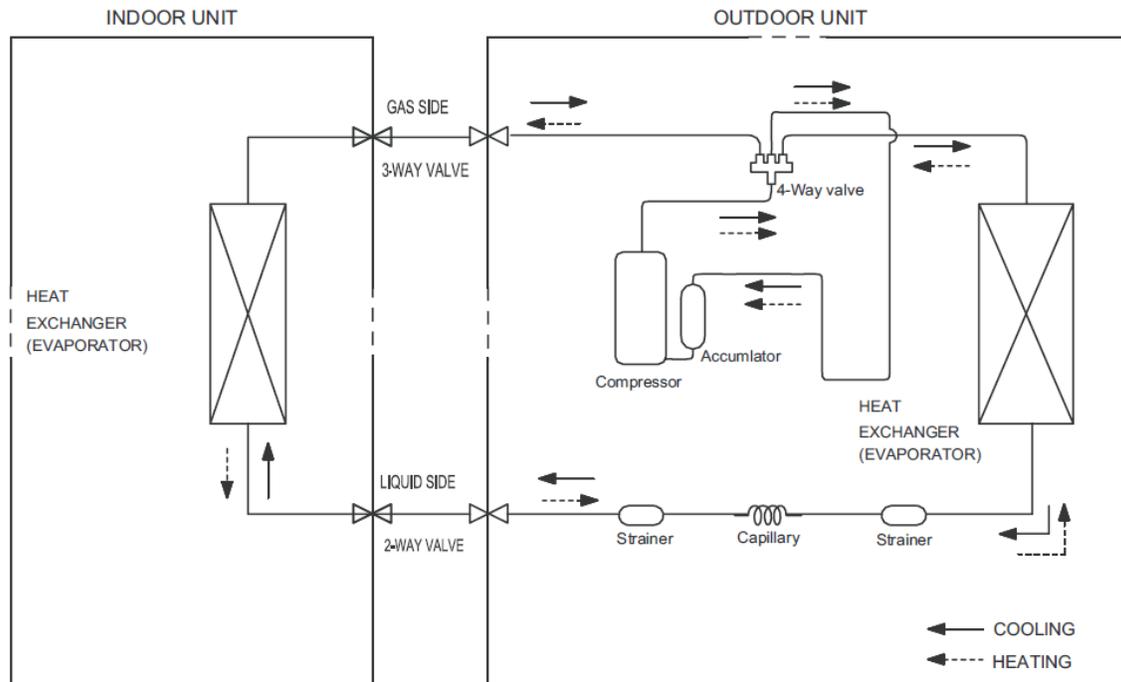


Figure 3.1 Internal design of the air system “Cooling and Heating models” (Triple R, 2013).

### 3.7 Cooling Tower Systems

Cooling towers are widely used in the open recirculating cooling systems that reject heat. They come in different sizes, shapes, construction materials, and fill or packing. Two major problems could occur with the cooling towers; galvanized cooling towers are disposed to the white rust unique corrosion phenomenon, and high efficiency are filled with biological deposits. These two problems are directly affecting the water condensate quality, which can be controlled by proper water treatment (Boffardi, 1999). A cooling tower is basically a heat rejection device, which extracts wasted heat to the atmosphere through the cooling of a water stream to a lower temperature. The type of heat rejection in a cooling tower is defined as "evaporative", which lets a small portion of the water being cooled to evaporate into a moving air stream to provide significant cooling to the rest of the water stream. The heat from the water stream transferred to the air stream raises the

air's temperature and its relative humidity to 100%, then this air is discharged to the atmosphere. Common applications for cooling towers are providing cooled water for air-conditioning, manufacturing and electric power generation. Large office buildings, hospitals, and schools typically use one or more cooling towers as part of their air conditioning systems (CTI, 2012).

### **3.7.1 Condensate Water**

Changing the physical state of the water from gaseous phase into liquid phase, when water vapor in the air (described as humidity), contacts a colder surface, the water changes from a gas status to a liquid status, and the it is collected onto the cold surface. The air water vapor that is transferred to liquid is referred as condensate, for example, the water condensate that is collected on refrigeration equipment (cooling device) is of significant volume and a potential alternate water source. In the air conditioning system, cooling tower operation is simple, the circulating cooling water picks up the heat from the process heat exchangers and passes through the cooling tower. The recycled water is cooled by the evaporation, as it passes through the cooling tower. As a result of this process of evaporation, the dissolved solids in the water became concentrated. The water lost to evaporation and drift is replaced by the makeup of fresh water. During this process gases from the air, particulate matter and nutrients for biological growth are absorbed by the evaporative. It also reduces the solubility of the solids that remain in the recirculating water. These combined effects increase the corrosiveness of the cooling water, cause tenacious deposits that impede heat transfer, and create sites where microbes grow (Boffardi, 1999).

Removal of the condensate water is essential to prevent damages to the equipment and the building structure. Most often, in the central Air Conditioner (AC) systems, the condensate is drained off the coil into a drip pan; where it is connected to a hose leading the condensate water to the sewer

system. The condensate water can be quantified by 5 to 20 gallons (18.9 L to 75.7 L) per day, generated by an entire home, equating to more than 300 gallons (1135.3 L) per month in the summer. Depending on the location of the central AC coils, this water can be easily captured, stored and utilized (AWE, 2010). Maintenance and damages control for the AC systems are necessary, which mainly control the corrosion, scale, deposit, and biological control (Boffardi, 1999).

### **3.7.2 Water Management Plan through Air Condensate Recovery**

In lined with the Federal Energy Management Program, a water management plan has been developed aiming at reducing the potable water usage through an air handler condensate recovery project. In 2008, the Environmental Protection Agency (EPA) completed an air handler condensate recovery system. The system routes condensate from the air handler units to the cooling tower, reducing potable water usage and improving cooling tower water chemistry. The project was designed based heating and cooling air handler units operation. During cooling, air passes through the chilled cooling coils in the air handler units, where condensate is formed and collected rapidly depending on the humidity factor. On the other hand, the cooling tower requires a generous amount of make-up water to replace water lost to evaporation. The main objective of this project was to let waste meet need. Pumping equipment and piping was installed from the air handler units to the nearby cooling tower. Whereas, the recovered water then flows directly into the cooling tower reducing the amount of potable water needed for cooling tower processes (FEMP, 2008).

❖ *This study will mainly review the scope of the air-conditioning systems using a closed-loop compression-decompression cycle of a refrigerant. Which is mainly absorbing heat from inside building, then transferring the heat to the outside. This implies no water supply for the cooling*

*towers, therefore no water makeup recovery by the water condensate is considered as an option of recovery.*

### **3.8 Previous Initiatives Capturing Air-Conditioning Condensate**

As water becomes more of a scarce resource, many initiatives were developed based on effective water usage strategies in the world. Using water more efficiently should remain as one of the top priorities. Therefore during the past years, alternative sources of water, including those we can harvest at the building level were highlighted as unconventional water sources that can be used in and around the buildings. Air conditioning condensate is a relatively untapped alternative source of water that might be readily available especially in hot arid climates. One of the experiment was held in Qatar, where the main objective of the initiative was to establish the feasibility of the condensate water as the alternative source of water in the Qatar, where high economic growth and migrating population are posing challenge for the country to meet water demand in near future (Kant et al, 2012).

Water condensate from air-conditioning systems can be used efficiently either by circulating it again to be used for the cooling towers (as indicated above) or other purposes such as outdoor irrigation. Water efficiency can be applied in many facilities, where cooling towers are used. Increasing the rate of condensate recycle in the cooling towers results in multiple savings, at the level of the water and sewer costs to savings on the purchase of chemicals used to treat both incoming and discharged water (GE,2008).

The condensate water should no longer be viewed as a waste product to be sent down sanitary sewer lines. Increases in water and sewer rates have made the investment of condensate recovery systems very cost effective. The previous attempts to study the condensate water from the air-conditioning systems have been highly appreciated. One of the experiments has been carried out in San Antonio, which became the first city to require all new commercial buildings to design drain lines so that condensate capture is practical (Guz,2005). The projects that had been carried out until the year 2012, can be summarized as:

- In San Antonio, the experiment have yielded surprising quantities of water. The downtown mall generates 250 gallons (946 L) each day from its air handlers. A central library system produces {0.06 L/second) or 43.200 gallons per month (163 500 L) (Guz, 2005).
- Bahrain Airport Services in the Middle East uses 2.3 million gallons (8,7 million L) per year of condensate water for diverse purposes such as toilet flushing, washing and landscape (Guz,2005).
- At the University of Texas in Austin, the massive central cooling systems include condensate recovery for cost savings (Guz, 2005).
- In Qatar, the experiment resulted that over 6 million liters (1.6 million gallons) of condensate water can be potentially captured, each year from the air conditioning systems in one of the buildings (Bryant, et al 2008).
- In Qatar, the air condition condensate quantity and quality were evaluated for potential the water reuse. This experiment showed high volume of air conditioning condensate water that were collected. From urban area especially in arid/semi-arid region. Approximately 250-300 gallon/month of condensate formation occurs from a single unit of air conditioner. At the same time high water quality of air conditioning condensate make it potential alternative water for unrestricted or domestic water use. This research has marked that the overall concept of air conditioning condensate collection can help in maintaining environmental sustainability for

the region by minimizing fresh water use and decreasing dependency on desalination plants (Kant et al, 2012).

### **3.9 Condensate Water Yield**

Within the frame of atmospheric water harvesting through climate conditioning process, it is indicated that the experimented technologies can lead to a source of limited amounts of potable water at a free cost. It is mainly highlighted that the water obtained from water harvesting technologies reported at a maximum daily fresh water yield of 11.4 L/m<sup>2</sup> of the collector surface. Moreover, the amount of collected fresh water may be improved by installing the net catchers at different mountain elevations because of the relatively high fog concentration at high altitude. (Habeebullah, 2008). The amount of water yield depends directly on the collector surface nets (water catchers). In Chile, a station was tested to produce a total condensing area of 48 m<sup>2</sup> in a fishing village, with reported production rate of 3.3 L/m<sup>2</sup> per Day. In Saudi Arabia, an experiment was developed based on the energy balance with a maximum reported yield of 0.22 L/m<sup>2</sup> per night. Another one developed based on the recovery of the absorbed moisture, where water is collected under a glass cover. This experiment had yielded to a maximum fresh water production of 1.25 l/m<sup>2</sup> per day (Habeebullah, 2008). In Qatar, the experiment that was presented in the year 2012 with a demonstration of the average condensate water generated from the unit was of 10-13 gallons per day during the months of April, May and July (Kant et al, 2012).

#### **3.9.1 Factors Affecting the Water Yield**

The existing literature has indicated that there are many factors influencing the quantity of the condensate water produced from the air conditioning systems. This was clearly demonstrated through practical projects capturing air-conditioning water condensate. It is acutely noticed that

the condensate water production in a system is highly depending on the temperature and humidity conditions (both outdoors and indoors) (Wilson, 2008). The water production rate is also highly influenced by how a building is used; for instance if some manufacturing processes are carried out inside the building, the production rate will be affected.

The type of activities implemented in the building whether it is domestic or industrial activities, contributes to the production rates. Another important element is the existence of the machinery and lighting, however if this creates a greater load on air conditioning than an empty building (Guz, 2005).

On the other hand, companies that require closely controlling the humidity conditions for facilities like technology manufacturing or pharmacy storage, are particularly good producers for condensate water. Shopping centers where a high turnover of indoor air exists also produce higher levels of condensate. In tall buildings where air handlers are on many floors, the ones where outside air is brought in will have the greatest water yield. Consequently, the rate of the condensate water production is also depending on the local climate and cooling device design and type (Guz, 2005).

### **3.9.2 Calculation of the Condensate Rate**

A rule of thumb has been developed for a typical rate of production for large buildings during summer months in 2005. Considering this rule, the condensate water production rate can be standardized per every hour of operation as 0.1 to 0.3 gallons (0.4–1.1 L) of condensate water per ton capacity. This range is based on average production rates measured at a small number of large facilities. For those planning buildings in hot and humid climates, an estimate of expected condensate production also can be made from the square footage of climate controlled space. The

amount of the generated condensate water can be estimated from 3 to 10 gallons per Day per 1,000 square feet of air-conditioned space (11.35 L to 37.84 L/Day per 92.9 square meters). An area of 10,000 square foot (929 square meters) building can generate more than 15,000 gallons (56.8 m<sup>3</sup>) of condensate water per year (Guz, 2005).

On the other hand, the experiment held in Qatar in the year 2012, offered a new method to calculate the condensate water volume that could be generated through the air conditioning systems. Through this initiative computer simulation model was developed based on psychometrics to quantify the air condition condensate using relative humidity, dew point and temperature gradient of the outside and inside room conditions for unit mass of the dry air supply. It has been marked that the concept of psychometrics can be applied mathematically for evaluating the condensate generation from air conditioning system. Where the psychometric chart graphically represents the thermodynamic properties of the moist-air. In particular, the primary component of the psychometric chart includes the dry bulb temperature, wet bulb temperature, relative humidity, dew point and the enthalpy. The dry bulb temperature signifies the dry air temperature. The wet bulb temperature defines the temperature of the moist air. Theoretically an air conditioner supplies dry air at certain temperature through the vents, and recirculate the room air of high humidity and high temperature. During the recirculation process the moist air temperature reduces, which result in condensation of the water vapor. The research concluded that the graphical interpretation of the psychometric chart is not feasible for estimating the condensate volume for a time series data with varying temperature and humidity (Kant et al, 2012).

This experiment also stated that if the volume of the dry air supplied through an air conditioning is known, moisture content at the given relative humidity and temperature can be computed by

multiplying the specific humidity with the dry air mass. The condensate volume represents the difference of the moisture content of inside and outside air conditions. The model eliminates the need of computations, iterations, conditional scenes, and graph reading just by automating the process with predefined input parameters, and finally yields an estimated condensate over a period of time. Figures 3.2 shows an example of the model simulation results which are compared with the observed condensate volume, the figure shows a high r-square of 0.99 which was obtained for the months of April and May. This shows a close proximity between the observed and simulated condensate for specific dry mass air supply (270 kilo gram per hour) (Kant et al., 2012).

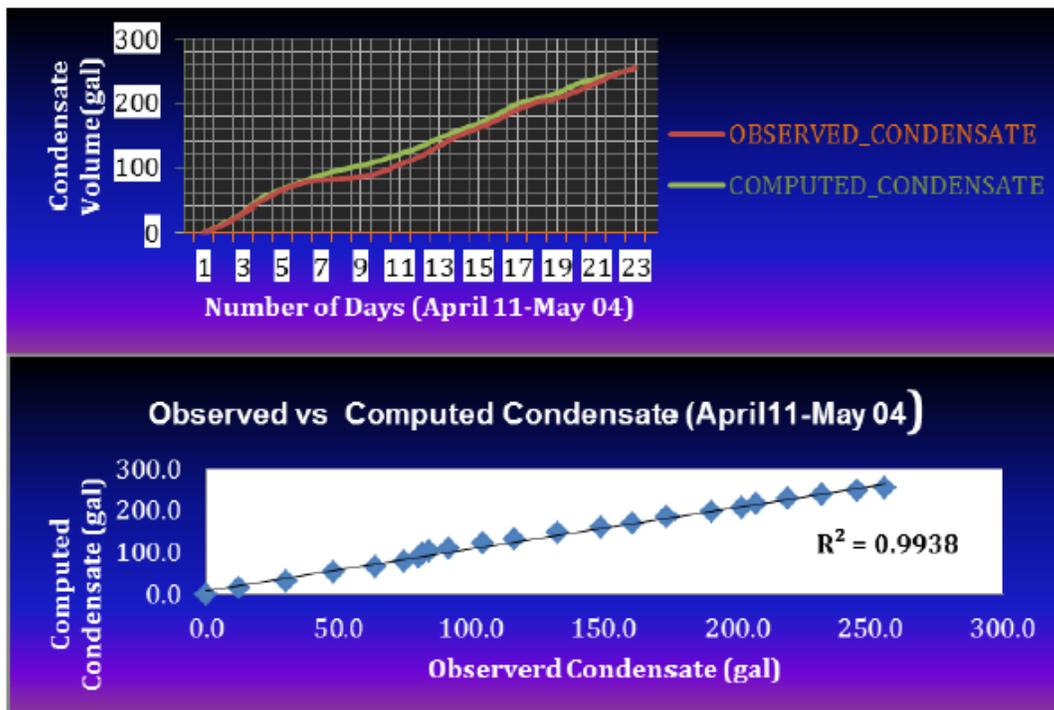


Figure 3.2: Model simulation results (April – May, 2011) (Kant et al, 2012).

Approximately same results were reached for the other comparison of the following simulation of the two months of May and July. The average per day condensate generation from the unit was observed between 10-13 gallons per day during this period (Kant et al, 2012).

### **3.10 Safe and Sustainable Use of Water**

The need of having safe water is considered as a basic need for human development, health and well-being, therefore it considered is an internationally accepted human right. Any new water source has to be fundamentally protecting the public health and the environment. There are also wider consequences to be considered, such as public and institutional confidence, which can be fragile and, once lost, and are difficult to build and regain (NWQMS, 2006).

The main principles to be applied when identifying the sustainability use of a conventional water source are based on public and environmental health. However, the specific concerns to public health are mainly set around the high probability of consumer exposure from the water, and the significant hazard to health (WHO, 2008).

The sustainability use of the recycled or recused water is developed within the national guidelines under the auspices of the National Water Quality Management Strategy (NWQMS, 2006). Furthermore, it is stated that the recycled water can be used in a safe and sustainable manner to reduce pressures on limited drinking water resources. Some of the requirements for the safe and sustainable water use are based on:

- Protection of public and environmental health, this is of paramount importance and should never be compromised.
- Protection of public and environmental health, which mainly depends on implementing a preventive risk management approach.
- Application of preventive measures and requirements for water quality should be commensurate with the source of recycled water and the intended uses.

### **3.11 Risk Management Approach to Water Quality**

The most effective way to assure the appropriate quality of water, is when a risk management system is adopted. The development of risk management systems for water quality is covered by the World Health Organization (WHO) through the Guidelines for Drinking-water Quality (WHO, 2008), which clearly describes ‘water safety plans’.

