An-Najah National University
Faculty of Graduate Studies

Chemical and Microbial Risk Assessment of Drinking Water in Faria Catchment

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Dedication

I dedicate my thesis to my family and many friends. A special feeling of gratitude to my loving parents Jamal and Faten Abu Hijleh, who have raised me to be the person I am today and whose words of encouragement and push ring in my ears. Thank you for all the unconditional love, guidance, and support that you have always given me. My sister Mais and two brothers Ahmad and Ashraf never left my side and are very special.

To all my friends, thank you for your understanding and encouragement in my many moments of crisis. Your friendship makes my life a wonderful experience. I cannot list all the names here, but you are always on my mind.

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This thesis is only the beginning of my journey.

الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

Chemical and Microbial Risk Assessment of Drinking Water in Faria Catchment

أقر بأن ما اشتملت عليه هذه الرسالة إنما هي انتاج جهدي الخاص، باستثناء ما تم الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل، أو أي جزء منها لم يقدم لنيل أي درجة أو لقب علمي أو بحثي لدى أية مؤسسة تعليمية أو بحثية أخرى.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name:	**الطالب اسم:**
Signature:	**التوقيع:**
Date:	**التاريخ:**

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Chemical and Microbial Risk Assessment of Drinking Water in Faria Catchment

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Abstract

Risk assessment is a process intended to estimate the risk to a given target, following exposure to a particular agent. The process begins with problem formulation and includes four fundamental steps: 1) hazard identification, 2) toxicity assessment, 3) exposure assessment 4) risk characterization. This thesis aims at describing the potential risk of chemicals and microbes to the general population of the Faria catchment, estimating the potential future risk, and proposing a risk management options to mitigate hazards for chemical and microbial contents of the catchment.

Drinking water data for chemicals, microbes, and some physical water properties for some selected wells and springs in the Faria catchment, were obtained from WESI in the context of UWIRA project. The water quality data were compared with local and international drinking water standards. The results showed that all the chemical concentrations are below the Palestinian and EPA maximum contamination levels, while the turbidity and fecal coliform (FC) are above both levels.

Structured interviews have been conducted through eleven villages located within the catchment, in order to determine the sources of exposure and the

intakes of the chemicals, which helped to identify the parameters for the risk formulas.

In order to estimate the chemical and microbial risks in the Faria catchment, mainly for drinking water, the fundamental steps of risk assessment have been conducted. Toxicity assessment resulted in screening and ranking the most common chemicals and microbes that are tested in drinking water resources which are, the major ions (Ca2+, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, PO_4^{3-}, and NO_3^{-}), total hardness, and the total FC. The exposure assessment described the levels of exposure using chronic daily intake equations for various pathways. All data collected from exposure and toxicity assessments were used in risk characterization step. Using an online QMRA Wiki analyst for microbial risk characterization, the risk probability results of E.coli doses indicates that at least one person out of one thousand people, will get sick by the presence of E.coli in the drinking water of the catchment resources. For chemical risk characterization, hazard index was used to find the potential toxicity for adult males, adult females, and children. The results showed that, each parameter individually may not cause non-carcinogen toxicity, but may collectively cause adverse health effects due to bioaccumulation of long-term exposure to chemicals.

Potential future risk of some heavy metals and organic compound of Faria stream was estimated using chemical risk formulas. The results indicated that there is a great potential of non-carcinogen toxicity if these pollutants have been proven to reach the catchment drinking water resources.

Risk management practices such as, installing sanitation systems to provide treatment and proper disposal of wastewater for all the villages that use cesspits, and continuous monitoring of chemicals and microbes of the catchment water resources, were recommended to mitigate any potential risk caused by the presence of chemicals and microbes in the drinking water, and to enhance the quality of the catchment's water resources.

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Background

Throughout human history, the search for clean, fresh and palatable water has been man's priority. During the last 20 centuries, serious attempts have been made to serve communities with sufficient amount of drinking water. However, water quality criteria have been developed during the last two centuries, with chemical and bacteriological examination to form the base standards. When the relationship between waterborne diseases and drinking water was established, the technology for treatment and disinfection developed rapidly. Standards were developed at the same time, mostly originated by the Health Authorities and by dedicated sanitary engineers and scientists (DeZuane, 1997).

Worldwide, the availability of adequate water of appropriate quality has become a major problem that affects the public health and the environment. Water quality criteria are developed by assessing the relationship between pollutants and their impact on human health and the environment. To develop criteria for water quality that accurately reflects the latest scientific knowledge, these criteria are based on pollutant concentrations and environmental or human health impact. A human health criterion is the highest concentration of a pollutant in water that is not expected to pose a significant risk to human health (Grubbs, 2000).

The quality of water, whether it is used for drinking, irrigation or recreational purposes, is significant for health in both developing and developed countries worldwide. Water quality can have a major impact on health, both through outbreaks of waterborne disease and by contributing to the background rates of disease. Accordingly, countries develop water quality standards to protect public health. Recognizing this, the World Health Organization (WHO) had developed a series of normative “guidelines” that present an authoritative assessment of the health risks associated with exposure to health hazards through water and of the effectiveness of approaches to their control (WHO, 2013)

Human health risk assessment is a process intended to estimate the risk to a given target organism, system or population. It includes the identification of attendant uncertainties, followed by exposure assessment and toxicity assessment, taking into account the inherent characteristics of the agent of concern as well as the characteristics of the specific target system. Human health risk assessment of chemicals refers to methods and techniques that apply to the evaluation of hazards, exposure and harm posed by chemicals. In summary the risk assessment process begins with problem formulation and includes four fundamental steps: 1) hazard identification, 2) toxicity assessment, 3) exposure assessment and 4) risk characterization (Rathi, 2012).

1.2 Problem Statement

The Faria catchment is under severe challenging conditions that cause the deterioration of drinking water quality in the catchment, which may pose chemical and microbial risks that could affect the public health of the general population in the catchment.

1.3 Research Statement

This research will help to find out the chemical and microbial risks in the Faria catchment, which would be of great importance to decision makers. It will help them to adopt the best management practices and mitigation measures to restore the local environment of the catchment, and provide water of high quality to protect the public health parallel with sustainable development in the catchment.

1.4 Research Objectives

The main objectives of this research are:

1. To describe the potential risk of chemicals and microbes to the general population of Faria catchment.

2. To estimate the potential future risk.

3. To propose a risk management options, to mitigate hazards for chemical and microbial contents of Faria catchment.

1.5 Research Methodology

To achieve the objectives of this study, an online QMRA Wiki analyst, ArcGIS software, and Ms-Excel software, were used to manipulate and analyze temporal and spatial data. **Figure 1.1** describes the overall methodology which was used in this research.

The following summarizes the main steps that were followed:

1. Drinking water data were obtained from WESI and compared with the Palestinian and EPA drinking water standards.
2. Structured interviews have been conducted, in order to determine the sources of exposure and the intakes of the chemicals.
3. Toxicity assessment, this step resulted in screening and ranking of most hazard posing chemicals and microbes.
4. Exposure assessment, by using the chemical intake equations.
5. Risk characterization, by using chemical risk formulas and an online QMRA Wiki analyst.
6. The results obtained from risk characterization were analyzed, in order to adopt the best risk management practices to enhance the quality of water in the Faria catchment.

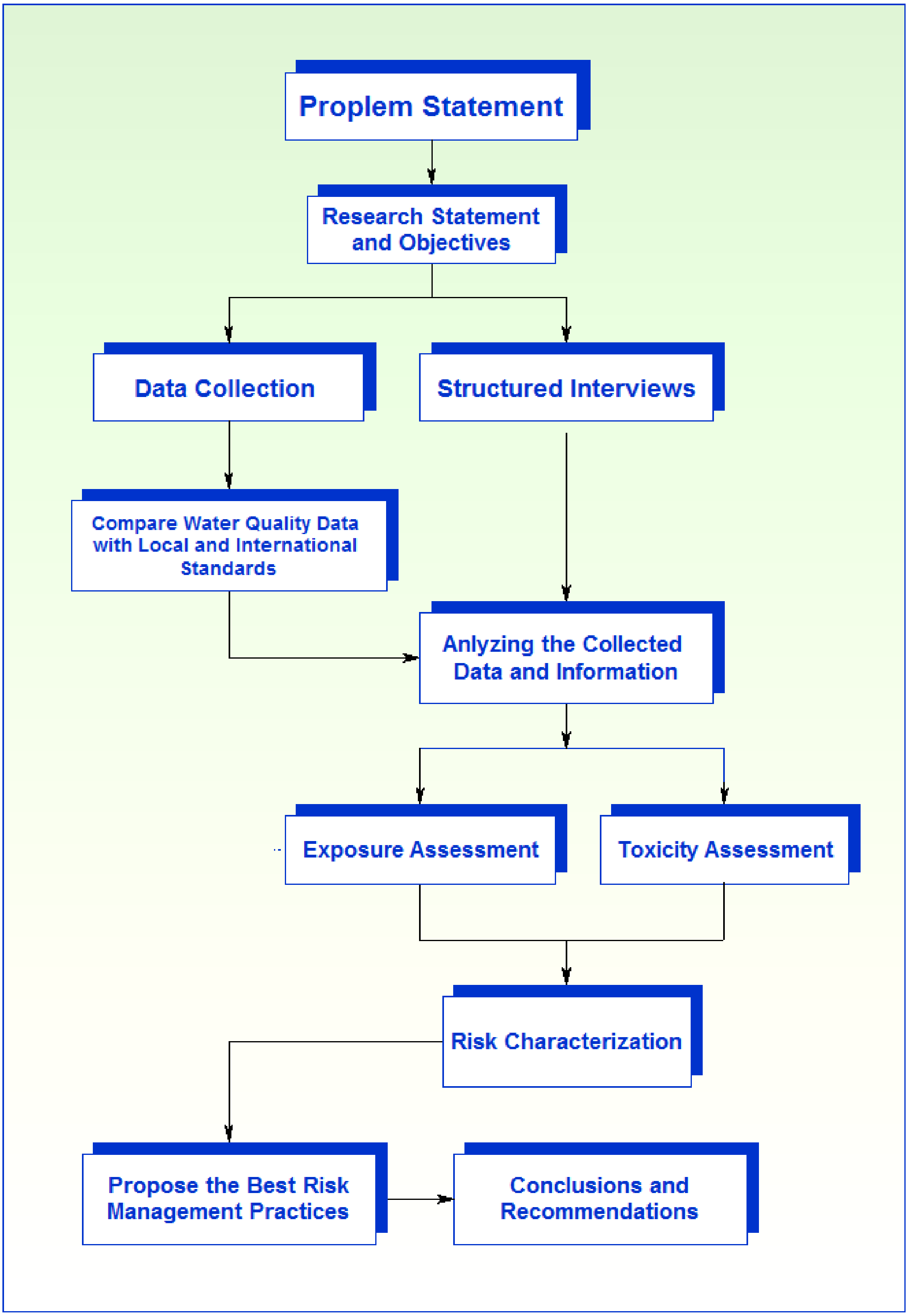


Figure 1.1: Methodology Flowchart of the Research

CHAPTER TWO

STUDY AREA

2.1 Geography, Topography and Geology

Faria catchment is located in the northeastern part of the West Bank extending for 30 km from Nablus in the West to the Jordan River in the East. The catchment is funnel-shaped with an area of (320 km^2), which accounts for about 6% of the total area of the West Bank (5600 km^2). Faria catchment overlies three districts of the West Bank, these are: Nablus, Tubas and Jericho, and lies within the EAB which is one of three major basins in the West Bank. The catchment borders are: North Jordan and Fassayel-Auja drainage basins from the north and south respectively, Alexander, Yarkon and Al- Khidera drainage basins from the west and Jordan River from the east. **Figure 2.1** Shows the regional location of Faria catchment. There are about twenty communities within the catchment borders. Ten of these communities are located around Faria stream in the area of the catchment known as Al-Faria Wadi. These are: (1) Ras Al-Faria, (2) Al-Faria regugee camp, Wadi Al-Faria, (4) Bathan, (5) Al-Aqrabania, (6) An-Nassariyya, (7) Beit Hasan, (8) Ein Shibli, (9) Froush Beit Dajan, and (10) Al-Jiftlik. In addition to these communities, there are three small communities namely, Khirbat Qishda, Khirbat An-Nawaji and Khirbat Tall El-Ghar. The rural population of the main villages in the catchment is estimated at a total of 55,261 by the year of 2009 (PCBS, 2009). **Figure 2.2** shows the population statistics by the year of 2009 in the catchment. Population growth rate is estimated to be about 3.5%, which means the population of the catchment is expected to reach 80,679 people by the year of 2020. The population in the catchment is classified as a young society because of the high percentage of young ages. Children under fifteen represent 36% of the whole population in the area. This young population has higher potential risk from the decreased water quality than adults in the catchment. Moreover, people are living in poor economic and environmental conditions, with housing density ranges from 6.5 in Ras Al-Faria to about 15 people per house in Froush Beit Dajan, which will result in higher exposure to the poor water quality and thus increase the adverse health effects in the catchment (EQA, 2004).