A risk management approach involves identifying and managing risks in a proactive way, rather than simply reacting when problems arise (NWQMS, 2006). In applying this approach to the proposed unconventional water source (the air conditioning condensate), the first step is to oversee systematically all the hazards in the reused water that could potentially affect human or the environmental health. Whereas, the second step is to identify possible preventive measures to control the estimated hazards, and to then develop monitoring programs. Thus, the preventive measures which should be ensured to operate effectively. Eventually, the final step will be to validate that the designed management system consistently provides reused water of a quality that is fit for the intended use.

The WHO guidelines for drinking water quality, 2008 acutely highlights the importance of water supply risk assessment and the risk management application. Applying this approach increases confidence in the safety of drinking-water. This tactic involves methodical assessment of risks throughout the water supply process, from the water source through to the end user consumer. Methods must be put in place to ensure that the quality control measures are working effectively.

Consequently, the risk management approach will be discussed in the following chapters of this study. The approach outlined in this study incorporates the concept of identifying and collecting

recovered water from the air conditioning condensate of a quality that is ‘fit-for-purpose’. More specifically to identify if the recovered water is potable, which we can use for drinking, cooking, and bathing. However, the recovered water must meet a high standards of purity and safety. Otherwise, non-potable water requires less standards to e follows, it can be used potentially for landscape irrigation, makeup water for cooling towers, and toilet flushing.

### **3.12 Condensate Water Quality**

Very few literatures have discussed the quality of the condensate water from the air conditioning systems. Guz, (2005) stated in his study, that the condensate water is more pure in content than most tap water. Thus, it is essentially considered the same as distilled water; mineral free and a Total Dissolved Solids (TDS) level of near zero. In another study carried out by the Alliance for Water Efficiency in 2010, it was outlined that the condensate water should never be used for human consumption. Moreover, this study highlights that there is a great possibility for the condensate water to contain heavy metals from the direct contact with the cooling coils and other part of the air conditioning equipment (AWE, 2010). In a similar practical study carried out by Bryant et.al. (2008) in Qatar, it was concluded that: “the water as tested was of very good quality and would be considered acceptable for human consumption with minimal treatment for biological contaminants”. It was stated that the samples of condensate were collected from the air handling units at the discharge pipe before entering the roof drain. And thus the water samples were then tested for common water quality metrics. The water quality analysis results were as follows:

According to Wilson et al., (2008) in another study, where the condensate water quality was reviewed; it is also demonstrated that the water is pure. Moreover, it is also reported that there is

potential for contamination, especially if it is collected in a warm environment. For this reason, chlorine is usually used to treat condensate (Wilson et. al., 2008).

Table 3.1: Water quality analysis results

Test	Value	Acceptable range
Conductivity	86 $\mu\text{S}/\text{cm}$	0-400 $\mu\text{S}/\text{cm}$
Dissolved oxygen	7.15 mg/L	5-11 mg/L
Turbidity	0.7 NTU	0-1 NTU
Nitrates	0.6 mg/L	0-45 mg/L
Chlorides	1.2 mg/L	0-250 mg/L
pH	6.5	8.5

Source: (Bryant et al., 2008)

Some experiment hadn't experienced problems with the moderate chlorine concentrations while using the water for irrigation purposes. However, according to Guz, (2005) particular attention should be directed to the chlorination process, since the chlorine could harm some plants (Guz, 2005). According to the "A/C Condensate for Water Reuse: An Approach towards Environmental Sustainability in Doha" article, the condensate water analyzed showed no signification chemical or microbial contamination. Traces of copper and zinc were observed in the most of the samples. The water quality showed a promising result for reuse potential. Nevertheless the study recommends that further evaluations of the condensate quality and potential risk should continue to be evaluated in near future (Kant et al., 2012).

### **3.13 International Drinking Water Quality**

In the year 2000, the United Nations Millennium Declaration was a milestone in international cooperation, stimulating the effort for development that aimed at improving the lives of hundreds of millions of people around the world. As a result, the Millennium Development Goals (MDGs), were established stressing importance quantitative benchmarks to halve extreme poverty in all its forms. The eight goals that all 191 UN member states have agreed on, to try to achieve by the year 2015. The eight developed goals characterize basic human needs and rights that every individual around the world should be able to have. The goals address mainly the extreme poverty and hunger; quality education, productive and decent employment, good health and shelter; the right of women to give birth without risking their lives; and a world where environmental sustainability is a priority, and women and men live in equality. The achievement of the established goals is now susceptible by many factors, such as negative economic growth, diminished resources, fewer trade opportunities for the developing countries, and possible reductions in aid flows from donor nations. In addition, the effects of global climate change are becoming highly significant, with a potentially devastating impact on rich and poor countries (UN, 2010).

The achievement of the targeted eight goals are directly and indirectly affected by the water quality management, even though it is most closely linked to the goal of the environmental sustainability development. In which the indicators of water quality can be used to demonstrate progress toward the targets, by plotting trends in water quality over time and over space (UN, 2006). Ten years later, the achievement towards reaching the goals had been reviewed, resulting to report that the safety of water supply remains a challenge and urgently needs to be addressed (UN, 2010).

### **3.14 Guidelines for Drinking Water Quality**

The main aim of the water quality guidelines is the protection of public health. The water quality guidelines are meant to guide the basis for the development of national standards. If these guidelines are properly implemented, then the safety of drinking-water supplies is ensured through the minimal reduction of constituents concentrations in water, which are identified to be hazardous to health. According to the WHO publications in regards to the water quality guidelines; it is well highlighted that the guideline values for each contaminant or substance recommended are not mandatory limits. Therefore, it is essential that the guideline values are considered in the context of local or national environmental, social, economic, and cultural conditions (WHO, 1996).

However, the adoption of the international standards for drinking water quality hadn't been promoted effectively. This is mainly due to the advantage provided by the use of a risk-benefit approach (qualitative or quantitative), when establishing the national standards and regulations. The mentioned approach must lead to standards and regulations that can be readily applied and imposed. For instance, the availability of water supplies could be limited, if the drinking-water standards that are too stringent are adopted, in this case the water shortage in the regions is significantly considered. Conceptually, the standards that individual countries will develop can thus be influenced by national priorities and economic factors. Though, public health should not be endangered by the consideration of policy, the implementation of standards and regulations will require suitable facilities and expertise as well as the appropriate legislative framework (WHO, 1996).

The whole society has to play a significant role in the judgment of safety - or what is an acceptable level of risk in particular circumstances. The final judgment to whether the benefit resulting from

the adoption of any of the guideline values given in the guidelines as standards justifies the cost is for each country to decide. However, water is essential for life, and a satisfactory supply must be made available to consumers. Efforts should be made to achieve a drinking-water quality as high as practicable (WHO, 1996).

### **3.15 Water Quality**

According to the WHO, 2008 the water quality is commonly defined by its physical, chemical, biological and aesthetic (appearance and smell) characteristics. Water is used for different activities and purposes: drinking, irrigation and watering stock, industrial developments, creation of fish, shellfish and crustaceans, wildlife habitats, protection of aquatic ecosystems, navigation and shipping, recreation, and scientific study and education. Water quality is closely linked to the surrounding environment and land use. The water liquid water is never found pure and is it highly affected by agriculture, urban, industrial and recreation uses. The presence of contaminants in water decides the water characteristics and thus indicates the water quality (WHO, 2008).

#### **3.15.1 WHO Drinking Water Standards**

One of the established goals of WHO and its Member States is that *'all people, whatever their stage of development and their social and economic conditions have the right to have access to an adequate supply of safe drinking-water'* (WHO, 2008). 'Safe drinking water' in this context reflects a water supply which is of a quality which does not represent a significant health risk, moreover it is of sufficient quantity to meet all domestic needs, with continuous affordable availability to all the population. These conditions can be represented in five key terms: quality; quantity; continuity; coverage; and, cost (WHO, 2008).

The first WHO publication dealing specifically with drinking water quality was published in 1958 as '*International Standards for Drinking-Water*'. In drinking water supplies, there are thousands of organisms and substances identified, but the WHO Guidelines do not specifically deliberate each substance or organism, because it is neither necessary nor feasible to develop recommendations for all these. Through internal consultation process, key microorganisms were selected for evaluation, on the basis of the presence in water and likely risk to human health. A special attention has been given to developing guidance on selection of indicator organisms that can give early warning of faecal contamination and likely potential risks of disease.

A well-developed policy was stated through the WHO Guidelines in regards to the microbiological quality, where the water quality is the main priority, and thus the chemicals for evaluation were selected through an international consultative process, guided by three main criteria: i) The substance presents a potential hazard for human health; ii) The substance was detected relatively frequently and at relatively high concentrations in drinking-water indicating that there may be significant exposure to humans; iii) The substance was of major international concern (i.e. of interest to several countries). Based on this, 128 selected chemicals were prioritized for evaluation in the WHO *Guidelines* and health-based acceptable levels of exposure from drinking-water (Guideline Values) recommended for 95 of these, taking into account all sources of exposure. Some guideline values were not discussed for some selected chemicals because it was found that they were not hazardous to health. This was due to the fact that these chemicals are insufficient health effects information, or because the concentration of the chemical normally found in drinking-water does not represent a hazard to human health (WHO, 2008).

The WHO guideline values characterize the concentration of a chemical constituent that does not result in any significant risk to the health of the consumer over a lifetime of consumption. *Guidelines* are set for indicator bacteria - *E.colior* thermotolerant (faecal) coliforms and total coliforms, which give a good indication of the likelihood of faecal contamination in a water supply.

### 3.15.2 Chemical and Physical Parameters in Water

Drinking water supplies contain naturally chemical substances, In general, these substances are only a concern if they are present above guideline levels and if a person is exposed to them over a period of years. The recent scientific experiments confirm that short term concerns could be raised by the exposure to some chemical contaminants above guideline levels. The consumers acceptance of the drinking water (color, taste and odor), may be affected by the parameters physical and aesthetic quality guidelines. A description of each of these parameters, based on scientific references (Eletta. A, 2012; WHO, 2011; EPA, 2009) is presented below:

- **Temperature:** Temperature determines many physical characteristics of a water body, therefore it is an important water parameter. It also influenced by the quantity of other water parameters. In general cool water is considered more palatable than warm water, where temperature will have an impact on the acceptability of a number of other inorganic constituents and chemical contaminants that may affect taste. In contrast, the growth of microorganisms is enhanced in high water temperature and may increase problems related to taste, odour, colour and corrosion (WHO, 2011).
- **Turbidity:** Suspended particles or colloidal matter in water cause turbidity that obstructs light transmission through the water. Turbidity may be caused by inorganic or organic matter or a combination of the two. Microorganisms (bacteria, viruses and protozoa) are naturally

attached to particulates, and removal of turbidity in treated water is done by filtration which will significantly reduce microbial contamination. The measurement unit for the turbidity is Nephelometric Turbidity Units (NTU). Turbidity above 4.0 NTU, can be observed easily. However, to ensure effectiveness of disinfection, turbidity should be no more than 1 NTU and preferably lower (EPA, 2009).

- **Hardness:** Calcium and magnesium cause hardness which is usually indicated by precipitation of soap scum and the need for additional soap usage to achieve cleaning. Changes in hardness are possibly observed by consumers. The calcium ion could range between 100–300 mg/l, depending on the associated anion, and the taste threshold for magnesium is probably lower than that for calcium. In some cases, water users stand water hardness in excess of 500 mg/l. The interaction of other factors such as PH and alkalinity highly affects the hardness level in water, water with a hardness above approximately 200 mg/l could cause scale deposition in the treatment works, distribution system and pipework and tanks within buildings (EPA, 2009).
- **Total dissolved solids:** Good water palatability normally have a level of a total dissolved solids (TDS) of less than 600 mg/l; drinking-water becomes considerably and increasingly unpalatable at TDS levels higher than 1000 mg/l. The occurrence of high levels of TDS may also be unpleasant to consumers, due to excessive water networks scaling, heaters, boilers and household appliances (Eletta. A, 2012).
- **Dissolved oxygen:** The dissolved oxygen content of water is affected many factors such as the source, raw water temperature, treatment and chemical or biological processes taking place in the distribution system. The reduction of dissolved oxygen in water supplies motivates the reduction of the microbial nitrate to nitrite and sulfate to sulfide. Moreover, it

can cause an increase in the concentration of ferrous iron in solution, with subsequent discoloration at the tap when the water is aerated. The WHO had not recommended any health-based guideline values for the dissolved oxygen levels. However, very high levels of dissolved oxygen may exacerbate corrosion of metal pipes (WHO, 2011).

- **pH value:** The measurement of the acidity of water represent the pH value. The pH is considered as an important parameter in water chemistry, as many of the developments involved in water treatment are pH dependent. A solution is considered to be neutral when the numbers of hydrogen ions and hydroxyl ions are equal, each corresponding to an approximate concentration of  $10^{-7}$  moles/l. This neutral point happens at pH 7.0 at 25°C. When the water has acid characteristics, this indicates that the pH values are less than 7.0, at pH values greater than 7.0, the water has basic characteristics. Waters which have infiltrated through chalk or limestone, as is the case in most of the West Bank, generally have higher pH values. The WHO guidelines give a range of 6.5-8.5 for the pH value of drinking water and a treatment pH value of <8.0 for effective disinfection with chlorine (WHO, 2011).
- **Alkalinity:** The opposite of acidity is alkalinity, whereas the pH value increases, the alkalinity increases. The alkalinity of water is essentially coming from the sum of bicarbonates, carbonates, and hydroxides of calcium, sodium, and potassium. Alkalinity is considered as a key factor in determining the corrosive properties of water. The WHO guidelines do not specifically recommend a maximum value for alkalinity for water (WHO, 2011).
- **Aluminum:** Aluminum and aluminum salts are occurring naturally, they are used as coagulants in the process of the drinking-water treatment. The occurrence of aluminum at concentrations exceeding 0.1–0.2 mg/l often leads to consumer complaints due to the

deposition of aluminum hydroxide floc and the exacerbation of discoloration of water by iron. It is therefore important to optimize treatment processes in order to minimize any residual aluminum entering the distribution system (EPA, 2009).

- **Ammonia:** The ammonium cation has been proposed as the odour concentration of the ammonia with an approximate alkaline pH of 1.5 mg/l, and a taste level of 35 mg/l. at the mentioned levels the ammonia is not of direct relevance to health, and therefore there is no recommended health-based guideline value by the WHO (WHO, 2011).
- **Chloride:** The salty taste in water and beverage are caused by high concentrations of chloride. Taste thresholds for the chloride anion depend on the associated cation and are in the range of 200–300 mg/l for sodium, potassium and calcium chloride. Chloride concentrations higher than 250 mg/l are possible to be detected by taste, nevertheless some water users may become familiar to low levels of chloride-induced taste. There is no health-based guideline value proposed for chloride in drinking-water (EPA, 2009).
- **Copper:** The corrosive action of water is likely causing the occurrence of copper in a drinking-water supply, it is particularly arising from the corrosive action of water leaching copper from copper pipes in buildings. In some cases, the occurrence of high levels of dissolved oxygen shows an acceleration of copper corrosion. Therefore, high concentrations of copper can interfere with the intended domestic uses of the water. Staining of sanitary ware and laundry may occur at copper concentrations above 1 mg/l. At levels above 5 mg/l, copper also imparts a colour and an undesirable bitter taste to water. Although copper can give rise to taste, it should be acceptable at the health-based guideline value of 2 mg/l (WHO, 2011).

- **Calcium:** Calcium is realized in most water in the form of calcium carbonate or bicarbonate, especially in water that are associated with chalk or limestone, and as calcium sulphate. The type of rock is normally controlling the level of calcium, through which the water has passed. The WHO specify no maximum allowable limits for the calcium level in water. This is due to the fact that calcium element is an essential part of the human diet and the nutritional value from water is usually minimal compared to the amounts of calcium obtained from an average diet, therefore there are no health objections to high calcium content in drinking water (WHO, 2011).
- **Iron:** When water is directly pumped from a well, and in the case of the anaerobic groundwater, it may contain ferrous iron at concentrations up to several milligrams per liter without discoloration or turbidity in the water. When exposed to the atmosphere, however, the ferrous iron oxidizes to ferric iron, resulting in an objectionable reddish-brown colour to the water. The iron element also encourages the growth of “iron bacteria”, which originates their energy from the oxidation of ferrous iron to ferric iron and in the process deposit a slimy coating on the piping. At levels above 0.3 mg/l, iron stains laundry and plumbing fixtures. There is usually no noticeable taste at iron concentrations below 0.3 mg/l, although turbidity and colour may develop (WHO, 2011).
- **Manganese:** Manganese in water supplies causes an undesirable taste in beverages and stains sanitary ware and laundry, at levels exceeding 0.1 mg/l. The occurrence of manganese in drinking-water, may result in the accumulation of deposits in the water piping system. Manganese concentrations which are below 0.1 mg/l are usually acceptable to water users. At a concentration of 0.2 mg/l, manganese will often form a coating on pipes, which may

slough off as a black precipitate. The health-based value of 0.4 mg/l for manganese is higher than this acceptability threshold of 0.1 mg/l (WHO, 2011).

- **Sulfate:** The occurrence of sulfate in drinking-water can lead to noticeable taste, and very high levels might cause a laxative effect in unaccustomed water users. Taste impairment varies with the nature of the associated cation; taste thresholds have been realized to range from 250 mg/l for sodium sulfate to 1000 mg/l for calcium sulfate. It is generally considered that taste impairment is minimal at levels below 250 mg/l (WHO, 2011).
- **Zinc:** Zinc delivers an adverse severe taste to water at a taste threshold concentration of about 4 mg/l (as zinc sulfate). At a zinc concentration above 3–5 mg/l, water may appear opalescent and create a greasy film while being boiled. Even though drinking-water should seldom contain zinc at concentrations above 0.1 mg/l, the tap water can contain high levels of zinc due to the old galvanized plumbing materials. The level of zinc in tap water could be considered as an indicator on the elevated cadmium from such older material (WHO, 2011).
- **Potassium:** Potassium is an abundant element, but barely found in high concentrations in natural waters. The WHO guideline does not recommend a specific maximum value for potassium concentration in water (WHO, 2011).
- **Fluoride:** Fluoride occurrence in drinking water has been linked with dental issues. Uncontrolled levels of fluoride can lead to fluorosis, resulting in mottling of the teeth, and low levels of fluoride may result in increased dental problems. The greatest reduction of dental decay occurs if the fluoridated water is drunk in childhood during the period of tooth formation. The WHO guideline value is 1.5 mg/l (WHO, 2011).
- **Sulphates:** Sulphates originate from several sources such as the dissolution of gypsum and other mineral deposits containing sulphates; from seawater intrusion; from the oxidation of

sulphides, sulphites, and thiosulphates in well aerated surface waters; and from industrial effluents where sulphates or sulphuric acid have been used in processes such as tanning and pulp paper manufacturing. The WHO recommends a maximum allowable value of 250 mg/l  $\text{SO}_4$  based on taste and corrosion potential (WHO, 2011).