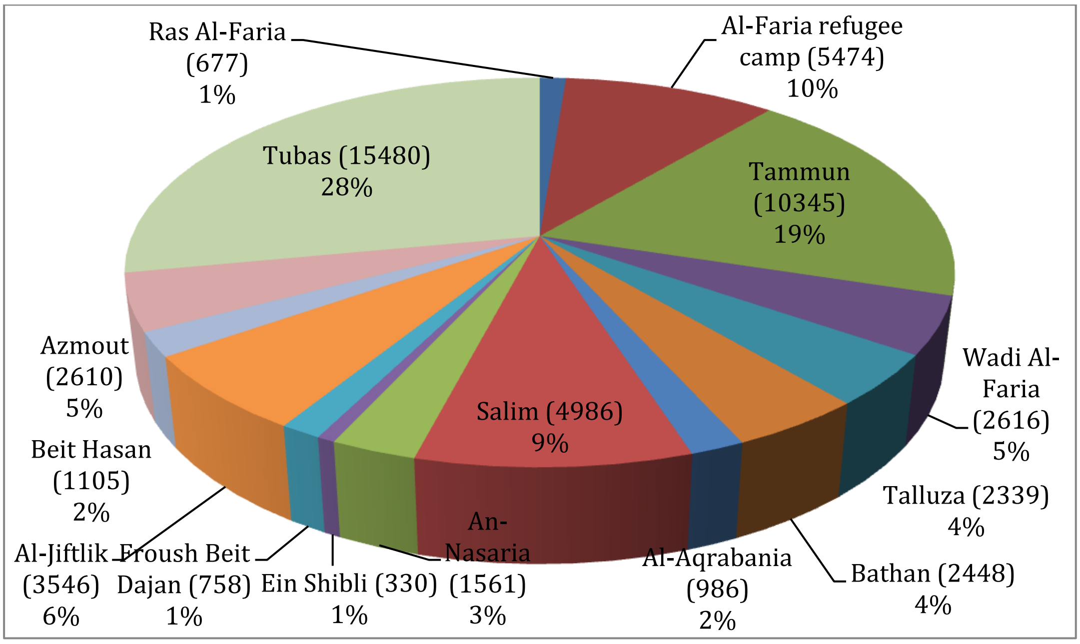


Figure 2.1: Population statistics by the year of 2009 in the catchment.

The ground surface elevations in the catchment change from about 920 m above mean sea level in Nablus Mountains to about 385 m below sea level at the confluence with the Jordan River. Topographic relief changes significantly throughout the catchment. In less than 30 km there is an average decline of 1.3 km in elevation. Such elevation decline rate in a relatively small distance has considerable effects on the prevailing meteorological conditions in the catchment, which may affect the evaporation that in turn affects the quantity and quality of water in the catchment (Shadeed, 2008).

Geologically, the groundwater aquifer of Faria catchment comprises several rock formations from the Triassic (Lower Cretaceous) to recent age. These formations are composed mainly of Limestone, Dolomite and marl. Faria catchment is a structurally complex system with the Faria Anticline that trends northeast to southwest acting as the primary controlling feature. Additionally, a series of smaller faults and joints perpendicular to this anticline have a significant effect on the surface water drainage area. The catchment also characterized as being composed of complicated and diverse geological structures dominated by small, parallel faults that trend north-south forming a faulting step. A number of major faults and joints exist parallel to the Jordan Rift Valley as a result of previous tectonic activity (EQA, 2004).

Figure 2.2: Regional Location Map of Faria Catchment (Google Earth)

2.2 Soil and Land Use

There are six soil types found in the Faria catchment. These are; Grumusols, this soil comprises (12.18%) of the total area of the catchment, it has heavy clay soil texture with a high shrink-swell potential. Loessial Seozems (6.16%), it has a sandy loam texture and the soil is calcareous on the surface and saline at the deeper layers due to restricted leaching. Regosols (9.25%), this soil has a weak structure forming crusts on the surface results in sealing it and preventing the entrance of water into the soil. Brown Litholsols and Loessial Arid Brown Soils (5%), the coverage of rock outcrops could reach 60% of the surface area in these soils and its texture is mainly loamy. Terra Rossas, Brown Rendzianas and Pale Rendzinas (46.16%), the texture of these soils is clay to clay loam. Brown Rendzianas and Pale Rendzinas (21.25%), this type of soil has numerous rock outcrops (EQA, 2004).

From the above it can be concluded that two basic soils cover most of the Faria catchment. These two types are terra rossas and brown rendzinas/pale rendzinas, taking up more than 65% of the total area.

The texture of these soils is mainly clay, which can slow the movement of contaminants to the water table and prevent contaminated surface water from entering the ground water (Harris et al., 1996).

There are 20 Palestinian villages, with a total built up area of about 9.5 km^2, and 11 Israeli settlements with a total built up area of 5.1 km^2. The remaining land use is primarily for agricultural activities such as vegetable plantation and trees, forests, natural grass, and bare rocks. Faria catchment is one of the most important agricultural areas in the West Bank. The agricultural areas form more than 40% of the total area of the catchment. Most agricultural crops in the catchment are: citrus, olives, and various types of vegetables. Some of these crops are irrigated, others are rainfed, and the rest are irrigated at the beginning of their life cycle and depend on rainwater soon after. Due to uncontrolled agricultural activities resulted from the use of natural organic fertilizers (manure), in addition to artificial agrochemicals such as ammonia and sulfur fertilizers, pesticides, and herbicides, the agricultural runoff contains complex pollutants which will affect the water quality of the catchment through the return flow from the surrounding agricultural land, and later on the quality of the groundwater aquifer (Shadeed, 2008).

2.3 Climatology

The climate in the area is dominantly a Mediterranean, semi-arid climate, characterized by mild rainy winters and moderately dry, hot summers. The climate is highly variable and is influenced by both elevation and the circulation of the air-stream. Faria catchment is characterized by high temporal and spatial variation in temperature. Temperatures reduce with increasing elevation in the catchment.

The mean annual temperature changes from 18 °C in the western side of the catchment (in Nablus) to 24 °C in the eastern side of the catchment (in Al-Jiftlik). While the mean monthly evaporation, and accordingly potential evapotranspiration, varies significantly throughout the year. In Nablus, there is a five-month period in winter (November – March) with a rainfall surplus, whereas in Al-Jiftlik, rainfall exceeds potential evapotranspiration in two months of the year (December and January). During the rest of the year, potential evapotranspiration greatly exceeds rainfall, making irrigation needed in almost most months of the year in the lower areas of the catchment. The annual average relative humidity ranges from about 58 to 61 percent for lower and upper areas, respectively, which affects the quantity and quality of water in the catchment (Jarrar et al., 2005).

The upper and western parts of the catchment are affected by moist, west-oriented air streams coming from the Mediterranean Sea. This air stream is responsible for most of the rainfall in the wet season and increases the relative air moisture in the dry season. Rainfall events predominantly occur in autumn and winter to account for 90% of the total annual precipitation events.

The climate of the catchment is highly influenced by elevations. The rainfall distribution within the Faria catchment ranges from 650 mm at the headwater to about 150 mm at the outlet to the Jordan River. The western part which has elevations less than 200 m above mean sea level has scarce rainfall and is dominated by hot dry weather. While the northern part of the catchment with elevations reaching 900 m above mean sea level has high annual precipitation (more than 600 mm) and frequent snow falls. In the areas which have an elevation of 750 m above mean sea level and lies within the path of the humid west winds originating from the Mediterranean Sea, the mean annual precipitation reaches 500mm. **Figure 2.3** shows the distribution of rainfall stations in Faira catchment (Shadeed et al., 2005).

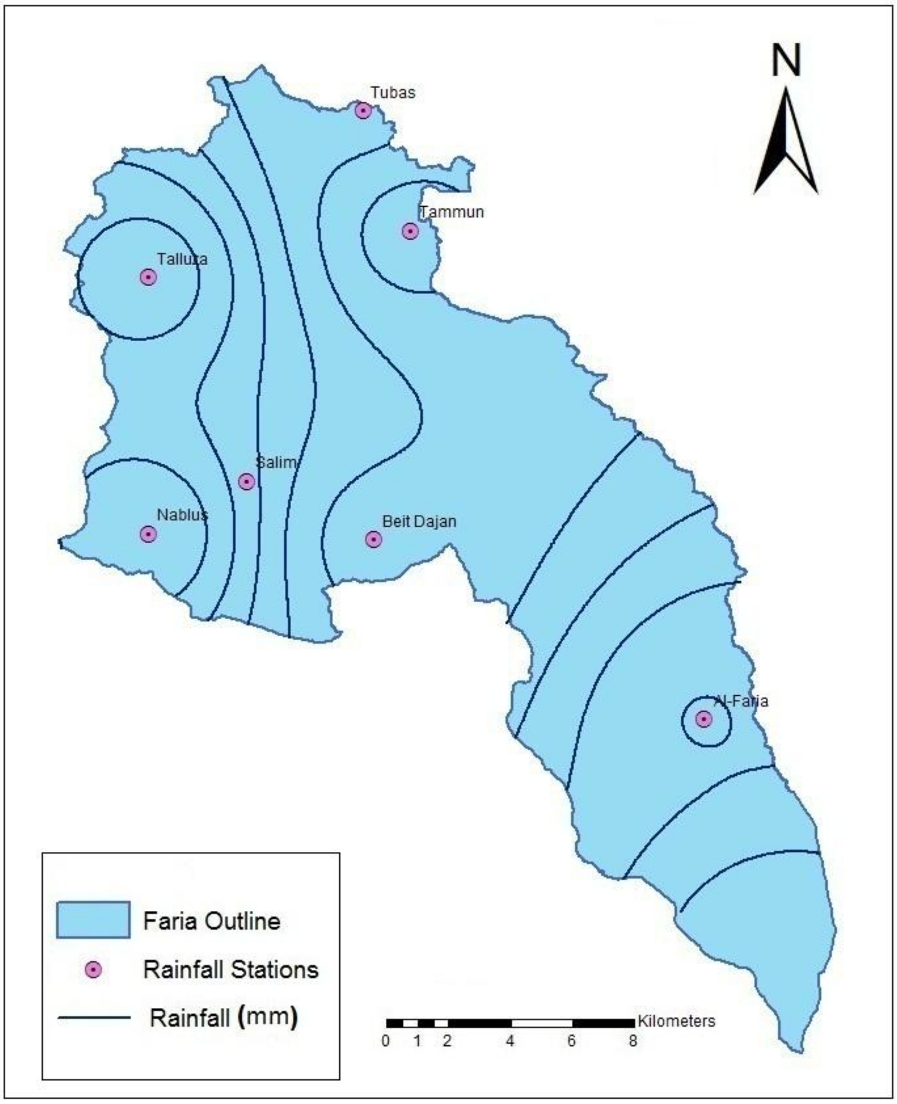


Figure 2.3: Rainfall Map of Faira Catchment

2.4 Water Resources

Water resources in the Faria catchment are either surface water or groundwater. Most of surface runoff in the catchment is usually lost in winter as there are no dams in the catchment to store that excess water.

2.4.1 Water Quantity

Within the catchment the surface runoff decreases from west to east as the slope becomes relatively gentile eastwards down the main stream where rainfall rates reduce also. The stream flow of the Faria catchment is a mix of, runoff generated from winter storms, untreated wastewater of the eastern part of Nablus city and of Faria refugee camp, and fresh water from springs which provides the baseflow for the catchment and preventing it from drying up during hot summers.