- **Nitrite and Nitrate:** Nitrite is considered as a transitional oxidation state of nitrogen. The presence of nitrites may sometimes be an indicator for sewage pollution. Nitrate is the final stage of oxidation of ammonia and the mineralization of nitrogen from organic matter. In both surface water and groundwater, the high Nitrate concentrations may be attributed to the use of nitrogenous fertilizers on the land. The 'Blue Baby Syndrome' or methaemoglobinemia, is caused by high nitrates water which is possibly harmful to infants. The WHO guideline value for nitrate as  $\text{NO}_3$  is 50 mg/l and for nitrite as  $\text{NO}_2$  is 3 mg/l (WHO, 2011).

## CHAPTER FOUR                      APPROACH AND METHODOLOGY

This chapter presents the research's selected methodology. The methodology has been designed to provide a comprehensive outlook in relation to the purpose of this study. It is based on different kind of assessments to clarify and respond to the research questions. Based on the purpose of the study and the research questions stated in chapter one, this chapter gives a detailed overview about the research approach adopted for the data collection phase and data analysis procedures.

### **4.1 Research Approach**

The overall research method used in this study is based on an interdisciplinary and integrated approach comprises of a combination of directions. This research is both desk-based and field-based. Scholarly articles and books consist of literature studies of published materials and data in line with the area of interest were reviewed and considered as secondary source of information. The secondary sources were concerning the condensate water assessments, water quality assessments, water standards, and generated water quantities produced by cooling systems. In addition, the primary source of data on condensate water quality and quantity was collected through sampling campaigns in the two cities of Ramallah and Jericho in the summer time. Semi-structured Interviews were also carried out with the main actors in the air conditioning system as an aid to reveal essential primary data. Research data was sourced, collected and collated accordingly. A questionnaire survey was conducted towards 85 users, to restate selected results and to provide the additional users' perception safety aspects to the discussion of water conservation. Figure 4.1 shows the key steps in the research approach process.

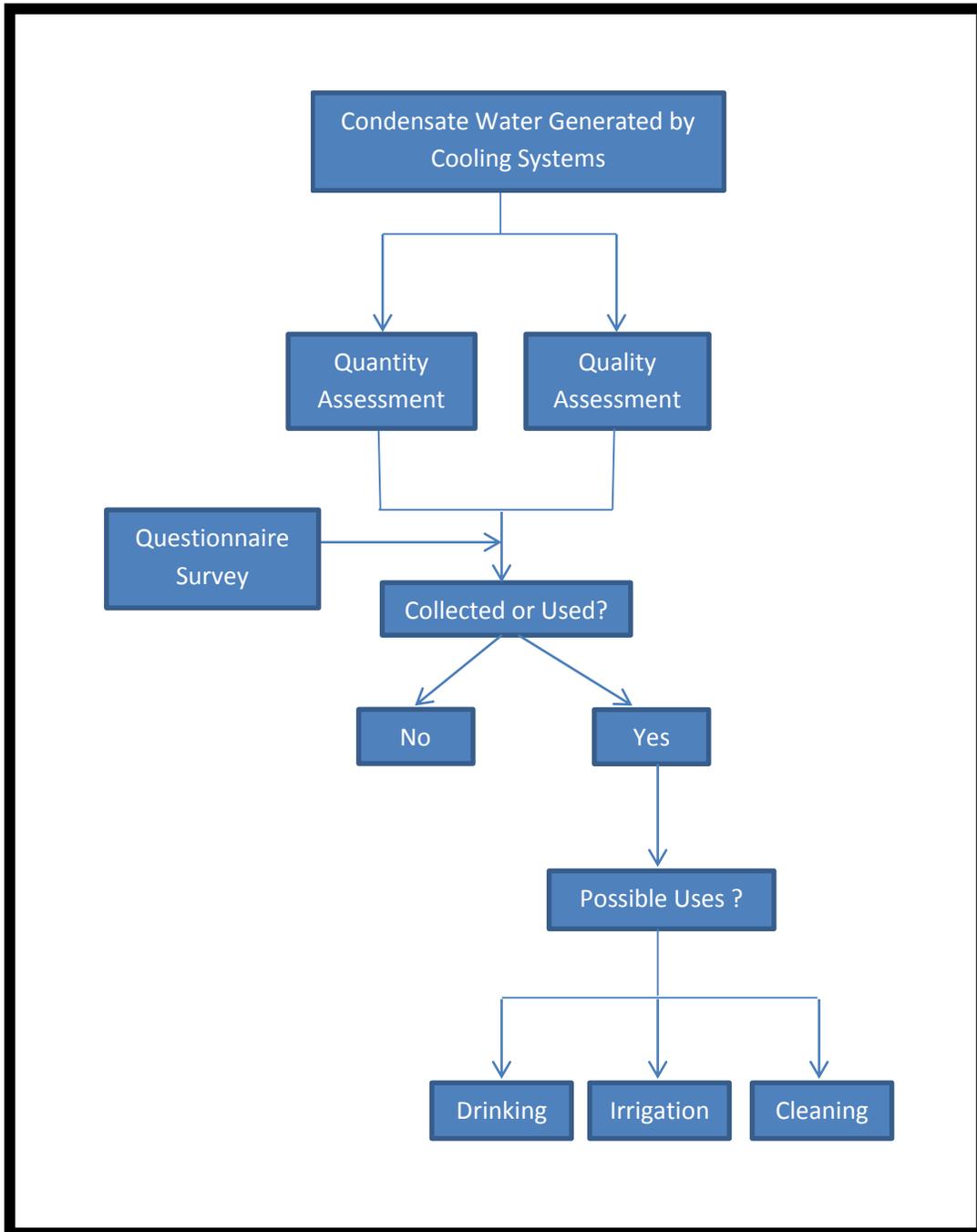


Figure 4.1: Key steps of the research process

## **4.2 Data Collection**

### **4.2.1 Literature Review**

Secondary data was primarily collected through desk-based research, where data was obtained from electronic databases, libraries, and scholarly articles and books concerning the condensate water quality and previous experiments quantifying the volume of this water source.

The literature review was designed based on the exploration of the current knowledge including substantive findings and strategies such as national frameworks developed worldwide. This process also outlook the guidelines set the water balance through explaining the baseline water footprint and in relation to the condensate water collection.

In order to give a handy guide in the completion of this research, the methodology followed in proceeding with the literature review, was reviewing the baseline as well as the past theoretical and methodological technical contributions which were implemented particularly to serve the objective of condensate water efficiency.

### **4.2.2 Water Quality Sampling**

In order to obtain a clear idea about the condensate water characteristics, an assessment of this water quality against the two main defined guidelines issued by the Palestinian Standards Institutions (PSI). This assessment comprised basically a condensate sampling campaign, which was carried out in October and November 2012 in the two cities of Ramallah and Jericho. This assessment process was conducted following a systematic method of sampling collection:

- 1) All collected water samples were accompanied by an appropriated collection form clearly indicates: Location, sample site, sample number, place, date and time. Water samples were labeled by a number which was orderly reflected the information filled in the form.
- 2) From the two cities of Ramallah and Jericho a total of 65 condensate water samples were collected in plastic one liter capacity bottles. Figure 4.2 shows sampling collection in the field.



Figure 4.2: Water sampling collection

- 3) For the 65 samples, analysis for some physical variables were run in the field using appropriate apparatus either at in situ or very soon after the sample has been collected. Most of the tests were carried out on fresh samples whose characteristics have not been contaminated.
- 4) All used instruments were calibrated and operated according to the instructed guidelines.
- 5) Field analysis was carried out measuring the following physical parameters: T, pH, EC, DO and TDS.
- 6) Other tests were run after transporting the samples to the laboratory after a period of time that did not exceed 6-24 hours.
- 7) Further water testing was undergone completely at the BZU Laboratories using procedures of the Standard Methods and ICP- OES (Inductively Coupled Plasma optical emission spectrometry):
  - Turbidity, BOD, COD, SO<sub>4</sub>, Copper, Iron, Lead, Cadmium, Arsenic, Selenium, Sn(Tin), Mo, Nickel, Cobalt, Aluminum, Manganese, Lithium, Chromium, Barium and Silver.

### **4.2.3 Water Quantity Assessment**

In order to formulate an overview about the condensate water yield generated from the air conditioning systems, a quantity assessment process was conducted in the two cities of Ramallah and Jericho. Therefore, similar to the quality sampling campaign presented in the previous section, water samples were also collected following a systematic quantifying method:

1. Samples were collected from different kinds and types of locations including, commercial building (cloths shops, restaurants, supermarkets, pharmacies and bakeries), residential households (apartments and houses), and building offices.
2. Following the same steps stated in the Water quality sampling process, the collected water samples were accompanied by the filling an appropriate form clearly indicates: Location, sample site, type and area of the served location, date, time, the capacity air conditioning unit (1 Ton, 2 Ton, 3 Ton) and the operational working temperature 16 °C, 18 °C or 20 °C.
3. From the two locations of Ramallah and Jericho a total number of 72 one liter plastic bottles were collected. Table 4.1 shows the number of the collected samples from different capacities of air conditioning units:

**Table 4.1: Condensate water quality samples**

<b>City</b>	<b>Operational Temperature</b>	<b>1 Ton</b>	<b>2 Ton</b>	<b>3 Ton</b>
<b>Ramallah</b>	<b>16°C</b>	7	7	7
	<b>18°C</b>	7	7	7
<b>Jericho</b>	<b>16°C</b>	7	7	7
	<b>20°C</b>	7	7	7
<b>Total</b>		<b>24</b>	<b>24</b>	<b>24</b>

4. Through the process, the condensate water was routed from the drain plastic pipe that is connected to the outer unit of the air conditioning system. Water was retrieved in the plastic bottles and in parallel the time of collection was recorded, to be averaged and plotted.

#### **4.2.4 Questionnaire Survey**

To gather supplementary data on the local users' perception, knowledge, behavior, attitudes and opinions regarding the use and the management of the condensate water as a new water source, a structured questionnaire was prepared and interviewed with 85 residents, whom were selected randomly, please refer to *Annex 1: Questionnaire survey form*. The questionnaires were distributed by 50 in Ramallah and 35 in Jericho to reflect the behaviors and opinions of the different contexts and circumstances. The questions asked aimed to gather information on:

- The number, capacity, age and served area of the air condition units used.
- Operational hours and operational temperature.
- The management mechanism of dealing with the generated water.
- The detection of users perception in regards to quality safely, quantity and possible uses.
- Common possible methods followed by users to conserve the condensate water.

The main purpose of the questionnaire survey is to obtain indicators for the possible generated condensate water volume based on the daily working hours, capacities and operational temperature of the air condition units. Furthermore, the survey aimed at better understanding the population perceptions regarding the management of the condensate water generated from the air conditioning unit. In addition, the survey highlighted the question of users' awareness in regard to the quality

of the generated water, and hence the in place methods used to benefit from this source of water efficiently.

#### **4.2.5 Semi-Structure Interviews**

The field study of the research consisted of a short market assessment conducted through semi-structure interviews with the main suppliers of the air conditioning systems in Palestine. A list of two main suppliers was provided through the market assessment, the interviews were arranged with the directors, managers and/or technicians of each company. Un-structured questions were designed, exploring the general supply through importation of the units. The interviews also provided information about the most used units' brands, capacities, constrains, installation rules and guidelines...etc. Based on the information collected through this process and the results demonstrated by the analysis of the questionnaires, the calculation of the global condensate water generated from the sold units in the year 2012, was calculated.

#### **4.3 Analytical Procedures**

The analysis adopted in this research is generally inspired by the water quality national strategies, and thus begins with the water quality assessments for the gathered samples. Where the chemical and microbial water characteristics were tested at in BZU laboratories and analyzed against two Palestinian standards of: Palestinian Standard Institution guidelines for 'Drinking Water Quality and Treated water reused for Irrigation'.

The second phase of the analysis was based on the identification of the water condensate quantity, in which equations were developed to standardize the calculation of the condensate water volume generated by different units' capacities.

Another important aspect adopted in this research was linking actual use of the air condition units (capacity, time and temperature), with the developed equations through the previous step. Therefore, an actual overview of the condensate generated volume was scoped. Through this analytical step, observations of the responses had developed some general overview on the collected volume versus the wasted volume.

Finally, a general quantity of possible water resource was explored through the semi-structure interviews. The main analysis was based on the collected information, in which it was linked with the equations developed for volume calculations.

### ***Summary***

The methods outlined in this chapter will provide general guidance for the research carried out within this study. The next chapter will apply these methods and will offer additional details for the adopted methods within this research.

This chapter discusses the results of the generated condensate water quality and quantity analysis which was carried out for the Ramallah and Jericho cities, based on the conducted sampling campaigns. The results of the field survey questionnaires exploring the users' perception in regard to the usage circumstances to the system linked to the generated quantity and quality safety, are discussed in the next sections. In addition, a short Palestinian market assessment is presented in this chapter, highlighting the main suppliers for the units and the trend of the demand in Palestine. Furthermore, some rational calculations were carried out in order to approximately quantify the possible volume of condensate water that could be generated by the installed air conditioning units in the year 2012.

### **5.1 Condensate Water Quality Assessment**

The primary purpose of the condensate water quality assessment is to identify a specific understanding of the elements that could occur in this source of water and are of concern to public health. The undergone assessment will help to develop a deep overview on why users today don't pay attention to this source of water, and thus this source has been highly ignored. Water quality assessment are crucial for demonstrating the comparability of data obtained from the carried out assessment and water quality assessments worldwide. In assessing the quality of drinking water, users rely principally upon their senses. The water can be considered as potable for human use, is the water that does not create threat to the health of a human being over its extended use over the lifetime of the human. The constituents of water whether it is microbial, chemical and physical may affect the appearance, odour or taste of the water. Consequently, the user will evaluate the quality and acceptability of the water on the basis of these criteria. Although no linked health

effects are recorded by these substances, water that is highly turbid, is highly coloured or has an objectionable taste or odour may be considered by consumers as unsafe and may be rejected (WHO, 2008). Conceptually, the water used to meet agricultural purposes can differ in terms of quality upon dissolve salts concentration and type. Even though the irrigation water contains relatively small amounts of salts, but they are considered to be significant. During the irrigation process, the salts are applied with the water and remain behind in the soil as water evaporates or is used by the crop. Irrigation water requirement is determined by the crop water requirement and the water naturally available to the crops, with a great focus on the long-term effect of the quality of water linked to the crop production, soil conditions and farm management (Ayers, et al, 1994).

To reach a comprehensive and rational assessment of the condensate water quality, it is at great important to assess the quality of the water generated at the source (the unit), in which water is drained through a plastic pipe connection. This will provide a view on the water quality measurements before being contaminated.

### **5.1.1 Measurements of Chemical, Physical and Microbiological Parameters**

Based on the collected samples which were generated from 65 air conditioning units in the two cities of Ramallah and Jericho, the main chemical, physical and microbiological parameters were tested. The results of the tests were then plotted against the PSI standard values to analyze the compliance of the condensate water with the PSI drinking water and the treated water reused for irrigation standards. The analysis depicted in table 5.1, were undergone to detect the condensate water quality in regard to the selected parameters. The selected parameters are necessary for water quality monitoring programs. The values of the tested parameters for the condensate water generated by the air conditioning units are presenting the results of the tests for the 65 samples

(S1-S65), for the main physical and microbiological parameters. The following table presents the relevant Palestinian standards for the quality of drinking water and the reused irrigation water.

*Annex 2 presents the detailed data analysis for the condensate water tests.*

Table 5.1 Chemical, Physical and Microbiological Analysis for the condensate water samples

Parameter	Reading Range	Reading Mean	PSI (2005) Drinking Water Guidelines <sup>1</sup>	PSI (2012) Reused Irrigation Water <sup>2</sup>
T (°C)	15.5-22.5	18.05	20	25
pH	6.4-7.59	7.12	6.5 - 8.5	6-9
TDS (ppm)	15.2-76.4	42.48	<1000	1200
EC (µs/ cm)	30-220.4	79.40	-	700-3000
DO (mg/l)	0.36 - 5.9	2.52	-	>0.5
Turbidity (NTU)	0.55 - 6.69	1.97	1	5
BOD(mg/l)	1-6	2.23	-	20 (A Category)
COD(mg/l)	18- 150	101.71	-	50 (A Category)
SO <sub>4</sub> (mg/l)	0.001-0.006	0.0033	200	300

<sup>1</sup>Source:(PSI,2005), <sup>2</sup> Source:(PSI,2012)

By comparing the obtained results shown with the PSI standards demonstrated in table 5.1, the following analysis can be developed in regard to the major parameters occurrence:

- Temperature:** The results of the temperature measurements for the condensate water samples, present that the samples fall approximately within the acceptable ranges of both the drinking water guidelines (less than 20°C) and treated water reused for irrigation(less than 25°C), ranged at (15.5-22.5°C). Some exceptions related to the drinking water comparison were demonstrated

among the water samples S9=21°C, S16=21.5°C, S20=21.5°C, S28=20.8°C, S39=20.1°C, S46=22.5°C, and S64=20.4°C.

- PH:** The values of pH for the 65 collected samples are shown in figure 5.1, where all values fall within the range of (6.4-7.59), with a mean value of 7.12. Therefore the pH measurements performed in this part of the research, indicates that the condensate water is considered to be approximately neutral, in which the neutral point occurred at many of the collected condensate water samples. No major acidic or basic characteristics can be concluded. According to the PSI, 2005 guidelines the pH values of the samples enable them to be acceptable for drinking water, whereas the acceptable range is (6.5-8.5). On the other hand, and according to the PSI, 2012 (treated water reused for irrigation), the pH values for the condensate water confirms that it can be used of agricultural purposes, moreover it is ranked as A category in terms of quality.

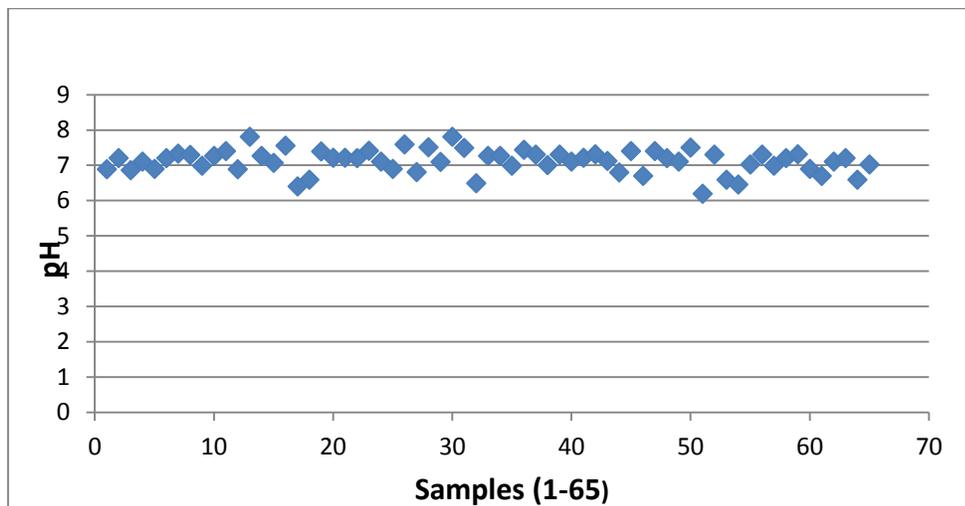


Figure 5.1: PH levels in the tested condensate water

- TDS:** The above demonstrated analysis shows that the TDS parameter occurred in the condensate water samples ranges between (15.2-76.4) ppm, with a mean value of 42.48 ppm. This indicates that all measured values fall below the PSI standards value for drinking water

and treated water reused for irrigation. It can be noticed that the TDS occurrence in the collected condensate samples are nearly valued at zero and can be neglected in comparison to the maximum allowable standards stated by the PSI for the drinking water (1000 mg/l) and the treated water reused in irrigation A category (1200 mg/l).

- **EC:** The measurements of the EC confirm the above measured TDS values which all fall near zero. The EC in water estimates the total amount of solids dissolved in water. Very low values of EC were presented during the measurements ranged at (30 - 220.4 $\mu$ s/ cm), with a mean value of 79.40 $\mu$ s/ cm.
- **DO:** The dissolved oxygen concentration in the 65 condensate water samples was ranged at (0.36 - 5.9 mg/l) with a mean value of 2.52 mg/l. This puts mostly 66% of the collected samples in an anaerobic water status, in particular 44 water samples DO assessments revealed that they can be used for drinking water with DO concentration less than 5mg/l. Whereas, 37 water samples analysis demonstrated that the DO concentration falls above the minimum requirements of the PSI, 2012 for irrigation (DO above 1 mg/l).
- **Turbidity:** The turbidity analysis for the tested samples show that the range of the measured turbidity is ranged at (0.55- 6.69 NTU), with a mean value of 1.97 NTU. According to PSI the acceptable limits for drinking water turbidity is 1 NTU, since high turbidity in drinking water means that it may not be acceptable for consumers due to high amounts of sediments, possibly sand and other unappealing matter. The reason behind the high values of turbidity is mainly due to the dust and sediments transferred from that atmosphere (cars, street and construction work on the roads). For the agricultural purposes water with a maximum turbidity of 50 NTU is allowed to be used, therefore all samples turbidity measurements fall under the acceptable agricultural water limits.

- BOD:** As shown in figure 5.2, the tested condensate water samples for the BOD level was ranged at (1 - 6 mg/l) with a mean value of 2.23 mg/l. As of the total water sample collected, 44 samples are considered as clean water based on the BOD calculations which ranged between 1 and 2 mg/l. This places almost 100% of the collected samples within the range of the acceptable water used for agricultural purposes. The PSI standards state that the concentration of 20 mg/l BOD places the water within the A category of the water quality used for agricultural purposes.

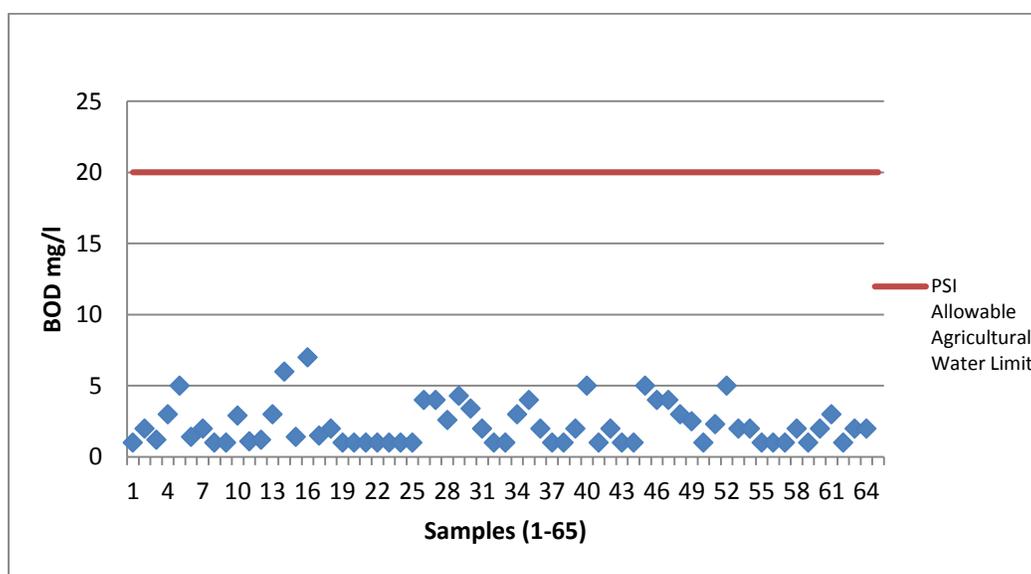


Figure 5.2: BOD concentration in the tested condensate water

- COD:** As shown in figure 5.3, the tested condensate water samples for the COD level was ranged at (18-150 mg/l), with a mean value of 101.71 mg/l. As of the total water sample collected, 7 samples are placed within the range of A category of the water quality limits used for agricultural purposes with COD level less than 50 mg/l. Within the total samples, it was noticed that 19 water samples are placed within the acceptable range of the agricultural water standards with a water quality ranked at category C, where all the COD concentration were tested to be less than 100 mg/l. Moreover, the COD concentration of 39 water samples was

ranged within 100 mg/l and 150 mg/l, placing these samples under the D category of the water used for agricultural purposes.

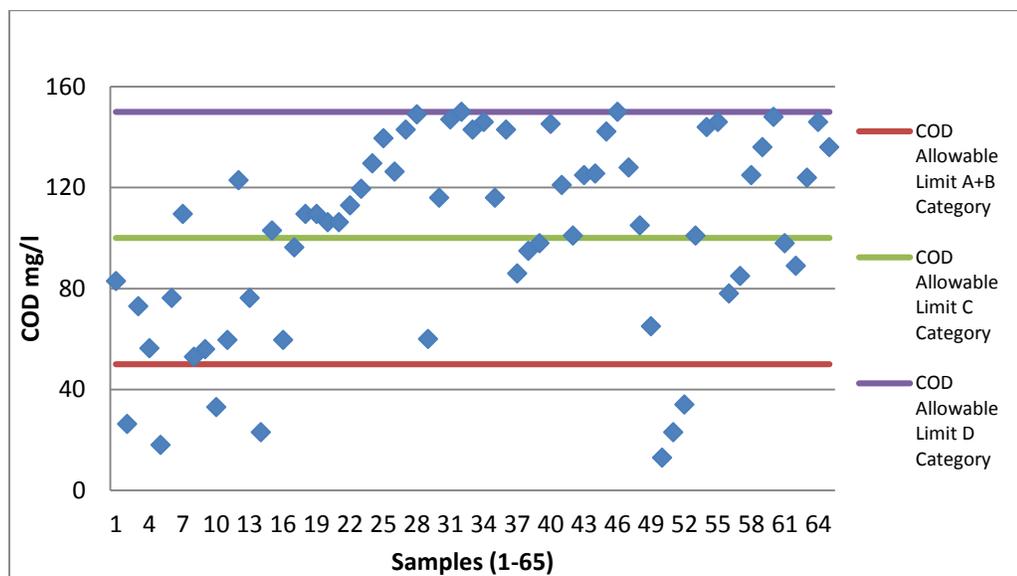


Figure 5.3: COD concentration in the tested condensate water

- **Sulfate SO<sub>4</sub>:** The sulfate concentration occurred in the condensate water samples in very low concentrations ranged at (0.001-0.006 mg/l), with a mean value of 0.0033 mg/l. This result demonstrates that the tested condensate water falls within the acceptable limits of the drinking water (limit of 200 mg/l) and the agricultural water (limit of 300 mg/l).

### 5.1.2 Measurements of Heavy Metals Concentrations

Identification and quantification of heavy metals concentrations in the condensate water is at great importance in the development of this research. As indicated in chapter 3, previous literatures had highlighted the possibility of heavy metals occurrence in the condensate water. Therefore, 17 samples were selected based on the results of the previous section, to be detected for the heavy metals. Table 5.2 displays the selected heavy metals tests for the samples with the relevant Palestinian water quality standards, while table 5.3 shows the results of the heavy metals detection tests.

Table 5.2: PSI Drinking Water and treated water reused for irrigation standards

Parameter	UNIT	Drinking Water <sup>1</sup>	Reused Irrigation Water <sup>2</sup>
Cu	mg/l	1	0.2
Fe	mg/l	0.3	5
Pb	mg/l	0.01	0.2
Cd	mg/l	0.005	0.01
As	mg/l	0.05	0.1
Se	mg/l	0.01	0.02
Sn(Tin)	mg/l	-	-
Mo	mg/l	-	-
Ni	mg/l	0.05	0.2
Co	mg/l	-	0.05
Al	mg/l	0.2	5
Mn	mg/l	0.01	0.2
Li	mg/l	-	-
Cr	mg/l	0.05	0.1
Ba	mg/l	2	2
Ag	mg/l	0.01	-
Zn	mg/l	5	2

<sup>1</sup>Source:(PSI,2005), <sup>2</sup> Source:(PSI,2012)

The results obtained from the heavy metals detection tests for the 17 condensate water sample are shown in table 5.3. These results were compiled and plotted against the PSI drinking water and treated water reused for irrigation standards. The comparison is depicted in the graphs below, figures 5.4-5.9, for the major heavy metals concentration in condensate water.

Table 5.4: Heavy metals characteristics of the collected condensate water samples

(mg/l)	S1	S4	S6	S8	S9	S10	S11	S13	S17	S19	S28	S29	S33	S41	S48	S55	S59
<b>Cu</b>	BDL	BDL	1.81*	BDL	BDL	BDL	0.068*	0.85*	BDL	BDL	BDL	BDL	BDL	1.55*	BDL	BDL	0.56*
<b>Fe</b>	BDL	BDL	9.29*	BDL	BDL	BDL	ND	0.069	0.056	BDL	0.032	BDL	BDL	0.092	ND	BDL	0.098
<b>Pb</b>	ND	ND	ND	BDL	ND	ND	ND	BDL	ND	ND	ND	ND	ND	BD	ND	ND	BDL
<b>Cd</b>	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	BDL
<b>As</b>	ND	ND	ND	BDL	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	BDL	ND	ND
<b>Se</b>	ND	ND	ND	ND	ND	ND	ND	BDL	ND	ND	ND	ND	ND	BDL	ND	ND	ND
<b>Mo</b>	ND	ND	BDL	ND													
<b>Ni</b>	BDL	BDL	BDL	BDL	BDL	BDL	ND	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
<b>Co</b>	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
<b>Al</b>	BDL	BDL	11.5*	BDL	BDL	BDL	ND	8.9*	0.078	BDL	0.086	BDL	BDL	0.056	0.068	0.079	BDL
<b>Mn</b>	BDL	BDL	0.013	ND	BDL	BDL	ND	0.013	0.19	BDL	0.034	BDL	ND	0.086	BDL	0.021	BDL
<b>Li</b>	ND	ND	ND	ND	ND	ND	ND	BDL	ND	BDL	ND	ND	ND	BDL	BDL	ND	ND
<b>Cr</b>	BDL	BDL	0.19	0.05	BDL	BDL	ND	0.03	BD	0.042	BDL	BDL	BDL	0.03	0.021	BDL	BDL
<b>Ba</b>	0.079	0.033	0.092	0.053	0.061	0.053	0.05	0.1	0.048	ND	0.048	0.077	0.046	0.09	ND	BDL	0.75
<b>Ag</b>	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
<b>Zn</b>	0.105	0.022	0.02	0.101	0.021	0.046	ND	0.56	0.358	BDL	0.278	0.055	ND	0.56	0.352	0.01	0.49