Groundwater aquifers are usually utilized through springs and wells. On average the annual obtainable water resources in Faria catchment are very limited. Springs are the only natural drainage outlets for groundwater in Faria catchment, and are major water resources that should be efficiently utilized. Most of the springs of Faria catchmentare are located in the upper and middle parts of the catchment. There are 11 fresh water main springs in the catchment which can be divided into three groups: Faria, Al-Bathan and Miska in addition to two springs within the borders of the city of Nablus. The annual discharge from springs varies from about 3.8 to 38.3 MCM with an average amount of 14.4 MCM (Shadeed, 2011).

There are also 69 wells in Faria catchment; of which 61 agricultural wells, 3 domestic and israeli wells. Based on the data available, the total utilization of the Palestinian wells ranges from 4.5 to 11.5 MCM/year. **Figure 2.4** shows the distribution of wells and springs in Faira catchment.

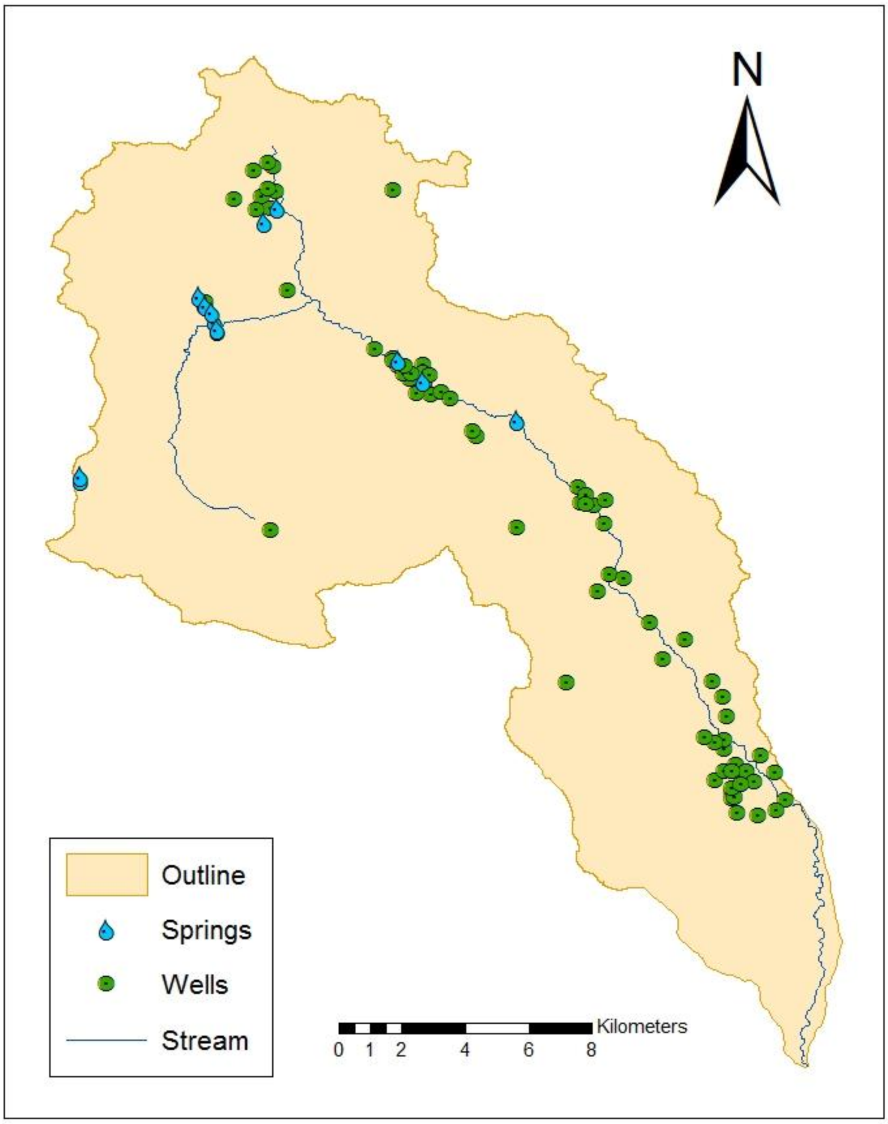


Figure 2.4: Distribution of Wells and Springs in Faira Catchment

Water from agricultural wells is used in conjunction with spring discharge in most of the catchment. During wet years when the spring discharge is high, abstraction from wells reduces while pumping increases in dry years.

Palestinian agricultural wells are usually small wells with shallow depths. However, Israeli wells in the area are usually deeper, larger, and their average production is about 2 MCM/year per well. Thus the 5 Israeli wells produce about 10 MCM/year which is more than the 61 Palestinian agricultural wells combined (EQA, 2004).

2.4.2 Water Quality

Two sets of criteria may be used to assess the quality of groundwater depending on the type of water use, namely domestic or agricultural purposes. The quality of water for domestic purposes is highly affected by the existence and count of pathogenic microorganisms in water resources and the concentration of certain ions that affect the health or preferences of users such as the concentration of nitrate. On the other hand, the assessment of water quality for agricultural purposes depends on the type of crops irrigated, their tolerance to low quality waters, the amount of water applied to the crop and the irrigation system through which the water is applied (EQA, 2004).

In the Faria catchment the shortfall in water supplies has been compounded by a decrease in quality owing to the contamination of surface as well as groundwater resources. The sources of pollution that are contributing to the water contamination are either solid waste or liquid waste. Due to lack of sanitary landfills in the catchment, solid waste is being randomly thrown along the main wadi of the catchment. Thus; leachate from solid waste will potentially contaminate the water of the catchment. Moreover, and as a result of shortfall of local sewage networks, raw wastewater that is generated in the catchment may infiltrate directly to the upper unconfined aquifer through cesspits and may threaten the groundwater quality. In addition, surface water originating from the springs and contributing to the baseflow is mixed with untreated wastewater coming from Nablus City and Faria refugee camp. These sources of pollution have been deteriorating the water quality in the catchment. Untreated wastewater contains a cocktail of pollutants, some biodegradable and others are very persistent. In the catchments when water is plentiful, the quantity of water is enough to dilute these pollutants to insignificant levels. But, in the case of the Faria catchment, which is characterized by its limited water resources, there is no natural filter for these pollutants, which as a result will deteriorate the water quality in the catchment (Shadeed et al., 2007).

2.5 Water Crises

The available water resources in the Faria catchment have sustainable-yield limits that cannot be surpassed. Moreover, the water demand is increasing to fulfill the agricultural and domestic requirements, which is compounded by a decrease in water quality as a result of discharging untreated wastewater into the catchment, and uncontrolled use of pesticides and fertilizers. The polluted water mixes with fresh spring water and infiltrates to a large extent into shallow and deep groundwater bodies. Consequently, it pollutes the water resource in the catchment which poses great threats on human life. Additionally, farmers along the main stream, where the wastewater flowing, are commonly use the untreated wastewater to irrigate their crops. Thus, local population in the catchment (who rely on groundwater as the main drinking water source) is exposed to chemical and microbial contamination of the drinking water and also through the consumption of agricultural products that were irrigated with untreated wastewater (Shadeed et al., 2011).

There are many interrelated reasons that have contributed to water crises in the catchment. These are inefficient management, water shortages, environmental pollution, and Israeli occupation. The major causes of water quality deterioration in Faria catchment can be summarized as follows:

1. The use of open ditches as a conveyance system for irrigation, which consist of spring water mixed with wastewater as a way of compensating the shortage of water coming from springs;
2. The discharge of untreated wastewater effluents from built up areas mainly from the eastern parts of Nablus city into the open environment, contributes to the extent of health and environmental health hazards existing in the catchment;
3. Water is contaminated by cattle that use catchment stream and springs as a drinking water source, and pollutes the water with fecal matter;
4. Uncontrolled solid waste dumping in some areas adds additional complexity to the pollution problems; and

5. Unbalanced use of fertilizers and pesticides has a great potential to pollute of scarce water resources in the catchment.
6. Cesspits are a major threat that may pollute the groundwater aquifers in the future.

CHAPTER THREE

LITERATURE REVIEW

3.1 Water Quality Characterization

Water is vital to the existence of all living organisms, but this valued resource increasingly being threatened as human populations grow and demand more water of high quality for domestic purposes and agricultural activities. Water abstraction for domestic use, agricultural production, and industrial production, can lead to deterioration in water quality and quantity that impact not only the aquatic ecosystem, but also the availability of safe water for human consumption. The availability of water and its physical, chemical, and biological composition affect the ability of aquatic ecosystems to sustain healthy environments: as water quality eroded, organisms suffer and ecosystem services may be lost. Moreover, an abundant supply of clean, usable water is a basic requirement for many of the fundamental uses of water on which humans depend. It is now generally accepted that aquatic environments cannot be perceived simply as holding tanks that supply water for human activities. Rather, these environments are complex matrices that require wise use to ensure sustainable ecosystem functioning well into the future (Carr and Neary, 2008).

The quality of water whether used for drinking, domestic purposes, food production or recreational purposes has an important impact on health. Water of poor quality can cause disease outbreaks and it can contribute to background rates of disease manifesting themselves on different time scales. Initiatives to manage the safety of water do not only support public health, but often promote socioeconomic development as well (WHO, 2013).

Having safe drinking water is a human need and right for everyone. People need water of high quality to maintain their good health. Water quality refers to the physical, chemical and biological characteristics of water. It is evaluated from the standpoints of whether water is safe to drink, safe to come in contact with, and for ecosystem health. In fact, water quality is a very complex subject, in part because water is a complex medium intrinsically tied to the ecology of the Earth (Ertuo and Mirza, 2005).

The main cause of water pollution is human activities. Humans produce wastes that enter ground and surface water. Industries discharge variety of pollutants in wastewater including heavy metals, organic toxins, oils nutrients and solids. Many of these substances are toxic or even carcinogenic. These wastes also increase the concentration of suspended solids, bacteria and virus growth leading to potential health impacts. Pathogens can obviously produce waterborne diseases in either human or animal hosts. Increase in nutrient load may lead to eutrophication; organic wastes increase the oxygen demand in water leading to oxygen reduction in water with potentially severe impacts on whole ecosystem (Aqeel et al., 2010).

Water quality and environmental contamination are of increasing concern in the West Bank. There is a growing problem with microbial contamination, particularly with springs and wells. Depletion of water resources and deterioration of water quality in all districts are key environmental challenges that require urgent action. Scarpa et al. (1998) introduced the results of a chemical and microbial study of the wells extracting water from the unconfined aquifer system in the northern West Bank. The excessive use of fertilizers, wide distribution of cesspits, and uncontrolled disposal of wastewater were considered probable sources of the wide spread microbial contamination and the alarming nitrate, chloride, and potassium levels that were found in many of the wells studies.

In Gaza the quality of water is deteriorating rapidly, and until another source of water is found, the population in Gaza remains at risk as there is little that can be done as long as the Israel policy of closure continues. Ninety percent of the water available in Gaza coming from the coastal aquifer is undrinkable, with nitrate and chloride levels between 6 to 7 times above the level set by the World Health Organization (PGPF, 2011).

3.2 Waterborne Diseases

The quality of drinking water is a powerful environmental determinant of health. Assurance of drinking water safety is a foundation for the prevention and control of waterborne diseases. Waterborne diseases are any illness caused by drinking water contaminated by human or animal feces, which contain pathogenic microorganisms. This is likely to occur where public and private drinking water systems get their water from ground or surface water (wells, springs, streams, rivers etc.), which can be contaminated by infected animals or people. Runoff from landfills, discharge of untreated wastewater, residential or industrial developments can also contaminate ground and surface water (WWRD, 2000).

Contaminated drinking water serves as a mechanism to transmit communicable diseases such as diarrhoea, cholera, dysentery, typhoid and guinea worm infection. Infectious diseases caused by pathogenic bacteria, viruses, and protozoa are the most common and wide spread health risk associated with polluted drinking water. Those at greatest risk of waterborne disease are infants and young children, people who are debilitated or living under unsanitary conditions and the elderly. In developing countries four-fifths of all the illness is caused by waterborne diseases, with diarrhea being the leading cause of childhood death, this burden is greater than the combined burden of HIV/AIDS and malaria WHO estimates that in 2008 diarrhoeal disease claimed the lives of 2.5 million people (WHO, 2013).