\*Concentration in ppm, BDL: Below Detection Limits, ND: Not Detected

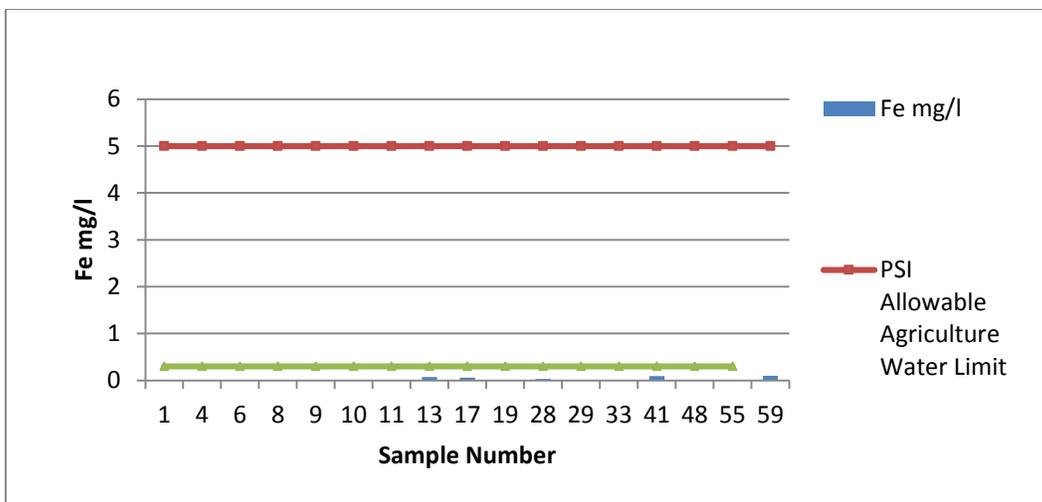


Figure 5.4: Measurement of the Iron concentrations

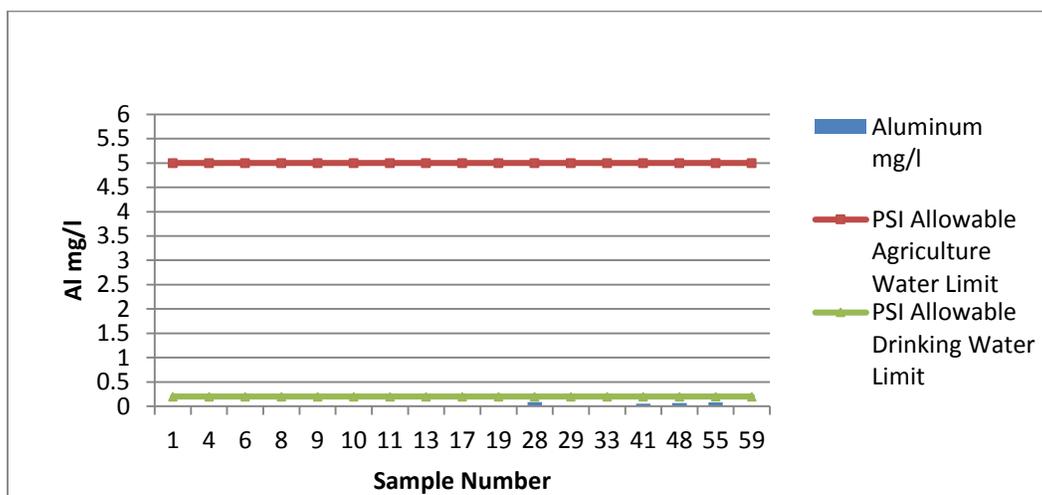


Figure 5.5: Measurement of the Aluminum concentrations

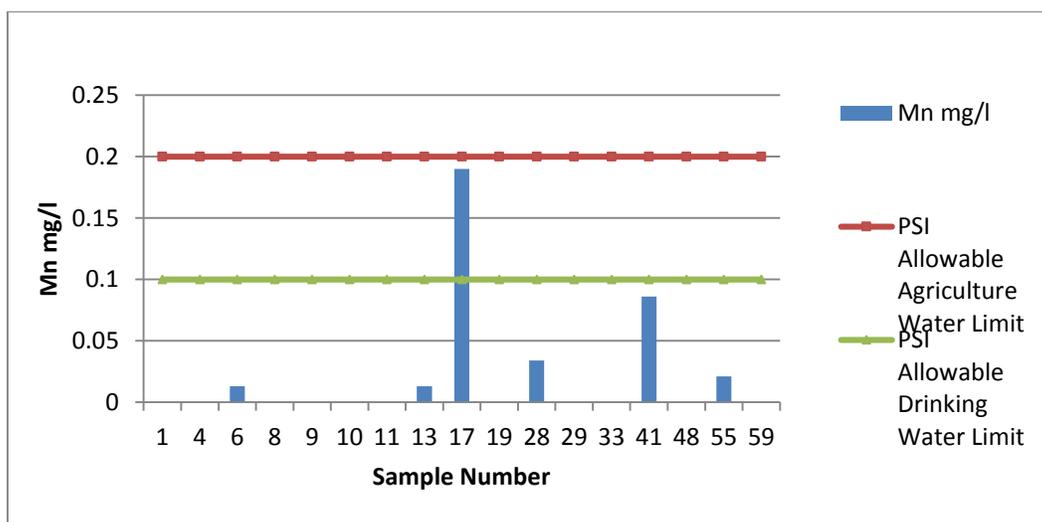


Figure 5.6: Measurement of the Manganese concentrations

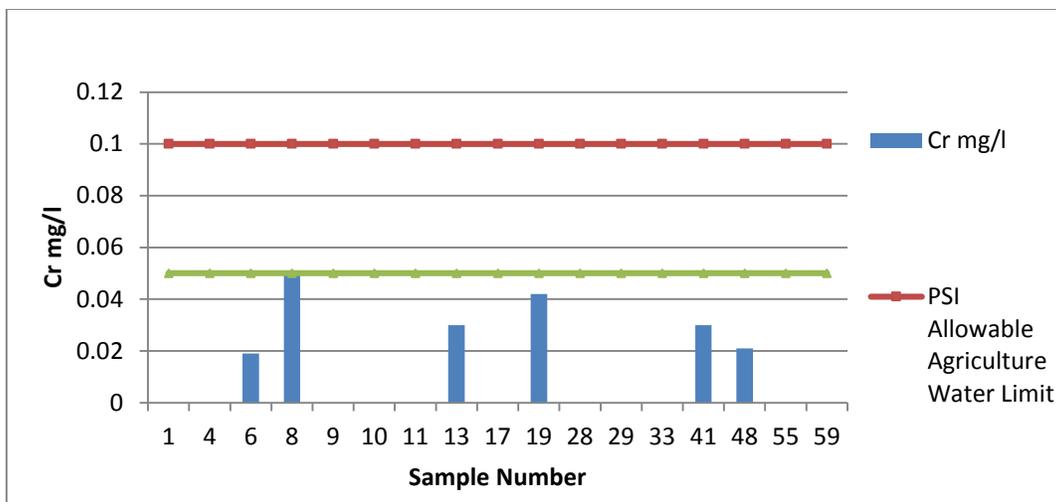


Figure 5.7: Measurement of the Chromium concentrations

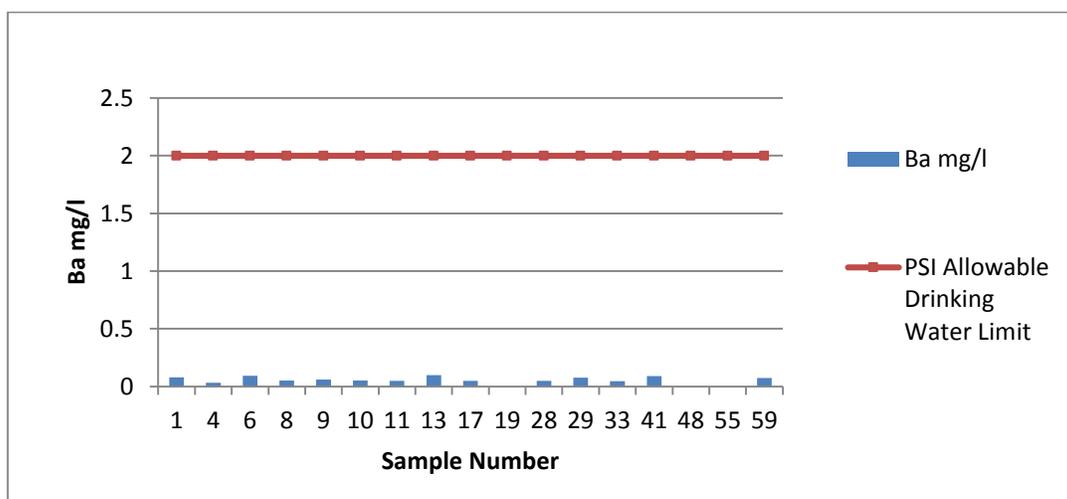


Figure 5.8: Measurement of the Barium concentrations

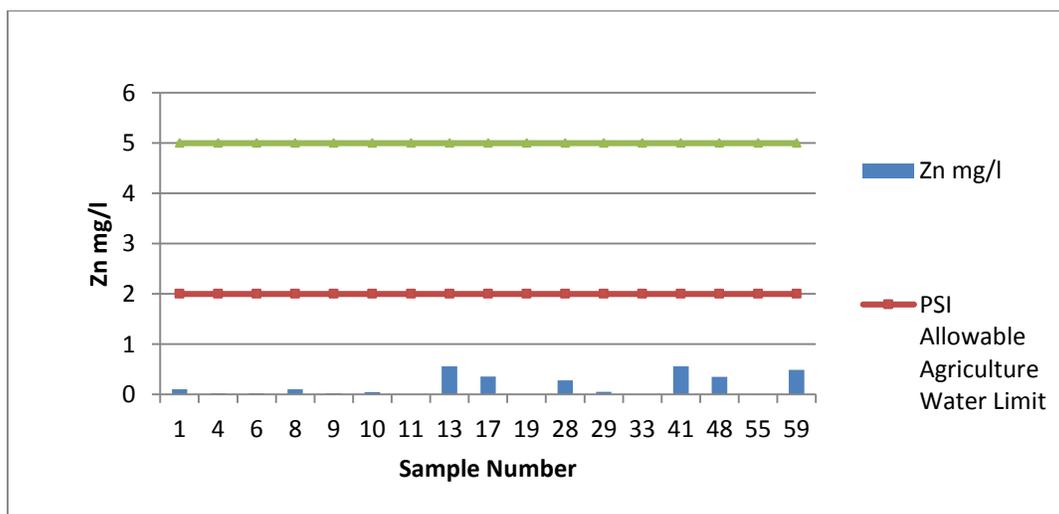


Figure 5.9: Measurement of the Zinc concentrations

From the above demonstrated graphs for the heavy metals concentration in the condensate water samples, the results of the analysis can be obtained as follows:

- The results of the heavy metals examination show that the tested condensate water samples are not contaminated by: Pb, Cd, As, Se, Sn, Mo, Ni, Co and Li elements. The results of the tests were concluded either as “BDL= Below Detection Limit” or “ND= Not Detected”.
- Other results concluded that some samples contain other metals such as: Cu, Fe, Al, Cr, Ba, Zn, and Mn. From the above figures, it can be noticed that the Cu concentration levels occurred in the condensate water samples in very letter magnitude and all concentration were found to be in part per million (ppm), which are less than the maximum allowable drinking and agricultural limits according to the PSI in 2005 and 2012.
- The concentrations of Fe, Al, Cr, Ba and Zn are found to be smaller than the acceptable limits for both the drinking and agricultural water standards stated by the PSI in 2005 and 2012.
- Higher levels of Mn were found among the tested condensate water samples, where one sample (No 17) falls above the acceptable limits of drinking water. This might be caused by the accumulation of air conditioning piping deposits. However, the indicated concentration does not create risk in regard to drinking water, since the health based value is 0.4 mg/l (WHO, 2011). All other samples are found to be within the acceptable range of the drinking and agricultural water standards.

## **5.2 Condensate Water Quantity Assessment**

As explained previously, different types of targeted locations were visited in Ramallah and Jericho cities, where condensate water quantities were observed and time was plotted. The common used

air conditioning split units are with the capacities of 1, 2 and 3 tons. The following sections explain the results of the observed condensate water volume over a period of time of one hour in both cities and in each location. Each graph shows the operational temperature 16°C, 18°C in Ramallah, and 18°C, 20°C in Jericho, in relation to the condensate water volume in liter per hour. From the real observed average volumes theoretical relations are developed for each condition in both cities and for each operational temperature.

### 5.2.1 Observed Water Quantity in Ramallah

In the city of Ramallah, the water quantity of the air conditioning units was measured by observing the volume of the generated water from a total number of 21 units (1, 2, 3 Tons) operating at 16°C and 18°C. The average of the measured quantity generated was calculated and presented in the following graphs. The analysis of the water quantity includes the calculations of the generated water quantity based on the average working hour for the tested units. The average working hours in Ramallah was calculated based on the questionnaire analysis presented in section 5.3.

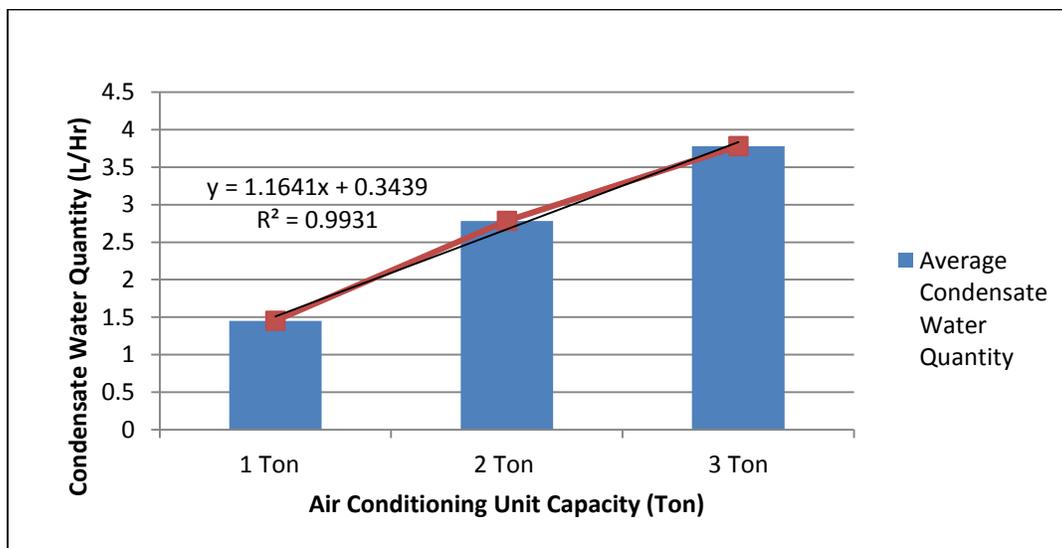


Figure 5.10: Condensate water quantity at 16°C operational temperature-Ramallah

The observed water condensate measurements in figure 5.10 show that at 16°C operational temperature the 1, 2 and 3 tons air conditioning units generate the averages of 1.45, 2.78 and 3.78 L/Hr respectively. The observed condensate volumes are considered to be significantly high. A high r-square (R<sup>2</sup>) of 0.99 is obtained from the developed linear regression, this shows a close proximity of the fitted data between the volume generated and the unit capacity. If these rates are calculated for an average working day of 6.64 hours per day (please refer to section 5.4: Questionnaire Analysis), the volume of the collected condensate water will reach 9.63, 18.46 and 25.1 L per day for the 1, 2 and 3 tons respectively. The relation developed through the collected data shows clearly the proportional increase between the condensate water volume and the air conditioning capacity in tons. Moreover, based on the field collected data the computed condensate water volume can be realized by the linear equation indicated in the graph above.

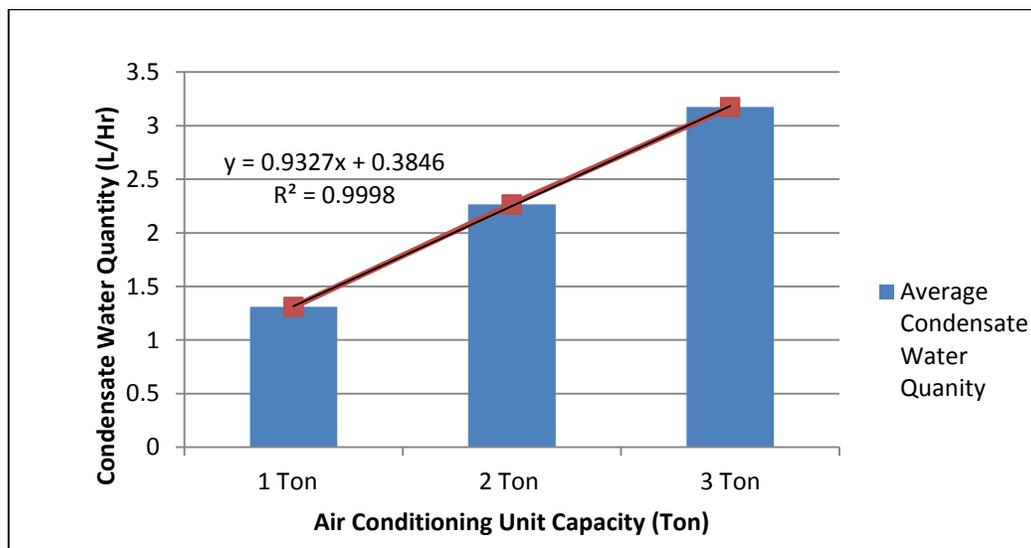


Figure 5.11: Condensate water quantity at 18°C operational temperature-Ramallah

The observed water condensate measurements in figure 5.11 shows that at 18°C operational temperature the 1, 2 and 3 tons air conditioning units generate the averages of 1.30, 2.26 and 3.17 L/Hr respectively. The observed condensate volumes are considered to be significantly high,

nevertheless these rates are less than the rates generated at less operational temperatures. A high r-square ( $R^2$ ) of 0.999 is obtained from the developed linear regression, this shows a close proximity of the fitted data between the volume generated and the unit capacity. If these rates is calculated for an average working day of 6.64 hours per day, the volume of the collected condensate water will reach 8.63, 15.00 and 21.10 L per day for the 1, 2 and 3 tons respectively. The relation developed through the collected data confirms the proportional increase between the condensate water volume and the air conditioning capacity in tons.

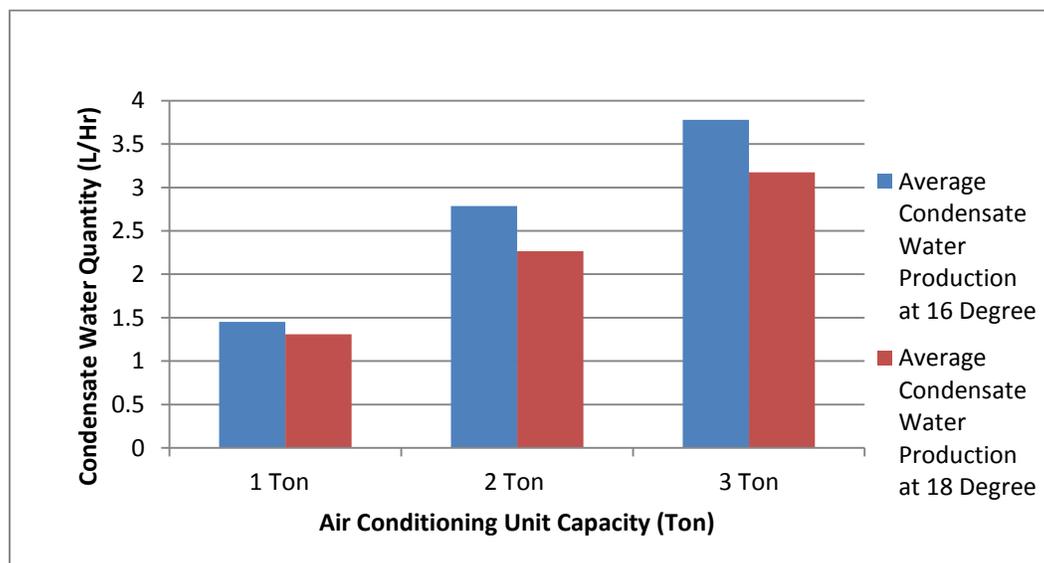


Figure 5.12: Condensate water quantity at 16°C and 18°C operational temperature-Ramallah

Figure 5.12 shows the relation between the condensate water quantities at the different operational temperatures for the same unit capacity. Where it can be noticed that as the operational temperature decreases the volume of the condensate water increases. The graph shows the condensate water generated at 16°C and 18°C operational temperatures. Conceptually, it can be said that a slight decrease in the generated water volume of 10.3% is caused by an increase of 2 degrees of the operational temperatures.

### 5.2.2 Observed Water Quantity in Jericho

In the city of Jericho, the water quantity of the air conditioning units was measured by observing the volume of the generated water from a total of 21 units (1, 2, 3 Tons) operating at 18°C and 20°C. The average of the measured quantities generated was calculated and presented in the following graphs. The analysis of the water quantity includes the calculations of the generated water quantity based on the average working hour for the tested units. The average working hours in Jericho was calculated based on the questionnaire analysis presented in section 5.3.

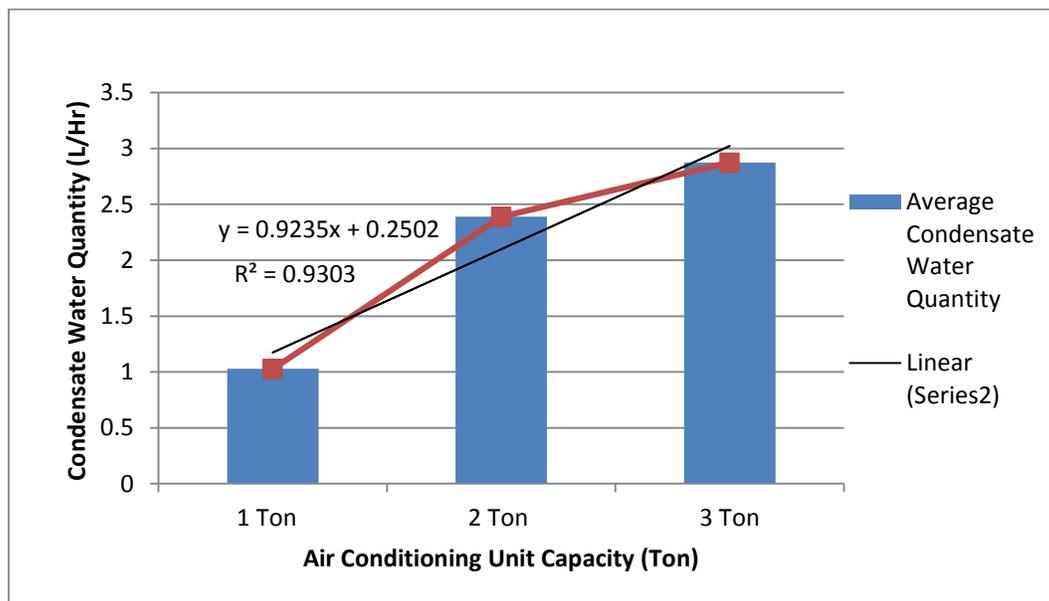


Figure 5.13: Condensate water at 18°C operational temperature-Jericho

The observed water condensate measurements in figure 5.13 show that at 18°C operational temperature the 1, 2 and 3 tons air conditioning units generate the averages of 1.02, 2.39 and 2.87 L/Hr respectively. The observed condensate volumes are considered to be significantly high, nevertheless these rates are considered to be less than the rates produced at the same operational temperatures in Ramallah city. A high r-square (R<sup>2</sup>) of 0.93 is obtained from the developed linear regression, this shows a close proximity of the fitted data between the volume generated and the

unit capacity. If these rates are calculated for an average working day of 15.1 hours per day, the volume of the total collected condensate water will reach 15.40, 36.09 and 43.34 L per day for the 1, 2 and 3 tons respectively. The relation developed through the collected data confirms again the proportional increase between the condensate water volume and the air conditioning capacity in tons.