The full picture of waterborne diseases is complex for a number of reasons. Over the past decades, the picture of water-related human health issues has become increasingly comprehensive, with the emergence of new waterborne infection diseases and the re-emergence of ones already known. Data are available for some water, sanitation and hygiene related diseases (which include Amoebiasis, Diarrhoea, Salmonellosis, Cholera, Shigellosis), but for others such Malaria, Schistosomiasis or the most modern infections such Legionellosis or SARS CoV the analyses remain to be done (WWRD, 2000).

Environmental health conditions in West Bank refugee camps are challenged by inadequate quantity and inappropriate quality of water and sanitation services. It poses a great threat on the health status of camp inhabitant, placing the population under severe risk of waterborne diseases or epidemics outbreaks. Watery diarrhea as well as acute bloody diarrhea and viral hepatitis, remain the major causes of morbidity among reportable infectious diseases in the refugee population of the West Bank (UNRWA, 2011).

Approximately 1.8 million people live in Gaza strip, some of the most densely populated areas on earth where adequate infrastructure is rare and the conditions for waterborne diseases are rife, thus increasing the chances of an outbreak in Gaza and the surrounding areas. As it is now, water related diseases among Gaza population, including the potentially fatal blue baby syndrome, are severe. Other equally lethal waterborne diseases include typhoid and hepatitis A. The environment is choked with untreated sewage, threatening Palestinians health and life. The escalating critical water problem in Gaza can give rise to a major outbreak of waterborne diseases such as cholera which would inevitably spread to the surrounding areas, the Mediterranean coasts and straight into Europe (PGPF, 2011).

3.3 Risk Assessment

Water quality criteria are developed by assessing the relationship between pollutants and their effect on human health and the environment. These criteria are based solely on data and scientific judgments on pollutant concentrations and environmental or human health effects. A human health criterion is the highest concentration of a pollutant in water that is not expected to pose a significant risk to human health (Grubbs, 2000).

Risk is associated with all human activities, while risk assessments are used extensively to provide information on identified impacts to feed decision making processes. Human activities consist of elements that may result in hazards that have the potential impact on the health of the community and hence need to be evaluated (Spickett et al., 2010).

According to international organizations such as International Program on Chemical Safety (IPCS), risk assessment can be defined as a process intended to estimate the risk to a given target organism, following exposure to a particular agent, taking into account the inherent characteristics of the agent of concern as well as the characteristics of the specific target system. The process begins with problem formulation and includes four fundamental steps:

1) hazard identification, 2) toxicity assessment, 3) exposure assessment 4) risk characterization, these steps are described in **Figure 3.1**. The primary objective of risk assessment is to avoid injury and harmfulness as well as to reduce risk impact on human health. Ruden (2006) stated that the scientific principle of risk assessment depends upon scientific data on the exposures and effects, and these data are usually obtained from three main sources: standardized experiments (i.e. animal models), studies of exposed humans

(epidemiology data) and from non-standardized experiments (i.e. toxicological research data).

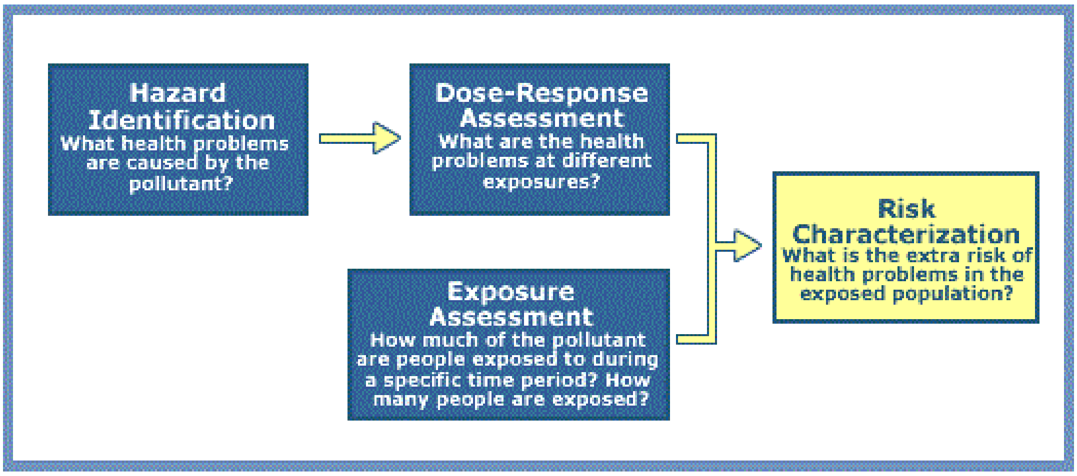


Figure 3.1: The Four Steps of Risk Assessment Process

3.3.1 Chemical Risk Assessment

Most chemicals arising in drinking water are of health concern only after extended exposure of years, rather than months. The principal exception is nitrate. Typically, changes in water quality occur progressively, except for those substances that are discharged or leach intermittently to flowing surface waters or groundwater supplies. For example, the discharge of untreated wastewater from built up areas into the open environment (WHO, 2011).

Human health risk assessment of chemicals refers to methods and techniques that apply to the evaluation of hazards, exposure and harm posed by chemicals, which in some cases may differ from approaches used to assess risks associated with biological and physical agents. It can be performed to evaluate past, current and even future exposures to any chemical found in air, soil, water, food, consumer products or other materials. It can be quantitative or qualitative in nature. Chemical risk assessment relies on scientific understanding of pollutant behavior, exposure, dose and toxicity. In general terms, chemical risk depends on the following factors (WHO, 2010):

- The amount of a chemical present in an environmental medium (e.g. soil, water, air), food and/or a product.
- The amount of contact (exposure) a person has with the pollutant in the medium.
- The toxicity of the chemical.

The health concerns associated with chemical constituents of drinking water differ from those associated with microbial contamination and arise primarily from the ability of chemical constituents to cause adverse health effects due to bioaccumulation. Bioaccumulation means an increase in the concentration of a chemical in a biological organism over time, compared to the chemical's concentration in the environment. Compounds accumulate in living things any time they are taken up and stored faster than they are broken down or excreted. Understanding the dynamic process of bioaccumulation is very important in protecting human beings from the adverse effects of chemical exposure, and it has become a critical consideration in the regulation of chemicals. There are few chemical constituents of water that can lead to health problems resulting from a single exposure, except through massive accidental contamination of a drinking water supply. Moreover, experience shows that in many, but not all, such incidents, the water becomes undrinkable owing to unacceptable taste, odor and appearance (WHO, 2011).

Major ions such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, PO_4^{3-}, and NO_3^{-} are naturally very variable in surface and groundwater due to local, geological, climatic and geographical conditions. Owing to this fact, all these ions are regularly tested in drinking water. Following is a summarization of the adverse affect of each one of these ions at high concentration levels;

Calcium (Ca^{2+}) ions:

Calcium ions can damage cells if they enter the body at high concentrations. Excessive entry of calcium into a cell may damage it or even cause it to undergo apoptosis, or death by necrosis. Calcium also acts as one of the primary regulators of osmotic stress (Osmotic shock). Chronically elevated plasma calcium (hypercalcemia) is associated with cardiac arrhythmias and decreased neuromuscular excitability. One cause of hypercalcemia is a condition known as hyperparathyroidism.

Magnesium (Mg^{2+}) ions:

Too much magnesium can cause several serious health problems, including nausea, vomiting, severely lowered blood pressure, confusion, slowed heart rate, respiratory paralysis, deficiencies of other minerals, coma, cardiac arrhythmia, cardiac arrest, and death. At very high doses, it can even be fatal. However the most common side effects of magnesium toxicity are stomach upset and diarrhea.

Potassium (K^+) ions:

Very high concentrations of potassium ion can kill tissue, and cause injury to the gastric or intestinal mucosa. Individuals suffering from kidney diseases may suffer adverse health effects from consuming large quantities of potassium. End stage renal failure patients undergoing therapy by renal dialysis must observe strict dietary limits on potassium intake, as the kidneys control potassium excretion, and buildup of blood concentrations of potassium may trigger fatal cardiac arrhythmia. Also, the reaction of potassium with water is dangerous because of its violent exothermic character and the production of hydrogen gas.

Sodium (Na^+) ions:

Too much sodium can cause swelling or bloating of the extremities. This is primarily because the kidneys are responsible for eliminating salt from the body, and if there is too much salt, the kidneys cannot eliminate it fast enough and there will fluid retention. The fluid retention is also capable of building around the heart. This will cause the heart to not be able to beat and function properly, which can cause high blood pressure, congestive heart failure or even strokes and heart attacks.

Chloride (Cl-) ions:

High concentrations of chloride can cause Hyperchloremia, often hyperchloremia does not produce any symptoms. However, hyperchloremia is sometimes associated with excess fluid loss such as vomiting and diarrhea. If the sufferer were to be a diabetic, hyperchloremia could lead to poor control of blood sugar concentration, which could cause it to become elevated.

Sulfate (SO_4^{2-}) ions:

Sulfate is one of the major dissolved components of rain. High concentrations of sulfate in the water we drink can have a laxative effect when combined with calcium and magnesium, the two most common constituents of hardness. Health concerns regarding sulfate in drinking water have been raised because of reports that diarrhea may be associated with the ingestion of water containing high levels of sulfate.

Bicarbonate (HCO_3^-) anions:

Every person's blood stream has a certain level of bicarbonate in it, but there is a point where this level can either drop too low or rise too high, causing serious health issues for the person. As a result of high levels of bicarbonates, a person can suffer from, heart attacks, strokes, metabolic alkalosis, and cardiopulmonary arrest.

Phosphate (PO_4^{3-}) ions:

High levels of phosphate can cause severe itching, which can be very uncomfortable, it also mean low calcium levels, which in turn can cause weakened bones. The body requires a fine balance of phosphate and calcium in the blood. When there are higher levels of phosphate, health issues such as osteoporosis, gum, and teeth problems begin to develop. Symptoms of high phosphate levels in blood indicate several medical conditions such as kidney disorders, malnutrition and other gastrointestinal disorders, and calcium and bone problems.

Nitrate (NO_3^-) ions:

Humans are subject to nitrate toxicity, nitrate would most often be ingested by infants in high nitrate drinking water. With infants being especially vulnerable to methemoglobinemia due to nitrate metabolizing triglycerides present at higher concentrations than at other stages of development. Methemoglobinemia in infants is known as blue baby syndrome.

Worldwide and since it was established, many chemical risk assessment studies which were intended to assess the potential risks of drinking water on human health have been reported in the body of literature. A Jordanian case study describes an incident in (1998) in which the residents of the Amman west region complained of being supplied with discolored, smelly water. A number of Jordanian government agencies and international consultants investigated the problem and concluded that the taste and odor originated from algae in the water, and that the local water treatment plant's processes and operations were insufficient to deal with the magnitude of the problem (Melkaw and Shiyyab, 2003).

Long-term overexploitation of water in the Gaza Strip has resulted in a decreasing water table, accompanied by the degradation of its water quality. Due to high levels of salinity, most of the groundwater is not suitable for both domestic and agricultural consumptions. Data were collected from the Palestinian Ministry of Health on the concentration of total dissolved solids (TDS), chloride (Cl^-) and nitrate (NO^{3-}) in drinking water wells. From the collected data on chemical water analysis, it was obtained that the average concentration of TDS (1687 mg/l), Cl^- (577 mg/l) and NO^{3-} (131 mg/l) were higher than that of the World Health Organization (WHO) standard, i.e., 1000, 250 and 50 mg/l, respectively. The chemical quality of drinking water thus deteriorated in Gaza Strip, and water demand is increasing rapidly due to rapid population growth and absence of alternative water resources. This may result in adverse human health impacts (Abu Malay and Abu Amr, 2010).

One of the main groundwater quality problems in the West Bank is the elevated nitrate concentrations. Agricultural practices involving inorganic fertilizer applications could be identified as the main sources of nitrate contamination of groundwater in the West Bank. The areas with the most elevated nitrate concentrations are areas characterized by heavy agricultural activities. Such activities are intense in Jenin, Tubas, Tulkarm, Qalqilya, and Jericho districts. In addition, detrimental effect of cesspits on the quality of groundwater is clearly witnessed (Anaya, 2006).

3.3.2 Microbial Risk Assessment

The greatest risk to public health from microbes in water is associated with consumption of drinking water that is contaminated with human and animal excreta, although other sources and routes of exposure may also be significant. Quantitative microbial risk assessment (QMRA), a mathematical framework for evaluating infectious risks from human pathogens, can assist in understanding and managing waterborne microbial hazards, especially those associated with sporadic diseases (WHO, 2011).