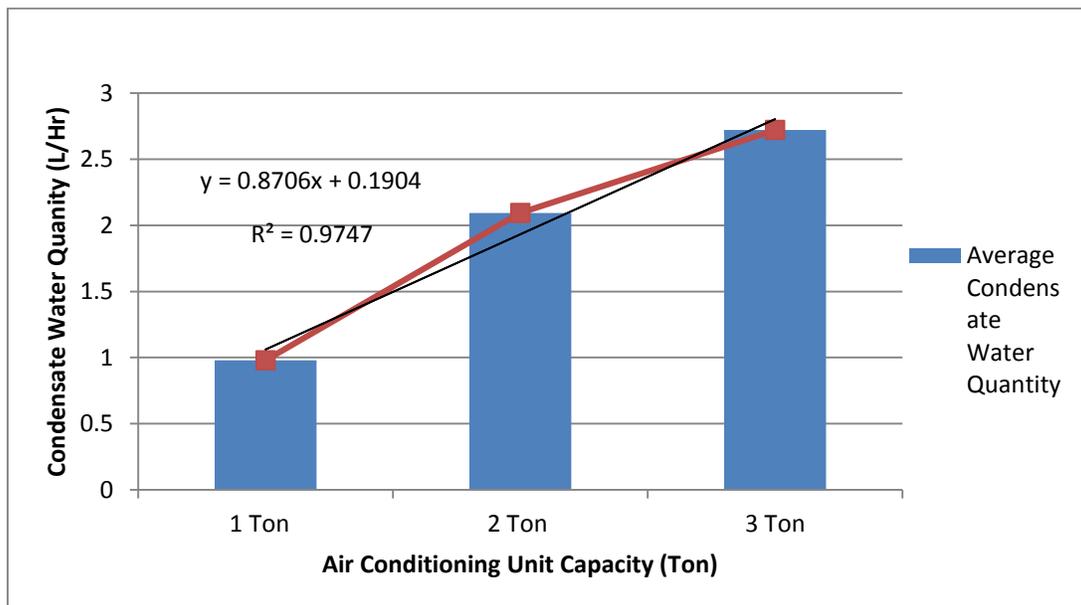


Figure 5.14: Condensate water quantity at 20°C operational temperature-Jericho

The second tested operational temperature in Jericho city was 20°C, where the examined air conditioning units are 1, 2 and 3 tons. As shown in figure 5.14, the 1 ton conditioning unit generates 0.98 L/Hr, while the 2 and 3 tons units generate 2.10 and 2.72 L/Hr respectively. The observed volumes are still considered to be significantly high, but less than the explained in the previous case (18°C operational temperature). A high r-square (R<sup>2</sup>) of 0.97 is obtained from the developed linear regression, this shows a close proximity of the fitted data between the volume generated and the unit capacity. Moreover, if these rates are calculated for an average working day of 15.1 hours

per day, the volume of the total collected condensate water will reach 14.80, 31.71 and 41.072 L per day for the 1, 2 and 3 tons respectively.

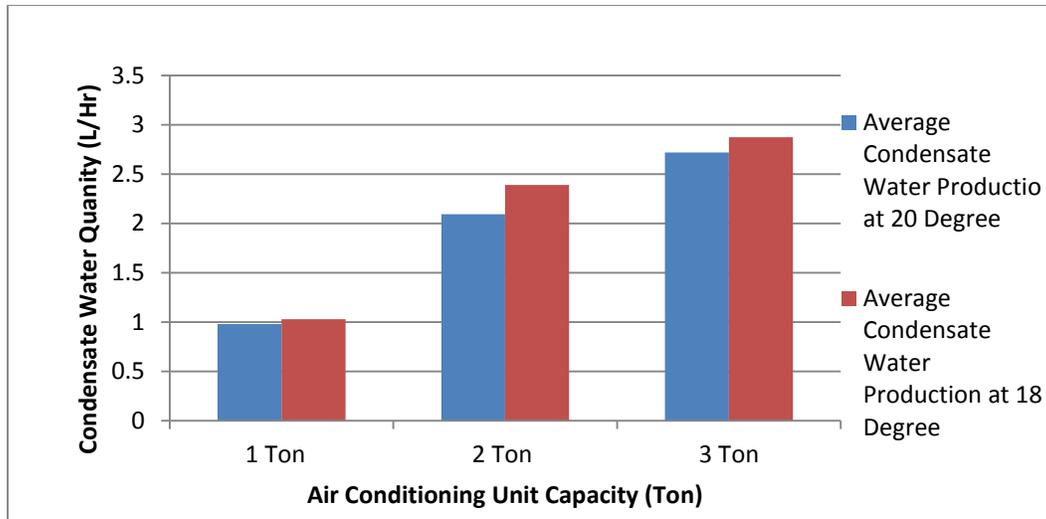


Figure 5.15: Condensate water quantity at 18 and 20°C Operational temperatures-Jericho

Figure 5.15 shows the relation between the condensate water quantities at different operational temperatures for the same unit capacity. Where it can be noticed that as the operational temperature decreases the volume of the condensate water increases. The graph shows the condensate water generated at 18°C and 20°C operational temperatures. Conceptually, it can be said that a slight decrease in the generated water volume of 9 % is caused by an increase of 2°C degrees of the operational temperatures.

### 5.2.3 Comparison of Water Quantity

To compare between the two different volumes generated in Ramallah and Jericho city, the figures calculated in figures 5.11 and 5.13 were combined. The following graph shows the two quantities generated in Ramallah and Jericho cities, by the same unit capacities at the same operational temperature of 18°C.

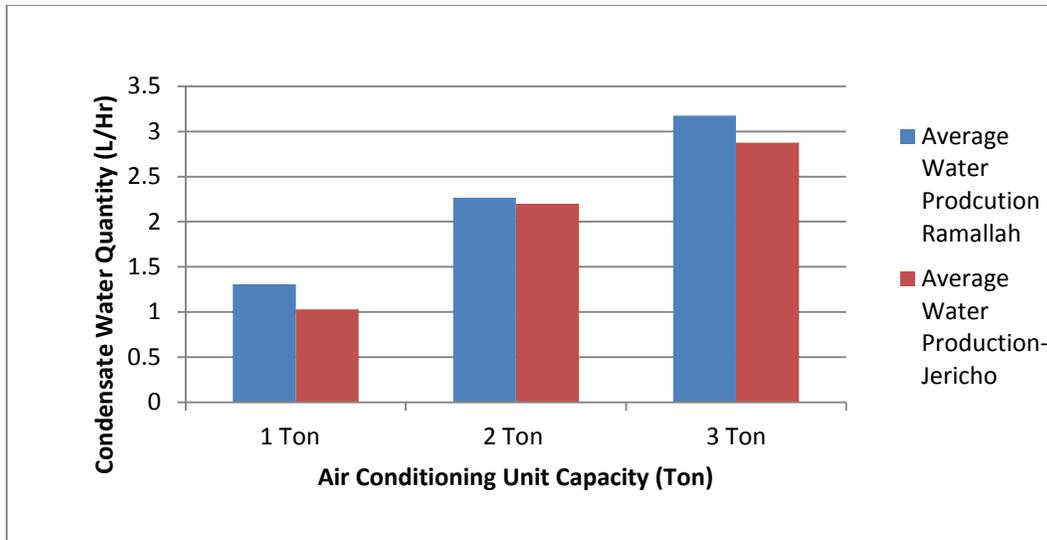


Figure 5.16: Condensate water quantity at 18°C operational temperature-Ramallah/Jericho

Based on the collected data presented in figure 5.16, it can be noticed that the generated condensate rates are higher in Ramallah city than Jericho city, knowing that the operational temperature was fixed at 18°C. This difference in the generated rates corresponds to an increase of 10% in the volume generated in Ramallah compared to Jericho. This difference in the condensate volume rates depends on a number of factors including the age of the unit and hence the cooling capacity, room surface area and the relative humidity.

### 5.3 Air Conditioning Units Supply in Palestine

The information concerning the conditioning systems supply was collected through several semi-structure interviews with the main suppliers and sub-contracting suppliers in the West Bank. The number of the national suppliers in this field is exclusive to two main suppliers covering the West Bank. The Palestinian national suppliers are covering mostly 50% of the demand, while the other 50% is covered by other sources. The Palestinian suppliers import the different types of air conditioning split systems of 1, 2 and 3 Tons capacities from China where the systems are manufactured and exported worldwide.

### 5.3.1 Palestinian Market Survey

Through the carried out interviews, it has been marked that the need of the heating, cooling and ventilation systems has increased sharply during the past several years in Palestine. More specifically, it can be noticed that the pattern of the demand is at increase, where it had increased by 25% from the year 2010 to 2011, and by 35% from the year 2011 and 2012. According to “Triple R for Trading and Marketing, (Triple R)” in Ramallah, there had been a market survey conducted in 2011, estimating the total number of sold air conditioning split units as around 18,000 units in the West Bank and Gaza Strip in the year 2011 only (Fatafta, 2013). The two main national suppliers are Triple r for Trading and Marketing and Sbitany company, whom they equally shared the provision of 9,000 air condition split units (Ghanayem, 2013). Figure 5.17 shows the distribution of the air conditioning units provision in Palestine.

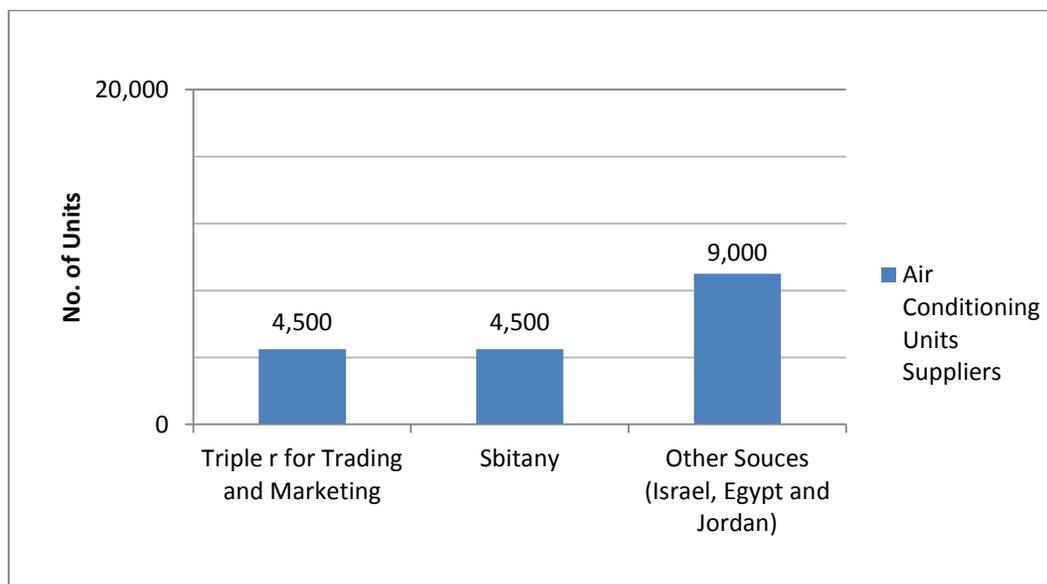


Figure 5.17: Air conditioning units supply distribution in Palestine

The distribution of the supply to the users concluded that 50% of the existing air conditioning units are supplied mainly by other sources than Palestinian sources. The majority of the non-Palestinian

suppliers are Israeli, while a limited percentage of units are supplied from Jordan and Egypt. The market survey also confines the estimated distribution of the supplied air conditioning split units per capacity, used at the Palestinian market level, as shown in figure 5.18 (Ghanayem, 2013).

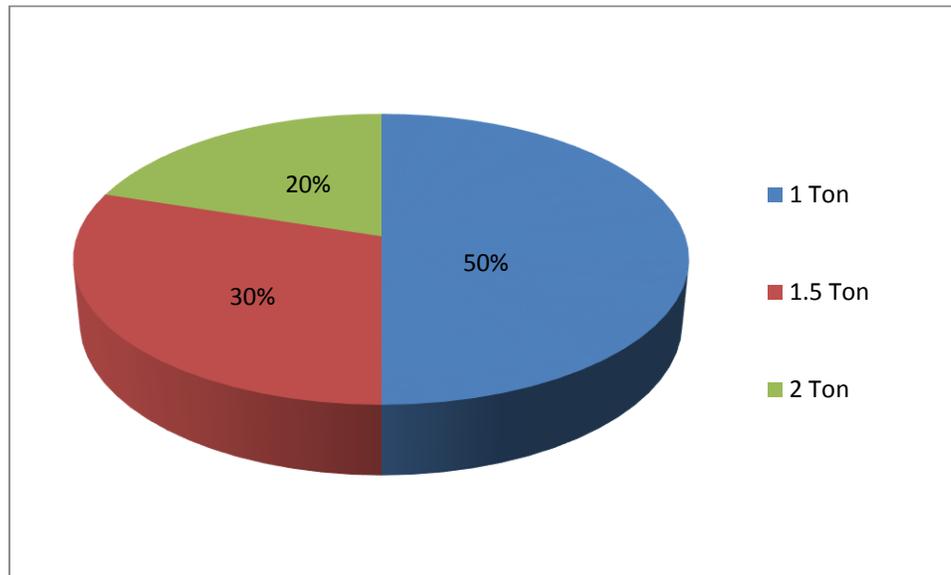


Figure 5.18: Air conditioning units supply distribution in Palestine

It can be noticed that the mostly sold split units are in the capacity of 1 Ton, this might indicate that the residential houses (apartments and houses) are the major users for this system. Where these units are usually used to heat and cool one room, or a small open-plan area, of up to 15 square meters. It is highlighted as well, that the above presented figures are generally estimating the Palestinian market, where the 3 tons capacity units are considered to be rarely supplied and therefore used (Fatafta, 2013).

### 5.3.2 Brands and Costs of the Common Air Conditioning Systems

In Palestine, different brands of air conditioning systems are imported and supplied since the beginning of the 1990's. Nevertheless, the various equipment are implicitly imported from China, which has been the leading manufacturer of the cooling and heating equipment systems this field.

Couple of years ago LG “Life’s Good” brand was widely used in Palestine (Ghanayem, 2013). However, it is no longer imported due the fact that it doesn’t match with the new required Palestinian specifications for the air conditioning systems. The two main brands currently supplied by the Palestinian suppliers are “GREE” and “MEDIA”, these two brands cover half of the market demand. The second half of the is covered by other sources as demonstrated in figure 5.16, in which the Israeli suppliers provide TADIRAN,ELECTRA, FAMILY, NORMANDY and TORNADO air conditioning brands. In addition to these brands, the Palestinian market also contains small percentage of PETRA and UNION AIR conditioning units, imported from Jordan and Egypt respectively (Fatafta, 2013).

According to the two main suppliers, the cost of the above mentioned air conditioning brands are approximately close, however the difference in the cost can occur due to the installation and maintenance cost. The average costs for the units in general are as follows:

- 1 Ton split unit: Average cost: 1,750 NIS, installation cost:2,200 NIS
- 1.5 Ton split unit: Average cost: 2,800 NIS, installation cost: 3,300 NIS
- 2 Ton split unit: Average cost: 3,900 NIS, installation cost: 4,400 NIS
- 3 Ton split unit: Average cost: 6,000 NIS, installation cost: 7,000 NIS

### **5.3.3 Standard Air Conditioning Installation**

The carried out semi-structure interviews explored if there are some required guidelines or procedures to be respected while installing the air condition systems, especially concerning the configuration of the condensate water pipes installation. It was figured out that the only guidelines followed aim at achieving energy efficiency in the installation, commissioning, operation and maintenance of air-conditioning installations in buildings. These guidelines are supplementary

recommendations to codes issued in relation to the best practices for energy efficiency of air-conditioning Installations. In addition, it was highlighted that the local sub-contractors are strictly following the safety recommendations of installation, for instance it is recommended that the condenser location must be accessible by commercial ladders and the wall is capable of supporting the weight of the equipment. The interview results confirmed that there are no recommendation or technical guidelines put in place by the Palestinian municipalities and ministries.

#### **5.4 Questionnaire Analysis**

As outlined in Chapter 4, 85 questionnaire (50 questionnaires in Ramallah and 35 questionnaires in Jericho), were distributed among residents, commercial shops and companies in the cities of Ramallah and Jericho to obtain indicator values for quantifying the condensate water volume. This survey discussed the use of different types and capacities of conditioning units, to estimate the generated quantity of water, the daily use of system, and furthermore, to better understand the population perceptions regarding the management of the condensate water generated from the air conditioning unit. In addition, the survey highlighted the question of users' awareness in regard to the quality of the generated water, and hence the in place methods used to benefit from this source of water efficiently.

##### **5.4.1 Current Condensate Water Management**

Within the selected interviewed sample in both cities, the distribution of the common methods used to deal with the generated condensate water was deliberate as shown in Figure 5.19.

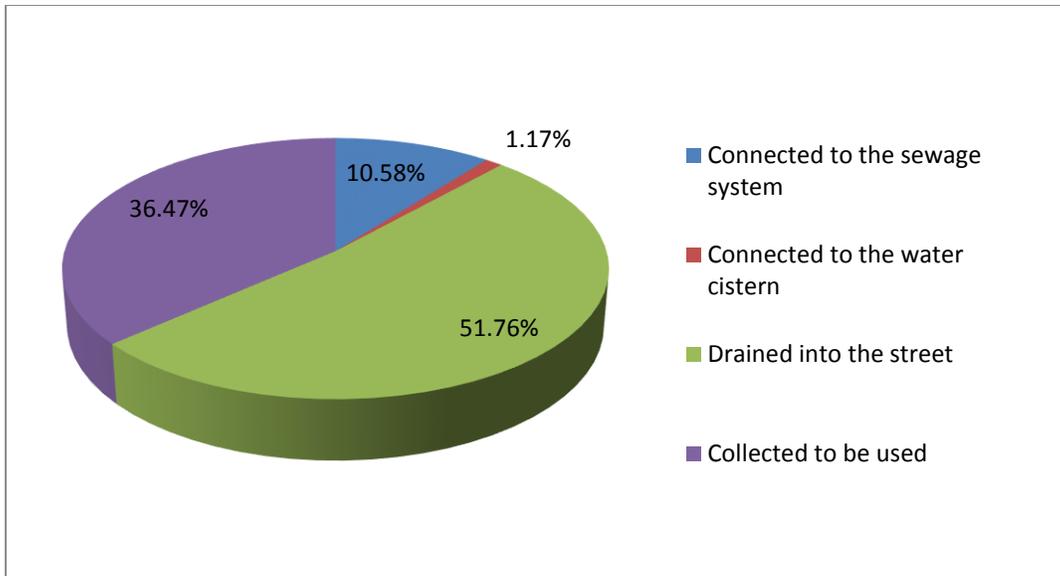


Figure5.19: Common methods used of managing the condensate water

As shown in Figure 5.19, 51.76 % of the interviewed sample drain the condensate water into the street, whereas 36.47% of the collect the generated condensate water to be used for different purposes, 11.75% have installed a special piping system to connect the generated water from the split unit to the cistern or the sewage system. Among the indicated 11.75%, the study shows that only 1.17% connect the generated water to the water harvesting cistern, where based on their perception, water can be conserved and used for gardening purposes.