Microbial risk assessment generally uses the same concept developed for chemical risk assessment. However, while there are many similarities between chemical and microbial risk assessment, there are also differences, since the major concern with microbial hazards is an acute illness from a single exposure, rather than illness from a low level, chronic exposure. Even so, sequel and other long-term effects are beginning to be recognized for some microorganisms, but knowledge is still limited in this area of research (USDA, 2003).

For microorganisms, hazard assessment (i.e. the identification of pathogen as an agent of potential significance) is generally a straightforward task. The major tasks of QMRA are, therefore, focused on exposure assessment, dose-response analysis and risk characterization. The purpose of an exposure assessment is to determine the microbial doses typically consumed by the direct user of water (or food). In the case of water microbiology, this may necessitate the estimation of the microbial concentration in water followed by estimation of likely changes in microbial concentration with treatment, storage and distribution on the end user. A second issue arising in exposure assessment is the amount of ingested material per 'exposure' (Haas and Eisenberg, 2011).

In order to ensure that drinking water is microbiologically safe to drink, there must be no pathogens in the water at this point of use. Since some pathogens are extremely resistant to certain water treatment processes, the microbial quality of drinking water is linked to the quality of treated water; hence both types of water should be monitored. Drinking water quality is used to inform treatment process selection, and treated water quality has a direct impact on public health. To protect the end user from waterborne diseases, different water sources including water distribution networks and storage reservoirs must be monitored to make sure they are free from microbial pollutants (Burgess and Pletschke, 2008).

Fecal coliform (FC) bacteria are the most commonly used indicators of microbial contamination in water. However, large quantities of FC bacteria in water are not harmful according to some authorities, but may indicate a higher risk of pathogens being present in the water such as Escherichia coli. Some waterborne pathogenic diseases that may coincide with FC contamination include, ear infections, dysentery, typhoid fever, viral and bacterial gastroenteritis, and hepatitis A. The presence of FC tends to affect humans more than it does aquatic creatures, though not exclusively.

In Egypt there are several water quality issues relating to reuse of water that is harvested from streets and agricultural areas. However, from a health perspective, high concentrations of harmful pathogens are of greatest concern. The quality of water in receiving drains is extremely poor in the Delta region, total coliform bacteria reach (10^6 MPN/11ml) in many drains in the delta which is considerably higher than the Egyptian standard of 5000 MPN/100ml. Overall it was confirmed that there are high levels of pathogenic contamination in the canal and drain network. Likely sources of contamination include domestic waste discharge, discharge of partially treated wastes from treatment plants, and industrial effluent discharges (WBWPP, 2012).

Contamination from wastewater was identified by the presence of fecal bacteria and high nitrate levels in the water sources, is widespread throughout the West Bank. Most solid waste dumps are unplanned sites for which no environmental protection measures were intended. In Faria catchment the available water quality data for different water resources, revealed that most of these resources are polluted with different levels of potential environmental risks. The upper catchment springs, which are far away from the pollution source of untreated municipal wastewater, are polluted from cesspits. Detected FC bacteria, in these springs, indicate cesspits are the potential source of pollution. In the middle areas, wells and springs water qualities were increasingly affected from untreated municipal wastewater (Shadeed et al., 2011).

3.4 Risk Characterization

Risk characterization is the last step in risk assessment, the starting point for risk management considerations and the foundation for regulatory decision-making, but it is only one of several important components in such decisions. As the last step in risk assessment, the risk characterization identifies and highlights, the noteworthy risk conclusions, and related uncertainties. Each of the environmental laws administered by
EPA calls for consideration of other factors at various stages in the regulatory process. EPA's Exposure Assessment Guidelines define risk characterization as the final step in the risk assessment process that (EPA, 1995):

- Integrates the individual characterizations from the hazard identification, dose- response assessments, and exposure assessments.
- Provides an evaluation of the overall quality of the assessment and the degree of confidence in the estimates of risk and conclusions drawn.
- Describes risks to individuals and populations in terms of extent and severity of probable harm.
- Communicates results of the risk assessment to the risk manager.

Characterizing risk to include qualitative information should be encouraged to assure that decision makers are fully informed. The risk managers will integrate these quantitative and qualitative factors into regulatory decisions involving numerous assumptions and uncertainties regarding technology, economics, and social factors. The difference between risk characterization and risk assessment is that risk characterization: identifies and explains default options and choices, selection of endpoints from among multiple options; discloses the ranges of predicted risk estimates, not just a single number; provides information about incomplete data bases and the impact on the nature and quality of the risk assessment (Ohanian, 1997).

Health risk can be characterized in various ways. In many cases, risk characterization consists of comparing an estimate of chemical exposure with a guideline value. The exposure and guideline value can be expressed as either a concentration or an exposure rate. The exposure and guideline values should reflect the same averaging time; if not, the evaluator should be aware of any differences when interpreting the results of the risk characterization (WHO, 2010).

As for microbial risk characterization, risk characterization brings together the data collected on pathogen exposure, dose–response, severity and disease burden. The probability of infection can be estimated as the product of the exposure by drinking water and the probability that exposure to one organism would result in infection. The probability of infection per day is multiplied by 365 to calculate the probability of infection per year. In doing so, it is assumed that different exposure events are independent, in that no protective immunity is built up. This simplification is justified for low risks only. Not all infected individuals will develop clinical illness; asymptomatic infection is common for most pathogens. The percentage of infected persons that will develop clinical illness depends on the pathogen, but also on other factors, such as the immune status of the host (WHO, 2011).

3.5 Risk Management

Risk assessment and risk management are closely related but with different processes, with the nature of the risk management decision often influencing the scope and depth of a risk assessment. In simple terms, risk assessors ask “How risky is this situation?” and risk managers then ask “What are we willing to accept?” and “What shall we do about it?” (Leeuwen, 2007).

Risk management is about taking a carefully considered course of action, as the obligation is to ensure safe water and protect public health. Effective risk management requires the identification of potential hazards, their sources and potential hazardous events and an assessment of the level of risk presented by each. Once potential hazards and their sources have been identified, the risk associated with each hazard or hazardous event should be compared so that priorities for risk management can be established and documented. Although there are numerous contaminants that can compromise drinking water quality, not every hazard will require the same degree of attention (WHO, 2011).

Since short-term exposure to hazards can lead to health effects, it is important to develop and implement standards and monitoring regimes that allow preventive and remedial actions to be taken within realistic timeframes (NHMRC, 2008).

3.5.1 Mitigation Measures

When potential sources of chemical contamination are known to exist in a catchment, management strategies should focus on catchment protection. For example, planning should address; the prevention or reduction of existing or future nitrogen pollution from agricultural sources through safer storage and spreading of animal manure and fertilisers, to prevent eutrophication in wells, springs and streams; and improved protection of soils against erosion through codes of good practice and action programs.

Monitoring of priority chemicals or indicators of chemical contamination should be more frequent for water from unprotected or partially protected catchments, or water that may be contaminated with industrial discharges or effluent, compared to water from protected catchments. The minimum required in any monitoring program for chemical characteristics is to collect representative samples routinely from water sources within the catchment (NHMRC, 2008).

Securing the microbial safety of drinking water sources is based on the use of multiple barriers, from catchment to consumer, to prevent the contamination of drinking water or to reduce contamination to levels not injurious to health. Safety is increased if multiple barriers are in place, including protection of water resources, proper selection and operation of a series of treatment steps and management of distribution systems to maintain and protect treated water quality. The preferred strategy is a management approach that places the primary emphasis on preventing or reducing the entry of pathogens into water sources and reducing reliance on treatment processes for removal of pathogens (WHO, 2011).

Discharge of untreated wastewater and unbalanced use of fertilizers and pesticides, cause pollution of the limited water resources in Faria catchment, for both groundwater as well as surface water. The contribution of fertilizers and pesticides to the groundwater pollution through infiltration of irrigation water return flow has not been yet quantified. In order to mitigate this problem, the farmers should be advised of the amount and types of fertilizers and pesticides to be used for different crops and plants (WASMAP, 2004).

Raw wastewater is being used since decades for irrigation in several sites in the West Bank; the use of untreated wastewater in irrigation is an established practice in Faria catchment. The eastern portion of the city of Nablus, Balata, and Askar refugee camps and the eastern industrial zone of Nablus city, discharge their untreated wastewater to the catchment. Wastewater effluent contains several chemicals and microbes that adversely affect human health. In order to mitigate the adverse affect of using untreated wastewater for irrigation, a wastewater treatment plant should be constructed at the eastern part of the Nablus city, enforcement of laws that regulate the reuse of treated wastewater should be prompted and the prohibition of the use of untreated wastewater in irrigation should be prioritized, in-site treatment of industrial wastewater should be considered, and public education regarding the hazards of reusing raw wastewater in irrigation should be emphasized on (Abu Baker, 2007).

3.5.2 Management Framework

Many of the major problems lie in rural areas, where there is scarcity of water resources, sometimes down to the household level. At this level, water availability and financial and technical resources are all limited. There are several available approaches, but there is a basic requirement for education. In particular, there is a need to understand the risks of high chemical and microbial exposure and the sources of exposure, including the uptake of chemicals and microbes by crops from contaminated irrigation water and the uptake of chemicals and microbes into food from contaminated cooking water (WHO, 2011).

Water safety frameworks should also be used during planning, installation and management of all new water points, especially ones based on surface water and very shallow groundwater, to minimize risks from fecal and other sources of contamination. Screening for possible chemical contaminants that can cause problems with health, is also important to ensure that new sources are acceptable (WHO, 2011).

Lack of proper management of water resources in Faria catchment causes over utilization of limited water resources in the catchment, coupled with a decrease in water quality owing to the contamination of surface as well as groundwater resources. Thus, management options were proposed to enhance the water quality in Faria catchment include, wastewater treatment plant; protection zones of the groundwater wells; control the agricultural practices to minimize any potential chemical contamination due to the use of fertilizers and pesticides (Shadeed, at el, 2007).

CHAPTER FOUR

DATA ANALYSIS AND ASSESSMENT

4.1 Water Quality Data Analysis

Throughout the UWIRA project, drinking water samples have been taken and tested by Water and Environmental Studies In statue (WESI) of An-Najah National University for chemical, biological, and some physical water properties for some selected wells and springs located in the middle and upper points of the Faria catchment, as shown in **Figure 4.1.**

UWIRA project stands for impact of untreated wastewater on natural water bodies: integrated risk assessment. The project is a multilateral research project running on the Faria catchment by An-Najah National University, Beirzeit University and PWA with the coordination of UNESCO IHE-Institute.

Description of the tested wells and springs are shown in **Table 4.1.**

Table 4.1: Description of the Tested Wells and Springs in Faria Catchment

ID	Name	Location	Utilized
W1	Well (18-18/031A)	Nasarya	Domestic/Agriculture
W2	Well (18-18/034)	Nasarya	Domestic/Agriculture
SP1	Tawaheen Spring	Bathan	Domestic/Agriculture
SP2	Shible Spring	Shibli	Domestic

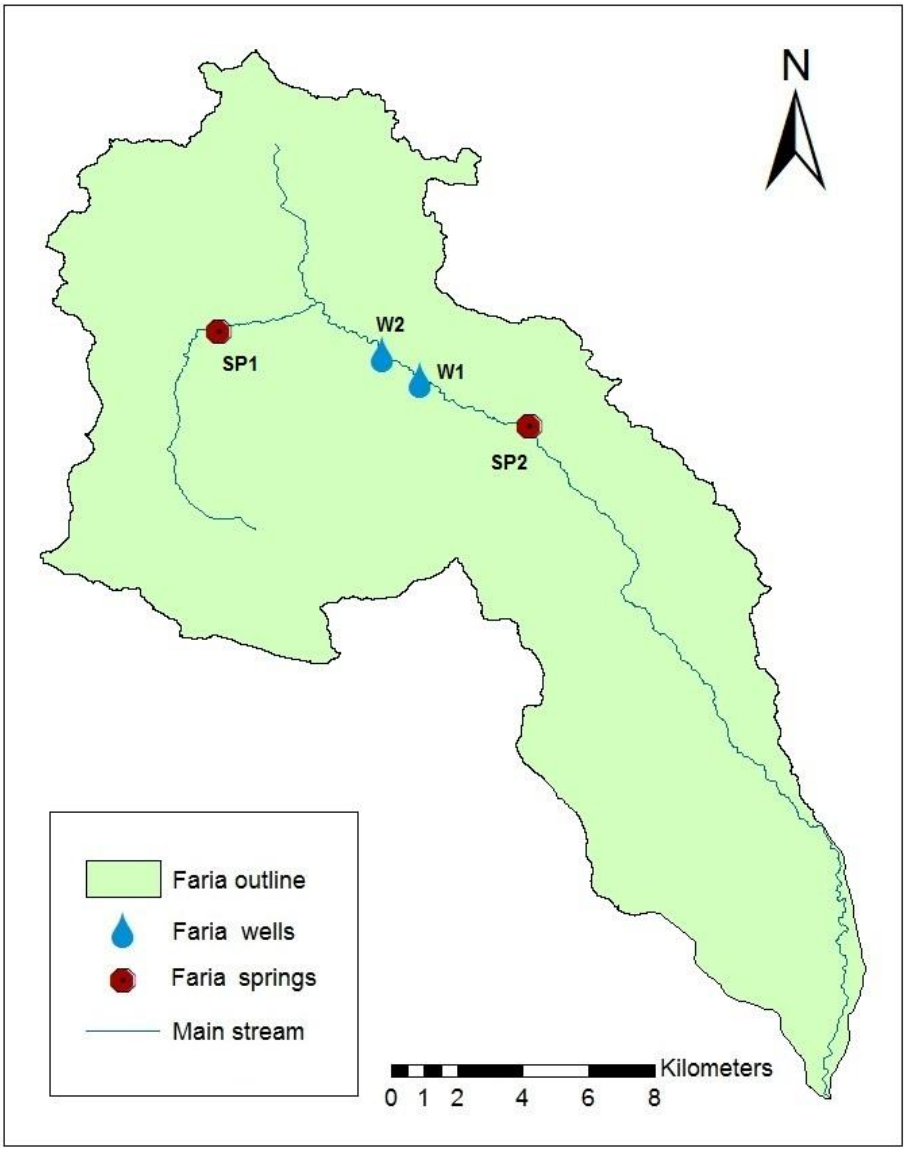


Figure 4.1: The Distribution of the Tested Wells and Springs in the Faria Catchment

Water quality data are available on monthly basis for the period between December 2010 and July 2012 as presented in **Annex A**.

The obtained water quality data are compared with local and international drinking water standards in order to recognize and adopt best management practices to mitigate the potential risks on public health.

Almost all countries in the region lack a clear strategy for the set up, propagation and review of drinking water quality standards. Issued standards do not include explanatory notes to facilitate interpretation, implementation and enforcement. Frequency of sampling is not adequately addressed in most issued standards. Furthermore, standards address drinking water quality in general, and do not specify requirements, for instance, in the distribution system, in tankers, and during times of emergency. There is a tendency in some countries to adopt an approach of setting limits to suit the actual prevailing characteristics of available water resources rather than setting limits to protect public health. This is unacceptable and will discourage long-term system improvement (WHO, 2006).

However, Palestinian drinking water standards are subjected to frequent observation and inspection, in order to keep up with scientific, technical and industrial development (PSI, 2005). **Table 4.2** shows a comparison between the obtained water quality data for each of the tested wells and springs, with the Palestinian and EPA drinking water standards.

Table 4.2: Comparison between the obtained water quality data for the tested wells and springs, with the Palestinian and EPA drinking water standards

Parameter	W1		W2		SP1		SP2		Palestinian Standards 41-2005	EPA Standards 2012
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	MCL (mg/L)	
Cl (mg/L)	104.4-126.1	115	83.3-115	95	39.4-48.3	46.5	103.9-142.2	112.2	250	250
Mg (mg/L)	7.3-42.1	31.9	19.0-43.3	33.1	3.6-24.7	15.3	13.0-43.3	27.9	50	50
Na (mg/L)	18.9-20.4	19.5	16.8-20.7	19.2	5.3-19.1	16.8	16.5-21.1	19.3	200	150
K (mg/L)	1.4-5.2	2.9	1.9-5.8	3.1	1.3-8.5	3.2	2.0-6.3	4.1	10	-
Ca (mg/L)	82.0-112.7	94	79.3-94.0	85.2	70.0-86.0	77.8	60.0-110.7	83.5	100	150
SO_4 (mg/L)	0.9-22.3	5.7	0.0-25.6	6.3	0.3-18.6	7.1	0.6-36.3	8.6	200	-
NO_3 (mg/L)	11.5-25.8	21.3	16.7-23.2	21.1	13.3-21.3	16.8	16.5-28.4	20.4	50	45
TDS(mg/L)	435-666	522	410-634	354	256-384	325	243-649	445	1000	500
$CaCO_3$ (mg/L)	235-398	366	317-403	354	190-293	257	203-407	326	500	500
HCO_3 (mg/L)	267-324	302	298-329	315	225-330	275	281-393	304	600	-
PO_4 (mg/L)	0.0-0.14	0.026	0.0-0.05	0.018	0.0-0.14	0.052	0.0-0.09	0.019	2	0.5
FC (counts)	0.0-1800	641	0.0-1000	179	4.0-7600	1806	12.0-1600	247	0/100 ml	5/100 ml
pH	6.9-7.7	7.35	6.97-7.9	7.36	7.4-9.4	7.92	6.9-7.85	7.36	6.5-8.5	6.5-8.5
Turbidity(NTU)	0.2-6.6	1.7	0.1-4.8	1.1	0.8-25.0	6.6	0.1-25.0	3.5	1.0	0.0
EC (µs)	680-1040	816	621-990	759	400-600	507	380-1013	707	1500	-

(-) Maximum contamination level (MCL) for the parameter has not been issued.

By comparing the mean value of the data of the wells and springs with the Palestinian and EPA drinking water standards, it was found that;

- All the chemical concentrations are below the Palestinian MCL.
- All the chemical concentrations are below EPA MCL, except for TDS in W1 which is slightly above MCL.
- The pH of water is within acceptable range, and the electrical conductivity below MCL.
- The turbidity and FC are above the Palestinian and EPA MCL for all the selected wells and springs.

When FC bacteria are present in high numbers in a water sample, it means that the water may have received fecal matter from one source or another. Although not necessarily agents of disease, FC may indicate the potential presence of disease-carrying organisms, which live in the same environment as the FC. The elevated levels of FC in the obtained water quality data are an indicator of a microbial contamination in Faria catchment (Linscott, 2011).

A High level of TDS is an indicator of potential concerns, and warrants further investigation. It results in undesirable taste which could be salty, bitter, or metallic. It could also indicate the presence of toxic minerals. Most often, high levels of TDS are caused by the presence of potassium, chlorides and sodium. These ions have little or no short-term effects, but toxic ions (lead arsenic, cadmium, nitrate and others) may also be dissolved in the water.

According to (Metcalf and Eddy, 1991), turbidity is used to indicate the quality of natural water with respect to colloidal and residual suspended matter. The levels of turbidity in the obtained water quality data indicate a high concentration of suspended particles. The high levels of turbidity help the attachment of heavy metals and many other toxic organic compounds and pesticides, which would have an adverse effect on human health. The considered option to mitigate the risk of high turbidity in Faria water resources is by using filtration process through home filters or water treatment plant.

The risk associated with chemical concentrations in drinking water which are below the MCL, appears when calculating the chemical risk as the sum of risks for each parameter.

4.2 Structured Interviews

A structured interview is a qualitative method commonly employed in survey research, in which it would be beneficial to compare participant responses in order to answer a research question. In this case, the data is collected by an interviewer rather than through a self-administered questionnaire. The aim of this approach is to ensure that each interview is presented with exactly the same questions in the same order. This ensures that answers can be reliably aggregated and that comparisons can be made with confidence (Lindlof and Taylor, 2010).

To determine the sources of exposure and the intakes of the chemicals, which will help to identify the parameters for the risk equations, structured interviews have been conducted through eleven villages located in the upper and middle parts of the Faria catchment covering the area of the study. These villages are; Salim, Azmout, Bathan, Talluza, Wadi Al-Fraia, Al-Faria refugee camp, Tammun, Tubas, Al-Aqrabania, An-Nasaria, and Beit Hasan. **Annex B** shows the questions of the structured interviews.

In order to have fruitful interviews, the structured interviews were made with four parties; municipalities, swimming pool owners, health centers, and farmers. Accordingly, the structured interviews have been analyzed for each party independently as follows;

4.2.1 Municipalities

After visiting the municipalities of all the villages, the results of interviews showed that, the sources of water supply in most of the villages come from domestic wells and/or springs, except for Salem and Azmout villages, which have their water supply from Mekorot. Mekarot is an Israeli water company that pumps groundwater from the Palestinian aquifers and sells it back to Palestinians in the West Bank.

The water quality of these sources is being monthly tested for chemical and microbial contamination, either by Ministry of Health, PWA, or Water and Environmental Studies Institute of An-Najah National University. The results of these tests showed an increase of calcium at Wadi Al-Faria, and fecal contamination at Al-Aqrabania, An-Nasaria, and Beit Hasan villages. No actions have been made to solve these problems except for using chlorine as a disinfectant agent. The percentage of chlorine added to water resources is about 0.3 ppm for all of the villages, which might not be enough for disinfection.

The water network is considered to be new for most of the villages, so it does not have any recorded problems, except for some corrosion and leakage in Salem and Azmout villages as they have an old water network.

Most of the villages except for Azmout, Salem and Beit Hasan, do not have sewerage network, they use cesspits as a way of wastewater disposal.

Using this method of disposal might caused a wastewater contamination to the groundwater aquifers, and due to increase of population and therefore increasing the need to use more cesspits at Bathan village, it's expected to have a wastewater leakage and a serious contamination of the groundwater aquifer in the long-term if no actions are made to solve the ongoing problem.

4.2.2 Swimming Pool Owners

Bathan village is the only village which has parks with swimming pools. Two parks have been visited and the results indicated that, in summer seasons, people go for swimming almost two times a month, and swim for about 2-4 hours a day.

The owners depend on springs as a water source to fill their pools. They add different types of chemical substances to the water as follows;

- Aluminium sulfate as sedimentation agent when the turbidity of water is high.
- Acid to lower the pH of water when it's high.
- Soda to increase the pH of water when it's low.
- Chlorine in the forms of (liquid, powder and solid) as disinfectant agent.

The owners make regular tests for water quality every second hour, to make sure that the percentage of chlorine in water stays within (1.5-3 ppm) and the pH around 7.6, according to the Ministry of Health regulations.

4.2.3. Health Centers

After visiting the health centers of the villages in the catchment, the questions of the structured interviews related to health centers have not been answered. This can be contributed to the lack of understanding of waterborne diseases in the catchment, thus, no statistical data has been collected. Therefore, waterborne diseases statistics were obtained from the Ministry of Health.

There is a lack of health centers in the catchment. Many health centers don’t have any clinical or health services. The existing small and poorly equipped health centers are operated by the UNRWA and the Palestinian Medical Relief Committees. UNRWA restricts its services to the registered refugees only. The entire catchment does not have any hospital, and so, most people have to travel to the hospitals in Nablus and Tubas cities to get the medical services they need.

For this reason, waterborne diseases statistics for Nablus and Tubas cities were obtained from the annual health report published by the Ministry of Health, as an indicator of the adverse health effects of the contaminated drinking water in the catchment. **Table 4.3** presents the number of cases of dangerous waterborne diseases in Nablus and Tubas cities for the mid year of 2012 (MoH, 2012).

Table 4.3: Waterborne Diseases in Nablus and Tubas Cities for the Mid Year of 2012

Disease	**Number of Recorded Cases**	
	Nablus	Tubas
Hepatitis A	41	12
Typhoid Fever	6	0
Giardiasis	7	1

4.2.4. Farmers

By interviewing a farmer in each village, it was concluded that, Bathan, Wadi Al-Faria, and Tammun farmers irrigate their lands according to the type of crops. It ranges from daily irrigation to once every two weeks. They use agricultural wells as a source of irrigation water.

As for Salem and Azmout farmers, they do not irrigate their lands, since they depend upon rainfed cultivation. Even though, some of the farmers use untreated wastewater for irrigation, mainly at the proximity of the wastewater outfall of Nablus.