In order to approximately quantify the volume generated from the air condition units, among the interviewed sample, the volumes were calculated based on the equations developed in the previous sections for each location (Ramallah and Jericho), unit capacity, average working hours, and the operational temperature. Descriptive graphs indicating the distribution of the calculated quantity and the different common possible methods of management in Ramallah and Jericho cities, are shown in figures 5.20-5.23.

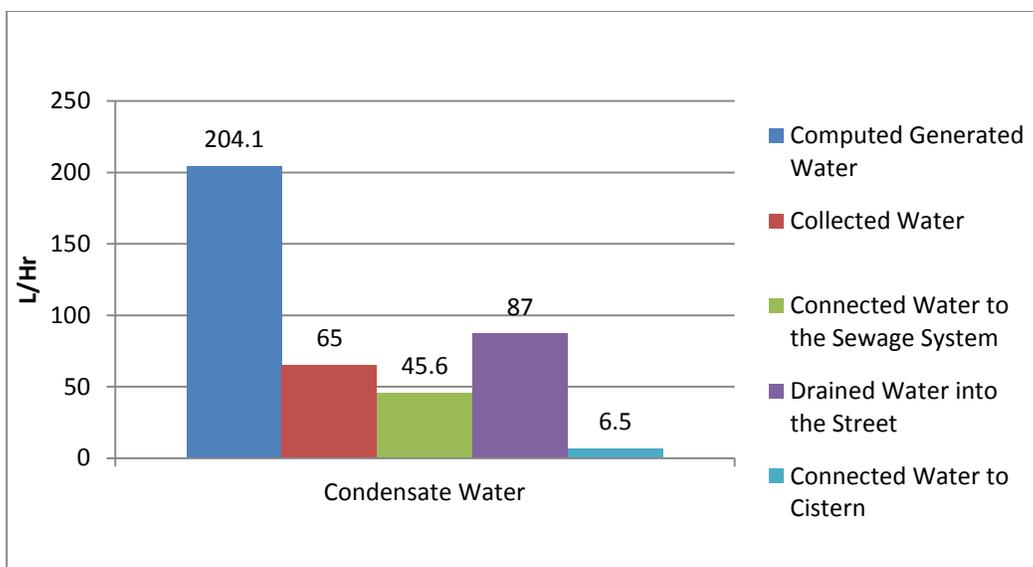


Figure 5.20: Condensate water volumes and possible methods of management-Ramallah

Among the interviewed Ramallah sample (55 questionnaires), the computed volume of the condensate water quantity was about 204.1 L/Hr, which resulted from a sum of 93 units with a total capacity of 157 tons. As shown in figure 5.18, between draining the water into the street and connecting the water to the sewage system, the wasted water can be quantify as 132.6 L/Hr.

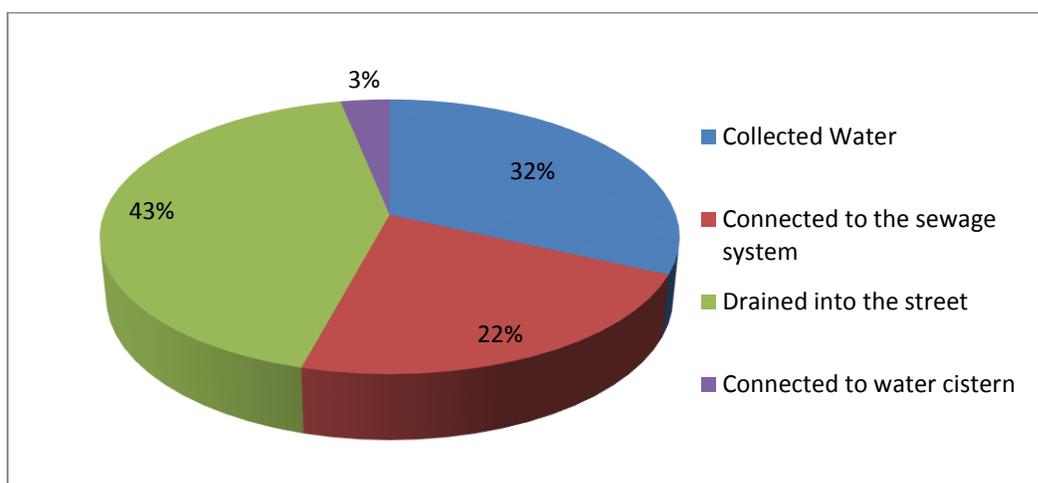


Figure 5.21: Common methods of condensate water management- Ramallah

Figure 5.21 shows that 43% of the sample drain the water into the street, while 22% connect it to the sewage system. It was found that 3% of the sample connect the water to the rainwater harvesting cistern, this management method is exclusively used in one 5 floor new building rented to 10 companies and organizations.

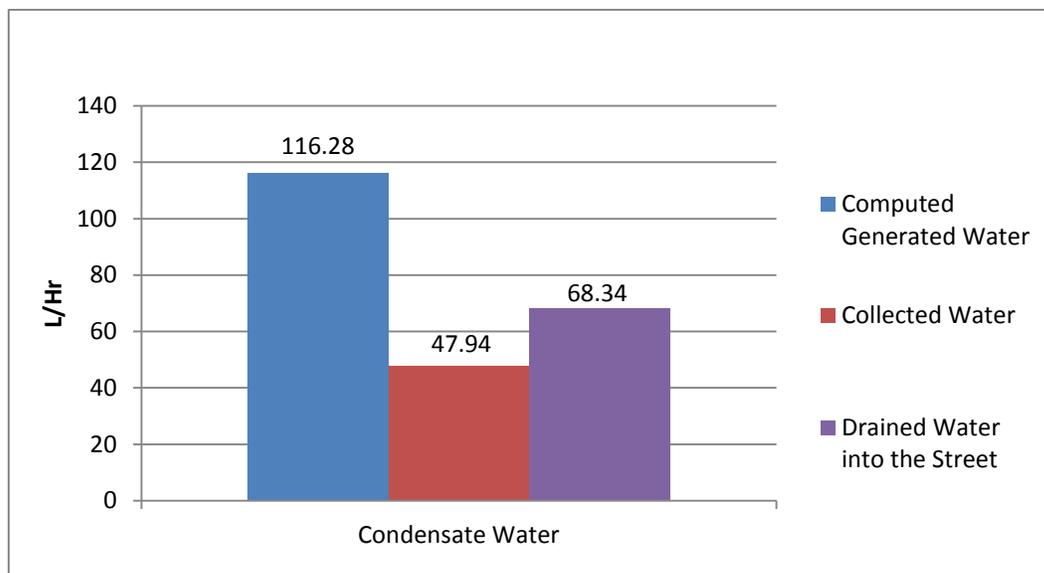


Figure 5.22: Condensate water volumes and possible methods of management-Jericho

Among the interviewed Jericho sample (35 questionnaires), the computed volume of the condensate water quantity was about 116.28 L/Hr, which resulted from a sum of 52 units with a total capacity of 114 tons. As shown in figure 5.22, in Jericho people have less possible options to deal with the condensate water, due to the lack of sewage systems and rainwater harvesting cisterns. Therefore, the drained water into the street was quantified as 68.34 L/Hr, while the collected condensate water was averaged at 47.94 L/Hr.

Figure 5.23 shows the results of the analyzed questionnaires indicating that in the city of Jericho, 41% of the interviewed sample collect the condensate water, while 59% drain the condensate water into the street.

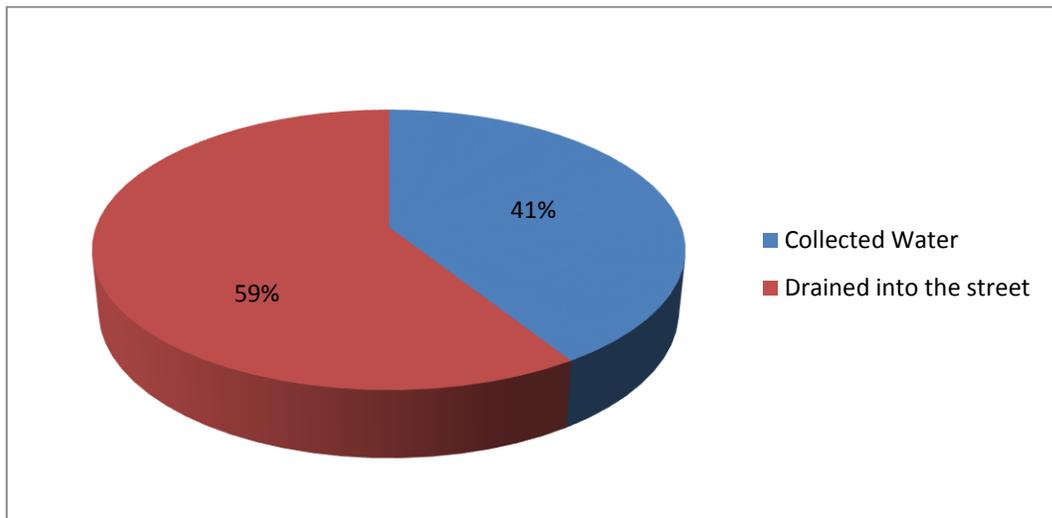


Figure 5.23: Common methods of condensate water management- Jericho

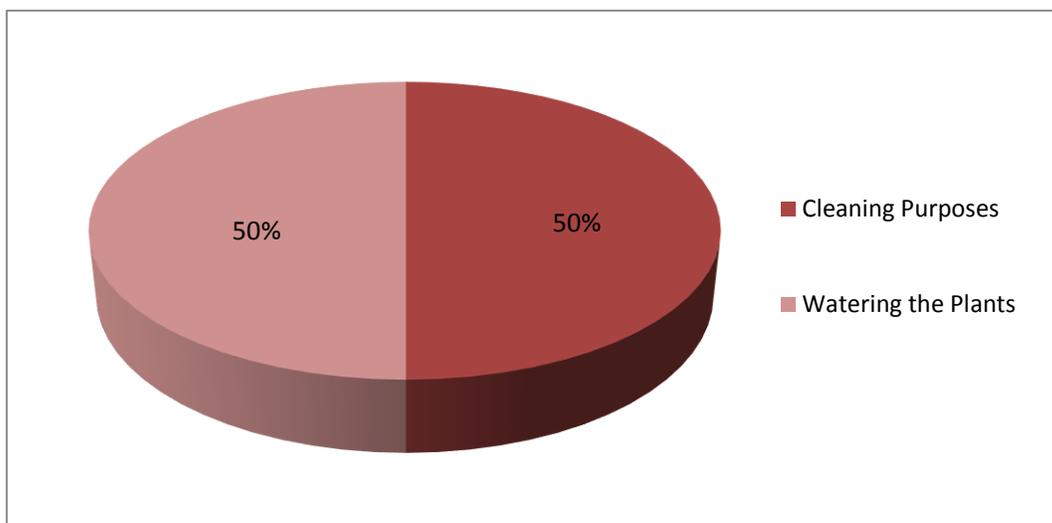


Figure 5.24: Uses of the collected condensate water-Ramallah and Jericho

It is important to note that the survey highlighted the users' conservation initiatives in terms of possible uses of the collected water. Throughout the users who collect the condensate water, two

possible ways of using the water were reported as shown in figure 5.24, it was indicated that that 50% of the sample had used the water to water the plants (inside green plants in the offices, shops and houses). Moreover, it was found that only 12.12% of the users connects the collected water directly to their home gardens, which are reported to be owned by 38.8% of the interviewed people in the two cities. Mostly in the commercial shops, the condensate collected water is used to clean the shops floors and toilets at the end of each day.

#### 5.4.2 Users' Perception

Another aim of the questionnaire survey is to better understand the perception of the air conditioning systems users in regard to the quality and quantity of the generated water and the possible safe uses. The answers reflecting the respondents' own awareness about the quality and quantity of the water, are displayed in figures 5.25 and 5.26.

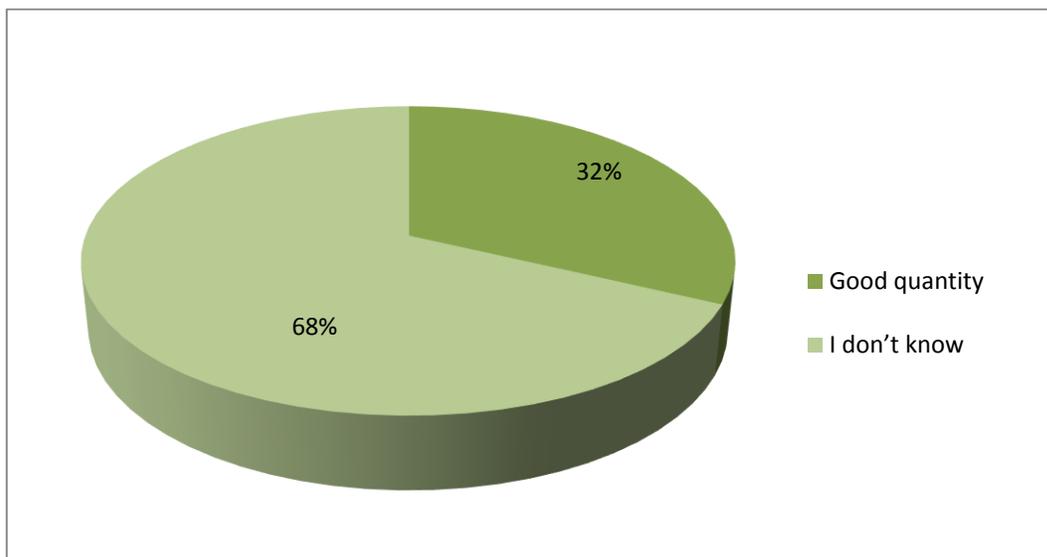


Figure 5.25: Quantity of generated water from the air conditioning units

When asked “How much quantity is generated by the air conditioning units”, the responses showed that the greatest percentage (68%) of the sample lack of awareness on the produced water quantity, the reason behind this might be that they don’t see the water which is connected to the sewage system, the cistern or drained into the street. About 32% of the sample declared that the condensate water produced by the air conditioning units are considered to be “good quantities”. Nevertheless, 3.57% from this sample are not collecting or using the condensate water stating that the water was originally connected to the water collection cistern.

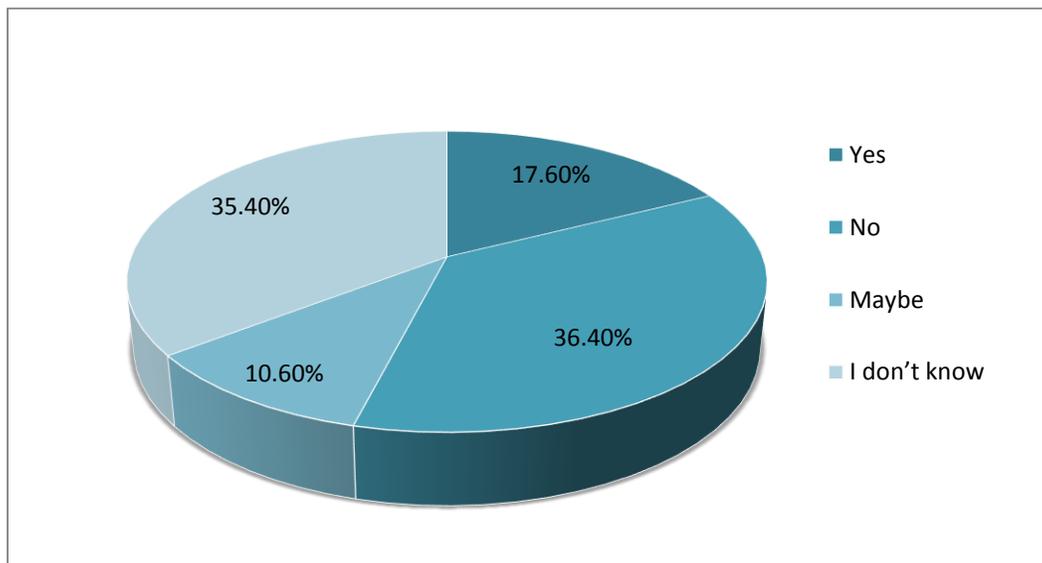


Figure 5.26: Safety of condensate water

Descriptive results were reported in the context of the quality and safety of the condensate water produced by the air conditioning units, where a strong relation can be suggested between the awareness indicator of the water quality and the possible uses for the collected water. About 36.4% of the users stated that the water is not safe, 17.6% confirmed that it is safe, 10.6% stated that it could be safe, and 35.4% stated that they don’t know whether it is safe or not.

Generally speaking, 100% of the interviewed sample confirmed that the condensate water cannot be used for drinking or domestic purposes, where 84.7% stated that the water cannot be used for irrigation purposes, 25% of the sample thought that it cannot be used even for cleaning. Among the interviewed sample in both cities, 14.1% of the users thought that the condensate water can be used safely for agricultural and cleaning purposes. It can be concluded that the conflicting perception of the users in regards to the safety of the condensate water is highly influence by the lack of awareness and definitely not based on any shock experience faced by the users.

## **5.5 Generated Condensate Water Quantities in Palestine**

Based on the information collected through the semi-structure interviews and the results demonstrated by the analysis of the questionnaires, the calculation of the global condensate water generated from the sold units in the year 2012, can be figured out. This could be useful to realize the quantity in cubic meters of the generated water at the Palestinian level, and therefore to start framing a reliable conservation method to be followed. The figures and data used in this part of the report are obtained from various sections throughout this study, along with the following assumptions and calculations.

### **5.5.1 Number and Capacity of air conditioning units in 2012**

The global condensate water volume generated from the air conditioning units sold in the year 2012, can be quantified following the steps:

The information presented in section 5.3.1 (Palestinian Market Survey), states that in the year 2011, the total number of sold air conditioning units was 18,000 unit. Since there had been an

increase of 35% in the year 2012, therefore the total number of the sold air conditioning systems in 2012 can be estimated as **24,300 Unit**.