According to a study by (Almasri et al., 2012), the irrigation with untreated wastewater seems to enhance the uptake of heavy metals by the Chinese cabbage where it was observed that concentrations in the leaves are higher when compared to those under fresh water irrigation. Consequently, irrigation with untreated wastewater may affect the public health of the Faria catchment.

Moreover, none of the villages' farmers make any chemical or microbial tests on the water resources which are used for irrigation. Therefore, the irrigation water might be contaminated with chemicals or/and microbes, that could cause adverse health effects on the population due to consumption of raw vegetables.

4.3 Risk Assessment

Human health risk assessments of chemicals and microbes can be performed to evaluate past, current and even future exposures to any chemical and microbe found in drinking water. Risk assessments rely on scientific understanding of pollutant behavior, exposure, dose and toxicity.

In order to estimate the chemical and microbial risks in Faria catchment drinking water, the fundamental steps of risk assessment, including toxicity assessment, exposure assessment, and risk characterization, have been used.

4.3.1 Toxicity Assessment

The most important factor to take into account is that, in most communities, the principal risk to human health derives from faecal contamination. In some countries there are also hazards associated with specific chemical contaminants such as fluoride or arsenic, but the levels of these substances are unlikely to change significantly with time. Thus, if a full range of chemical analyses is undertaken on new water sources and repeated thereafter at fairly long intervals chemical contaminants are unlikely to present an unrecognized hazard. In contrast, the potential for faecal contamination in untreated or inadequately treated community supplies is always present. The minimum level of analysis should therefore include testing for indicators of faecal pollution (faecal coliforms), major chemicals that are found in water, turbidity, and pH (if the water is disinfected with chlorine) (WHO, 2011).

Toxicity assessment for contaminants found in drinking water is generally accomplished in two steps: hazard identification and dose-response evaluation.

The first step, hazard identification, is the process of determining whether exposure to a chemical or microbe can cause an increase of a particular adverse health effects (e.g., cancer, birth defect) and whether the adverse health effects is likely to occur in humans. This step resulted in screening and ranking of the most hazard posing chemicals and microbes.

The second step, dose-response evaluation, is the process of quantitatively evaluating the toxicity information and characterizing the relationship between the dose of the contaminant received, and the adverse health effects in the exposed population. This step can be derived by experimenting on laboratory animals. It is done by exposing the animals to different doses of chemicals and microbes then study the adverse health affect associated with each dose. After that, the results are extrapolated from animals to humans, to obtain the dose-response curve for each chemical and microbe. This evaluation is beyond the scope and capabilities of this research.

Choosing which chemicals and microbes should be tested in drinking water, depends upon where you live, what is your water source, and what is located near your drinking water supply. Inorganic chemical constituents commonly found in water in significant quantities (1.0 to 1000 mg/L) include calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, and nitrate. Inorganic constituents that are generally present in lesser amounts (0.01 to 10 mg/L) include iron, lead, copper, arsenic, and manganese.

Due to wastewater contamination and the extensive use of fertilizers for agriculture in Faria catchment, the most common chemicals and microbes that are tested in drinking water resources are, the major ions (Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, SO_4^{2-}, HCO_3^-, PO_4^{3-}, and NO_3^-), total hardness, and the total FC.

4.3.2 Exposure Assessment

Public health scientists and physicians are challenged to protect populations from harmful exposures to environmental chemicals and microbes found in drinking water, and to recognize exposures that are not of health concern. When human beings are exposed to the environmental chemicals and microbes, these chemicals and microbes will enter the body through different routes of entry. These include inhalation through respiratory tract, ingestion through gastrointestinal tract and dermal contact through the skin. However, to produce a toxic effect, some chemicals or its biotransformation products must reach the targeted organ at a sufficiently high concentration and for a sufficient length of time, whereas microbes and other chemicals, can cause a threat to human lives with small concentrations in a short length of time (LaGrega et al, 2001).

For many risk assessments, exposure assessment is the most difficult task. The reason for this is that exposure assessment often depends on factors that are hard to estimate and for which there are few data. Critical information on the conditions of exposure is often lacking. To be comprehensive, an exposure assessment must describe the levels of exposure and all conditions that might be needed to assess the effects of such exposures, including their magnitude, duration, schedule, and route of entry (Ando, 1994).

The levels of exposure are measured based on the frequency and duration of exposure as well as the levels of contaminant in the exposure media, such as soil, water, air, and food. Chemical intake is the exposure to estimated amount of a constituent normalized for time and body weight and is expressed in units of mg chemical/kg body weight-day. For groundwater, chemical intakes should be calculated for ingestion and dermal contact pathways of exposure. The following equations were issued by EPA to calculate the chronic daily intake for various pathways of exposure (EPA, 2004)

- Ingestion in drinking water:

$$CDI = \frac{(CW)(IR)(EF)(ED)}{(BW)(AT)}$$

- Ingestion while swimming:

$$CDI = \frac{(CW)(CR)(ET)(EF)(ED)}{(BW)(AT)}$$

- Dermal contact while showering and while swimming:

$$AD = \frac{(CW)(SA)(PC)(ET)(EF)(ED)(CF)}{(BW)(AT)}$$

Where:

CDI = chronic daily intake (mg/kg body weight. day).

AD = absorbed dose (mg/kg body weight .day).

CW = chemical concentration in water (mg /L).

IR = ingestion rate (amount of water ingested daily) (L /day).

CR = contact rate while swimming (L/h).

ET = exposure time while showering (h/day).

EF = exposure frequency (day/year).

ED = exposure duration (years).

BW = body weight (kg).

AT = average time (days).

SA = skin surface area available for contact (cm^2).

PC = dermal permeability constant (cm/h).

CF = volumetric conversion factor for water.

EPA recommended values for estimating the intake are described in **Table 4.4**. However, by analyzing the results of the structured interviews, some of the exposure parameters for the chemical intake equations were obtained. The exposure frequency and exposure time during swimming in Faria catchment swimming pools, was estimated to be from 8-10 times per year for 2-4 hours a day.

Table 4.4: EPA Recommended Values for Estimating Intake

Parameter	Standard Value
ED	**70 years**
AT	**(ED)(365 day/year)**
ET (90^{th} percentile)	**12 min**
BW (adult)	**70 kg**
BW (child, 5-12 years)	**26 kg**
IR (adult)	**2 L**
IR (child)	**1 L**
CR	**50 mL/h**
SA (adult male)	**1.94 m^2**
SA (adult female)	**1.69 m^2**
SA (child male or female, 9-12 years)	**1.16 m^2**
PC	**0.002 m/h**
FC	**1000**

4.3.3 Risk Characterization

In the risk characterization step, all data collected from exposure and toxicity assessments are reviewed to corroborate qualitative and quantitative conclusions about risk. The risk for each media source and route of entry is calculated. This includes the evaluation of compounding effects due to the presence of more than one chemical contaminant and the combination of risk across all routes of entry.

This step has been done by using chemical risk formulas, and an online QMRA Wiki analyst for microbial risk, to estimate the likelihood of adverse effects on the public health of Faria catchment

4.3.3.1 Microbial Risk Characterization

The principal risk associated with water in small-community supplies is that of infectious disease related to fecal contamination. Hence, the microbial examination of drinking water emphasizes assessment of the hygienic quality of the supply.

Of all contaminants in drinking water, human and animal feces present the greatest danger to public health. Escherichia coli (E.coli) are naturally occurring FC found in human and animal intestines. Comparison with other practical candidate fecal indicators shows that E. coli is far superior overall. The reason E.coli is relied on heavily as a measure is that it is a good indicator of the bacteriological safety of drinking water. It is the only species in the coliform group that is exclusively found in the intestinal tract of humans and other warm-blooded animals, and it is excreted in large numbers in feces. E. coli survives in drinking water for between 4 and 12 weeks, depending on environmental conditions (temperature, microflora, etc.). If E.coli is found in the water, it means that the water has been contaminated by human or animal feces that can harbor a number of other pathogenic, or disease causing, organisms. The MCL of E.coli in drinking water is zero (Allen et al, 2000).

Nearly all of EPA's bacteria models and tools are designed for FC modeling. In the absence of a mathematical model to allocate E. coli, a method is needed to calculate E. coli by using a FC model. Several states in the United State have already developed U.S. EPA-approved bacteria translators for E. coli and FC. In the Northeast District of Ohio 2183 pairs of FC - E. coli were evaluated. FC - E. coli pairs were log-transformed prior to the correlation. The regression was simplified by taking the anti-log of both sides. The final relationship was expressed as (EPA, 2006):

$$\text{E. coli} = 0.667 * (\text{FC})^{1.034}$$

In order to estimate the potential risk of microbial contamination in the Faria catchment, and due to the absence of Palestinian EPA-approved bacteria translator, the Northeast District of Ohio translator was used. The mean values of FC counts in Faria drinking water resources, was converted into E.coli doses as shown in **Table 4.5.**

Table 4.5: Conversion of the Concentration of FC into E.coli

ID	W1	W2	SP1	SP2
Mean (FC)	641	179	1806	247
Mean (E.coli)	532	142	1554	198

4.3.3.2 Chemical Risk Characterization

Generally, the toxic substances can be classified into two kinds: carcinogenic and non-carcinogenic substances. Carcinogenic substances can be further subdivided into chemical carcinogenic substances and radioactive pollutants. Usually radioactive pollutants are rare and cannot be detected, so the assessment generally can be classified accordingly into chemical carcinogenic risk assessment and the non-carcinogenic risk.

For the carcinogenic compounds, the safe level could not be estimated. However, estimates were made such that concentrations of a compound in water could be correlated with an incremental lifetime cancer risk, assuming a person consuming 2 liters per day of water containing the compound for 70 years. For non-carcinogens, data from human or animal exposure to a toxic agent were reviewed and calculations made to determine the no-adverse-effect dosage in humans. Then, depending on the type and reliability of data, a safety factor was applied. This factor ranged from 10 (where good human chronic exposure data were available and supported by chronic oral toxicity data in other species) to 1000 (where limited chronic toxicity data were available). Based on these levels and estimates of the fraction of a substance ingested from water (compared to food, air, or other sources), the National Academy of Sciences (NAS) method allowed calculations of acceptable daily intake and a suggested no-adverse-effect level in drinking water (Crittenden et al., 2012).

1. Risk characterization for carcinogen compounds.

- For low-dose cancer risk (risk < 0.01):

The quantitative risk assessment for a single compound by a single route is calculated as:

$$Risk = (CDI)x(SF)$$

Where, SF = slope factor.

- For high carcinogenic risk levels (risk > 0.01):

The one-hit equation can be used:

$$Risk = 1 - \exp[-(CDI)(SF)]$$

2. Risk characterization for non-carcinogen compounds.

The measure used to describe the potential for non-carcinogenic toxicity to occur in an individual is not expressed as a probability. Instead, EPA uses the hazard index (HI):

HI = CDI/RfD

Where, RfD = reference dose.

When HI >1, there may be concern for potential non-cancer effects.

To assess the overall potential for non-cancer effects posed by multiple chemicals, the hazard index for multiple substances and pathways is estimated as:

$HI = \sum HI_{ij}$

RfD values are available in the Integrated Risk Information System (IRIS) database. However, for chemicals for which RfDs are not available in IRIS, national primary drinking water (EPA) MCLs and secondary drinking water regulation concentrations (SMCLs), expressed in milligrams of chemical per liter of drinking water, are converted to RfD values by multiplying by 2 liters (the average daily adult water intake) and dividing by 70 kg (the reference adult body weight). RfD values for each chemical are describes in **Table 4.6**.

Table 4.6: RfD Values of the Chemicals

Chemical	RfD (mg/kg.day)
Cl	7.14
Mg	2.86
Na	5.71
K	0.286
Ca	4.28
SO_4	5.71
NO_3	1.6
TDS	28.57
$CaCO_3$	14.28
HCO_3	17.14
PO_4	0.057

CHAPTER FIVE

RISK ANALYSIS AND MANAGEMENT

5.1 Microbial Risk

To calculate the risk associated with E. coli that present in the drinking water of the Faria catchment, an online QMRA Wiki analyst was used.

The QMRA Wiki is a community portal for current quantitative information and knowledge developed for QMRA field. It is an evolving knowledge depository intended to be the go to reference source for the microbial risk assessment community. It is in the public domain and is supported by EPA and the US Department of Homeland Security agencies. **Figure 5.1** shows the online QMRA Wiki analyst display window.