Following the capacity distribution per Ton of the sold units:

Total Number of sold 1 Ton air conditioning units:  $24,300 * 50\% = 12,150$  Unit.

Total Number of sold 1.5 Ton air conditioning units:  $24,300 * 30\% = 7,290$  Unit

Total Number of sold 2 Ton air conditioning units:  $24,300 * 20\% = 4,860$  Unit.

### **5.5.2 Total Condensate Water Volume**

Considering that there is no clear information about the number of air conditioning units installed and used in each Palestinian governorate since the 1990's. It is assumed that the pattern of use in all the Palestinian governorates is similar to Ramallah pattern, therefore the figures of the working hours, generated water condensate volume and working temperature of 16°C, will be used. The assumption of Ramallah city situation could be more rational compared to Jericho city circumstances. Moreover the calculations in this section aim at developing the minimum case scenario for the quantified water volume, since there is no clear idea about the already existing number of air condition units installed since the year 1995 .

Form the equation displayed developed in section: *5.2.1 Observed Water Quantity in Ramallah* and displayed in in figure 5.10: Condensate Water Quantity at 16 Operational Temperature-Ramallah, and the average working hours figured out from the questionnaire analysis of 6.64 hours, and with the assumption that the summer season in Palestine lasts for 5 months, then the condensate water quantity calculation can be as follows:

- If the unit of 1 Ton generate: 1.5079 L/Hr, 10.012 L/Day , 300.36 L/Month and Total of 1,501.8 L per year which is 1.501 cubic meter per year, so the 12,150 units generate 18,225 cubic meter per year.
- If the unit of 1.5 Ton generate: 2.09 L/Hr, 13.88 L/Day , 416.40 L/Month and Total of 2,08 L per year which is 2.08 cubic meter per year, then the 7,290 units generate 15,177.80 cubic meter per year.
- If the unit of 2 Ton generate: 2.672 L/Hr, 17.74 L/Day, 532.26 L/Month and Total of 2,661.3 L per year which is 2.66 cubic meter per year, then the 4,860 units generate 12,927.60 cubic meter per year.

This estimated volume of generated water in cubic meter, explains the minimum, case scenario of the potential generated volume. These calculations could be more reliable if the number of air conditioning units installed and operated is quantified since the year of 1995. The calculated water volume resulted in this study can't be neglected, since the total estimated water quantified from the new installed units in the year 2012 is around **46,330 cubic meter**. This significant quantity should draw the attention to the decision and policy makers to put in place strict technical guidelines to be followed the local level.

## CHAPTER SIX CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Conclusions

In Palestine, almost in all modern buildings, air conditioning cooling systems are used to provide conditioned indoor environment. These cooling systems generate significant and under-utilized source of water for landscape irrigation and other uses. This source of water is mostly drained to the streets and sewage systems. In light of the water resources scarcity in Palestine, the condensate water could be considered as an alternative source of water, which plays a vital role in water supply, when fresh water become limited.

The main objective of this research was to better understand the potential for recovery of condensate water form air conditioning systems in Ramallah and Jericho cities. The research also aimed at assessing the quality of the condensate water generated by the condition systems, and to estimate the potential quantity generated.

The assessment of chemical and microbial water quality data for the condensate water showed that generally speaking the condensate water is at good water quality, which conforms to the Palestinian standards for reused water for irrigation. Some concerns might raise in regards o the turbidity measurements, which were higher that the acceptable ranges for drinking water. This occurred due to the sediments, sands and dust transferred in the air. Apart from this, in comparison with drinking water standards, the water is considered to be safe and will does not harm users if uses. Reflecting the heavy metals occurrence in the collected condensate water, no particular risk was concluded for the drinking water and the reused irrigation standards comparison.

The results of the quantity measurements show that high quantity of condensate water could be collected from the air conditioning systems. More specifically, from a single unit capacity high quantity of water was observed at approximately 1.4 L/Hr and 8.63 L/Day in the city of Ramallah, while around 1.2 L/Hr and 15.1 L/Day in the city of Jericho. Per month these computed water quantities could reach 258.9 L and 453.0 L in Ramallah and Jericho cities respectively. These quantities of water should be collected and used, otherwise it will be wasted and drained to increase water rates in the sewer systems. Moreover, the recovery of this water can help in maintaining environmental sustainability for the Palestinian region by minimizing fresh water use and decreasing dependency on fresh water resources.

As of the survey of the users' perception in this regard to the condensate water, 51.76 % of the interviewed sample drain the condensate water into the street, whereas 36.47% of the collect the generated condensate water to be used for different purposes, 11.75% have installed a special piping system to connect the generated water from the split unit to the cistern or the sewage system. Among the indicated 11.75%, the study shows that only 1.17% connect the generated water to the water harvesting cistern, where based on their perception, water can be conserved and used for gardening purposes. On a similar note, 68% of the sample lack of awareness on the produced water quantity, the reason behind this might be that they don't see the water which is connected to the sewage system, the cistern or drained into the street. About 32% of the sample declared that the condensate water produced by the air conditioning units are considered to be "good quantities".

This research had outlook an overview about the quantity of water generally generated in Palestine, through the market survey for the units of conditioning system sold in the year 2011. The calculated water volume resulted that the total estimated water generated form the new installed

units in the year 2012 is around 46,330 cubic meter. This quantity should draw the attention to the decision and policy makers to put in place strict technical guidelines to be followed the local level.

This information shows that despite the fact that water quality data, obtained from the water assessment and the water quantity measurement, this source of water has been neglected to a large extent. Since there is no adverse health risks experienced with the use of the condensate water, there remains to be perceived risks among users and a significant amount of money is being lost in wasting the water generated by the air condition systems.

## **6.2 Recommendations**

It is apparent from this research that the general lack of awareness of the condensate water quality and quantity is leading many users to neglect and waste this significant amount of water source. For air condition users who have doubt in using and thus collecting the condensate water, it is recommended that the condensate water quality to be tested proper authorities, such as the Palestinian Water Authority and Ministry of Health who will carry out a professional testing and will provide an un-biased assessment. These actions can undoubtedly raise the level of trust among users would eventually reduce reliance on the fresh water supplied at their homes or commercial centers.

Some particular recommendations are derived from this research:

- 1) Conduct a water quality testing assessment by official authorities, to confirm the condensate water quality.

- 2) Raise the awareness of users' in regard to the actual quantities generated by the cooling system, and thus they can put in place a simple efficient collection mechanism to collect and reuse this source of water, for at least cleaning, non-domestic uses, landscape irrigation at a first step.
- 3) Include the condensate water conservation in the ongoing implemented programs aiming at water conservation awareness raising.

For the monitoring institutions and regulators:

- 1) The condensate water quality must be monitored more closely to encourage the Palestinian Standard institution to develop relevant standards and guidelines to direct the possible uses of such water source. In particular, to check the constituents of the condensate water and make sure that this water is useful to the growth of the irrigated crops. Although this research has confirmed that the condensate water is totally safe to be used for irrigation purposes, but there is a need to detect the contribution of the water to the growth of the crops. Therefore, there is a need to classify the plants that could be irrigated by this water.
- 2) The governorates and municipalities must develop and adopt new ordinance before licensing new buildings, requiring, to install proper piping system that collects and stores the condensate water, perhaps with the rainwater from all eligible sources and distribute it to irrigation landscape. This design consideration should be followed to return condensate flow to minimize the consumption of the supplied potable water. In addition, the collection could be distributed to the toilets and urinal flushing, laundries, dishwashers and any other use not requiring potable water.

- 3) Conduct a survey aiming at quantifying the installed and operational cooling systems unit in Palestine and to investigate the pattern of use, this might be conducted by the Palestinian Central Bureau of Statistics. This survey will be useful to quantify the real volume of generated condensate water in Palestine.

### **6.3 Further Research**

This study has provided a discussion of the condensate water quality and quality issues in Ramallah and Jericho cities. As with any study, further research is required to reveal additional information and to take this study to the next level. Some possible further research, which would elaborate on certain issues mentioned throughout this study, may be as follows:

- ❖ Study on the socio-economic aspects of the condensate water collection and use, taking into consideration factors such as household income, monthly expenditures on water, price of alternatives, preferences, etc.
- ❖ Further study on the quality of condensate water: threats and benefits, to be used for irrigation purposes.
- ❖ Study on possible addition on the condensate water constituents to be useful for growing up certain crops.
- ❖ In order to convince the decision makers and regulators, a study demonstrating clear figures of the actual generated quantity (considering all installed and operated cooling units), the price of the generated water and the amount of money wasted by not storing and using this source of water.

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**Semi-Structure Interviews:**

Fatafta, R. (2013). Operation Manager, Triple R for Trading and Marketing. Interviewed by Lubna SIAM [in person] Ramallah, 2013.

Ghanayem, P. (2013). Marketing and Sales General Director, Sbitany. Interviewed by Lubna SIAM [in person] Ramallah, 2013.

## Annex 1: Questionnaire Survey Form

### Air Conditioning/SURVEY

Date of interview : Day   Month   Year

**Name:**

**Location: 1. Ramallah 2. Jericho**

Type of the visited location: Commercial/ Residential

#### **A. General Information:**

1. Family size	<input type="text"/> <input type="text"/>	2. Workers Size	<input type="text"/> <input type="text"/>
3. Family average monthly income (NIS)	<input type="text"/> <input type="text"/>	5. Unit Capacity per ton	<input type="text"/> <input type="text"/> /ton
4. Number if Air conditioning units (AC)	<input type="text"/> <input type="text"/>	6. The average used hours per day in summer	<input type="text"/> <input type="text"/>
5. Served Area in m2	<input type="text"/> <input type="text"/> m2	7. The average used hours per day in winter	<input type="text"/> <input type="text"/>
6. Age of the unit	<input type="text"/> <input type="text"/>	8. Number of doors and windows in the served area?	<input type="text"/> <input type="text"/>

#### **B. Expenses**

1. What are your expenses related to electricity, water and wastes..etc:

Electricity in summer /monthly	.....NIS
Electricity in winter/monthly	.....NIS
Water in summer /monthly	.....NIS
Water in winter /monthly	
Wastewater /monthly	.....NIS
Solid Waste /monthly	.....NIS
Initial Cost of the AC	.....NIS
Maintenance expenses for the AC/yearly	.....NIS

#### **C. Type of Housing**

1. House area (m2)	
2. Total number of rooms in residence (including bedrooms, kitchen, bathroom, living room...etc)	<input type="text"/> <input type="text"/>
3. Total number of bathrooms	<input type="text"/>
4. Source of household water: 1. public water network 2. water tanker	

3. rainwater 4. -----	
5. Average household monthly water consumption -----(m3)	
6. Is there a water collection cisterns 1. Yes 2. No Capacity: m3	
7. Type of wastewater collection system:  1. Cesspit 2. Septic tank 3. Sewage collection network	
8. HomeGarden: 1. Yes 2. No Area: m2	
9. HomeGarden plants: 1. Vegetable to be eaten cooked 2. Vegetable to be eaten uncooked 3. Flowers (green plants) 4. Other	
10. Where do you drain the water produced from the AC: 1. Sewage system 2. Water cistern 3. Into the street 4. Home garden 5. Collection	
11. Average monthly quantity of the water produced from the AC ----(m3)	
12. Do you use the AC water condensate: 1. Yes, 2. No If yes where and how:	
13. Do you think that the AC condensate water is safe: 1. Yes 2. No	
14. Do you think that the AC condensate water can be used for: 1. Drinking 2. Irrigation 3. Cleaning 4. Domestic use	
15. Do you have individual water tanks 1. Yes 2. No	
Number	Total capacity
16.	

### Annex 2 Data analysis for the Condensate Water Tests

Parameter	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
T (°C)	20	19.5	17.3	17	19.5	17.2	17.9	16.5	21	17
pH	6.89	7.2	6.86	7.1	6.9	7.2	7.33	7.29	6.99	7.27
TDS (ppm)	41.7	51	19.8	52	50.2	76.4	29.2	50.8	41.6	32.8
EC (µs/ cm)	83.4	98	39.5	98.2	100.4	158.8	59.1	100.4	81.9	65.5
DO (mg/l)	1.75	2.32	4.33	3.18	2.24	0.64	4.44	3.15	3.75	0.58
Turbidity (NTU)	1.19	0.77	0.62	1.95	0.49	1.4	0.85	1.3	3.91	0.66
BOD(mg/l)	2	1	2	1.2	3	5	1.4	2	1	1
COD(mg/l)	83	26.3	73	56.3	18	76.3	109.6	53	56	33
SO <sub>4</sub> (mg/l)	0.001	0.002	0.002	0.001	0.001	0.017	0.001	0.002	0.004	0.006
Parameter	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
T (°C)	17.3	15.9	18	16.3	18.5	21.5	17	18.5	15.9	21.5
pH	7.4	6.89	7.81	7.27	7.07	7.55	6.4	6.59	7.39	7.21
TDS (ppm)	48.9	41.7	49.7	49.8	33.9	43.3	31.2	39.1	110.3	15.2
EC (µs/ cm)	97.9	83.4	98.7	99.3	68.1	68.1	68.2	75.8	220.4	30.5
DO (mg/l)	0.89	1.75	1	0.34	4.9	5.81	2.1	4.82	4.31	2.45
Turbidity (NTU)	2.15	29.2	6.69	1.02	1.4	0.96	0.58	1.25	3.19	1.75
BOD(mg/l)	2.9	1.1	1.2	3	6	1.4	7	1.5	2	1
COD(mg/l)	59.6	123	76.3	23	103	59.6	96.3	109.6	109.6	106.3
SO <sub>4</sub> (mg/l)	0.003	0.004	0.004	0.004	0.004	0.003	0.003	0.003	0.003	0.005

Parameter	S21	S22	S23	S24	S25	S26	S27	S28	S29	S30
T (°C)	17.5	17.2	17.5	17	19.5	17	21.5	20.8	17	15.9
pH	7.21	7.2	7.41	7.1	6.9	7.59	6.81	7.51	7.09	7.81
TDS (ppm)	28.9	76.4	24	52	50.2	33.5	25	34	47.1	49.7
EC (µs/ cm)	58.4	158.8	48	98.2	100.4	67	49.9	67.9	94.3	98.7
DO (mg/l)	4.21	0.64	0.36	3.18	2.24	5	3.55	3.99	0.83	1
Turbidity (NTU)	0.77	0.95	1.43	1.03	1.18	1.12	1.07	1.80	1.66	0.9
BOD(mg/l)	1	1	1	1	1	1	4	4	2.6	4.3
COD(mg/l)	106.3	113	119.6	129.6	139.6	126.3	143	149	60	116
SO <sub>4</sub> (mg/l)	0.003	0.002	0.003	0.003	0.003	0.003	0.003	0.002	0.002	0.004
Parameter	S31	S32	S33	S34	S35	S36	S37	S38	S39	S40
T (°C)	16.9	15.5	18	17	17.5	16.9	16	18	20.1	18
pH	7.49	6.49	7.27	7.27	6.99	7.44	7.3	7.0	7.3	7.1
TDS (ppm)	44.4	32.9	49.7	32.8	33	40.9	25	32	20.4	39.9
EC (µs/ cm)	88.8	65.8	99.3	65.5	66	81.2	64	97	59.3	45.5
DO (mg/l)	0.52	1.8	0.34	0.58	2.96	5.6	0.59	0.35	1.6	3.21
Turbidity (NTU)	2.49	1.16	2.38	1.80	0.97	0.95	2.3	1.2	2.55	1.37
BOD(mg/l)	3.4	2	1	1	3	4	2	1	1	2
COD(mg/l)	147	150	143	146	116	143	86	95	98	145.3
SO <sub>4</sub> (mg/l)	0.004	0.004	0.004	0.005	0.004	0.003	0.004	0.003	0.002	0.002
Parameter	S41	S42	S43	S44	S45	S46	S47	S48	S49	S50
T (°C)	17.9	18.5	17.9	17.5	17.8	22.5	19.8	17.8	17.9	18.9
pH	7.21	7.31	7.12	6.8	7.4	6.7	7.4	7.2	7.1	7.5
TDS (ppm)	45.4	27	63	48.2	46.5	31	43	51.1	61.7	39.4
EC (µs/ cm)	68.8	62	100.2	98.6	73	56.9	65.0	85.3	96.7	77.8

DO (mg/l)	1.14	3.06	3.7	2.39	4.99	2.98	4.99	2.38	2	1
Turbidity (NTU)	1.05	1.03	1.23	0.99	2.12	1.73	1.45	1.55	1.01	2.64
BOD(mg/l)	5	1	2	1	1	5	4	4	3	2.5
COD(mg/l)	121	101	125	125.6	142.3	150	128	105	65	13
SO <sub>4</sub> (mg/l)	0.002	0.003	0.003	0.004	0.004	0.005	0.002	0.002	0.002	0.004

Parameter	S51	S52	S53	S54	S55	S56	S57	S58	S59	S60
T (°C)	15.9	17.5	17.6	18.2	16.9	17	16	18.9	18.6	17.9
pH	6.19	7.3	6.59	6.45	7.02	7.3	6.99	7.2	7.31	6.9
TDS (ppm)	36.9	45.6	63.8	29	39.9	29	41	45.6	48.2	33
EC (µs/ cm)	68.8	93.3	65.5	59	74.2	84	65	67.8	63	95.8
DO (mg/l)	1.2	1.4	1.58	1.96	5.9	2.59	0.55	2.1	1.95	3.6
Turbidity (NTU)	2.16	2.07	1.45	1.01	0.93	2.4	1.6	2.54	1.07	1.7
BOD(mg/l)	1	2.3	5	2	2	1	1	1	2	1
COD(mg/l)	23	34	101	144	146	78	85	125	136	148
SO <sub>4</sub> (mg/l)	0.004	0.005	0.002	0.002	0.002	0.002	0.003	0.002	0.002	0.002

Parameter	S61	S62	S63	S64	S65
T (°C)	18	19	18.9	20.4	17.9
pH	6.7	7.1	7.2	6.59	7.02
TDS (ppm)	29	63	39.9	39.4	41
EC (µs/ cm)	65.9	76.5	38.2	35	55
DO (mg/l)	3.7	2.99	3.45	2.5	2.1
Turbidity (NTU)	2.03	0.98	0.95	1.23	0.99
BOD(mg/l)	2	3	1	2	2
COD(mg/l)	98	89	124	146	136
SO <sub>4</sub> (mg/l)	0.002	0.003	0.004	0.004	0.004