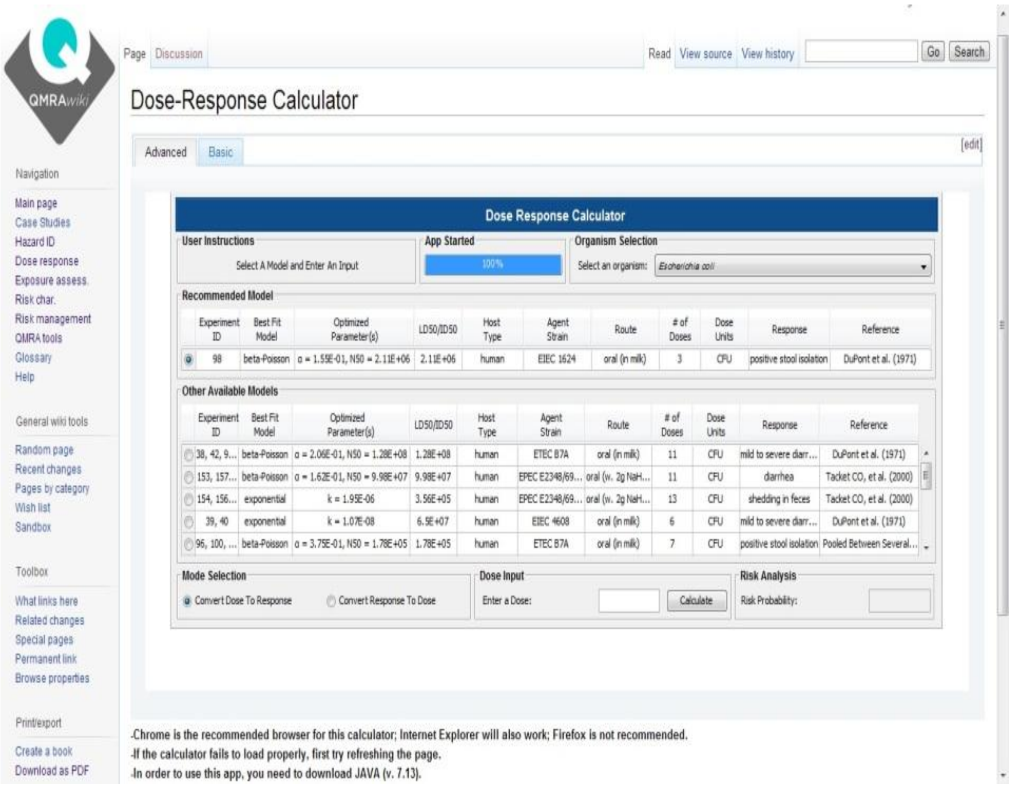


Figure 5.1: Display Window of the Online QMRA Wiki Analyst

After using the analyst, the risk probability results of E.coli doses are described in **Table 5.1.**

Table 5.1: Risk Probability Results of E. coli Doses

ID	W1	W2	SP1	SP2
E.coli Doses	532	142	1554	198
Risk Probability	3.5×10^{-3}	8.81×10^{-4}	8.94×10^{-3}	1.3×10^{-3}

These values indicate that out of one thousand people, at least one person will get sick due to the presence of E.coli in the catchment drinking water resources. E. coli can cause different adverse affects on human health. Its illness is characterized by severe cramping and diarrhea that is initially watery but becomes bloody, occasionally vomiting, and fever that is either low grade or absent. The illness is usually self-limited and lasts for an average of 8 days. Some victims develop hemolytic uremic syndrome (HUS), a rare condition affecting mostly children, characterized by destruction of red blood cells, damage to the lining of blood vessel walls, and in 10 percent of the cases kidney failure.

5.2 Chemical Risk

By applying the intake formulas using the mean value of the chemical concentrations for each of the tested wells and springs, the chronic daily intake for adult male, adult female, and child was calculated as shown in **Table 5.2**.

All the chemicals in the obtained data are considered non-carcinogenic. Therefore, the HI was used to find the potential non-carcinogen toxicity for adult male, adult female, and child as described in **Table 5.3**.

Table 5.2: Chronic Daily Intake (CDI) for Adult Male, Adult Female, and Child.

Chemical (mg/L)	W1 CDI (mg/kg.day)			W2 CDI (mg/kg.day)			SP1 CDI (mg/kg.day)			SP2 CDI (mg/kg.day)		
	Male	**Female**	**Child**	**Male**	**Female**	**Child**	**Male**	**Female**	**Child**	**Male**	**Female**	**Child**
Cl	4.39	4.25	6.21	3.63	3.51	5.13	1.77	1.56	2.51	4.28	4.15	6.06
Mg	1.22	1.18	1.72	1.26	1.26	1.79	0.58	0.58	0.82	1.06	1.03	1.51
Na	0.74	0.72	1.05	0.73	0.71	1.03	0.64	0.62	0.91	0.74	0.71	1.04
K	0.11	0.11	0.15	0.12	0.11	0.16	0.12	0.12	0.17	0.15	0.15	0.22
Ca	3.59	3.47	5.08	3.25	3.15	4.60	2.97	2.87	4.20	3.19	3.08	4.51
SO_4	0.22	0.21	0.31	0.24	0.23	0.34	0.27	0.26	0.38	0.33	0.32	0.46
NO_3	0.81	0.78	1.15	0.81	0.78	1.14	0.64	0.62	0.91	0.78	0.75	1.10
TDS	19.93	19.29	28.21	13.52	13.08	19.13	12.41	12.01	17.56	16.99	16.45	24.04
$CaCO_3$	13.97	13.53	19.77	13.52	13.08	19.13	9.81	9.49	13.89	12.45	12.05	17.61
HCO_3	11.53	11.16	16.32	12.03	11.64	17.02	10.50	10.16	14.86	11.61	11.24	16.43
PO_4	0.001	0.001	0.001	0.0007	0.0007	0.001	0.002	0.002	0.002	0.0007	0.0007	0.001

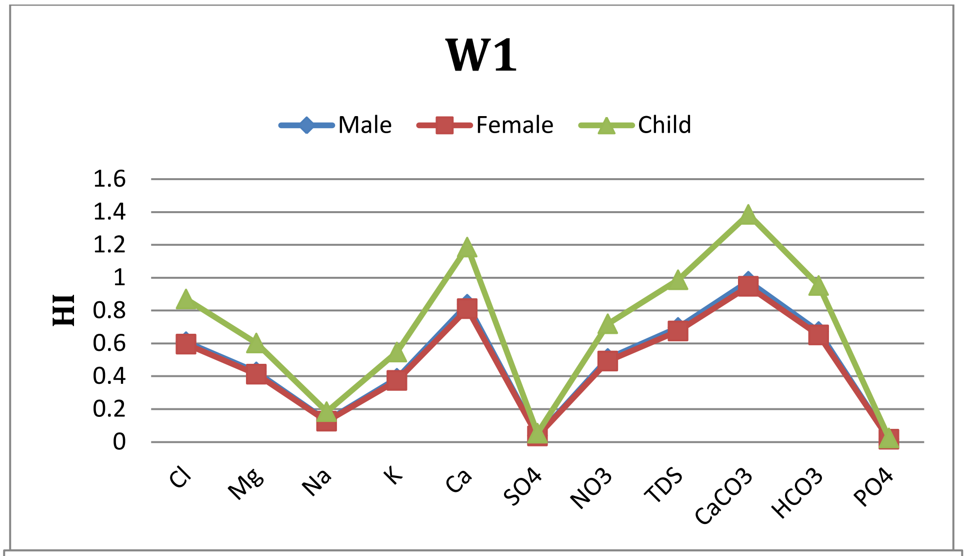
Table 5.3: Potential Non-carcinogen Toxicity for Adult Male, Adult Female, and Child.

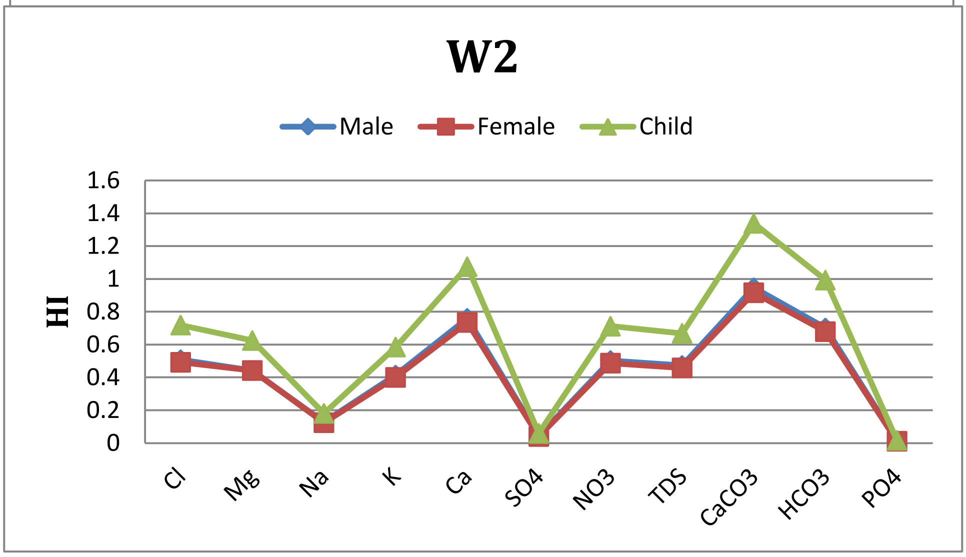
Chemical (mg/L)	W1 – HI			W2 – HI			SP1 - HI			SP2 - HI		
	Male	Female	Child	Male	Female	Child	Male	Female	Child	Male	Female	Child
Cl	0.610	0.595	0.870	0.508	0.492	0.719	0.248	0.240	0.351	0.600	0.580	0.849
Mg	0.426	0.412	0.602	0.442	0.442	0.625	0.204	0.204	0.289	0.372	0.360	0.527
Na	0.130	0.126	0.184	0.128	0.124	0.181	0.112	0.108	0.159	0.129	0.124	0.182
K	0.387	0.374	0.547	0.414	0.400	0.585	0.427	0.413	0.604	0.547	0.529	0.774
Ca	0.838	0.811	1.186	0.76	0.735	1.075	0.694	0.671	0.982	0.745	0.721	1.054
SO_4	0.038	0.036	0.053	0.042	0.040	0.059	0.047	0.046	0.067	0.057	0.055	0.081
NO_3	0.508	0.492	0.719	0.503	0.487	0.712	0.401	0.388	0.567	0.486	0.471	0.689
TDS	0.697	0.675	0.987	0.473	0.458	0.669	0.434	0.420	0.614	0.594	0.575	0.841
$CaCO_3$	0.978	0.947	1.385	0.946	0.916	1.339	0.687	0.665	0.972	0.871	0.843	1.233
HCO_3	0.672	0.651	0.952	0.701	0.679	0.993	0.612	0.593	0.867	0.677	0.655	0.958
PO_4	0.017	0.016	0.024	0.012	0.011	0.017	0.034	0.033	0.049	0.012	0.012	0.018
Total	5.301	5.135	7.509	4.929	4.783	6.974	3.9	3.738	5.521	5.09	4.925	7.206

When the HI exceeds unity, there may be concern for potential health effects. While any single chemical with an exposure level greater than the toxicity value will cause the HI to exceed unity, for multiple chemical exposures, the HI can also exceed unity even if no single chemical exposure exceeds its RfD.

The results indicate that, the HI for each chemical for adult male is a little bit higher than adult female, though it did not exceed unity in all the tested wells and springs. However, the HI for multiple chemicals exceeded unity, which means there might be concern for potential non-carcinogen effects caused by multiple chemical exposures in the drinking water of Faria catchment.

Whereas, for child, the HI for calcium and total hardness slightly exceeds unity and might pose adverse health effects on the children of the catchment. Thus, the HI for multiple chemical exposures exceeds unity too, with higher values than for adult male and female, which means, the potential non-carcinogen toxicity for children is higher than in adult male or female. **Figure 5.2** describes a comparison of HI between adult male, adult female, and child for each of the Tested wells and springs.


W1
Male
Female
Child
HI
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Cl
Mg
Na
K
Ca
SO4
NO3
TDS
CaCO3
HCO3
PO4


W2
Male
Female
Child
HI
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Cl
Mg
Na
K
Ca
SO4
NO3
TDS
CaCO3
HCO3
PO4

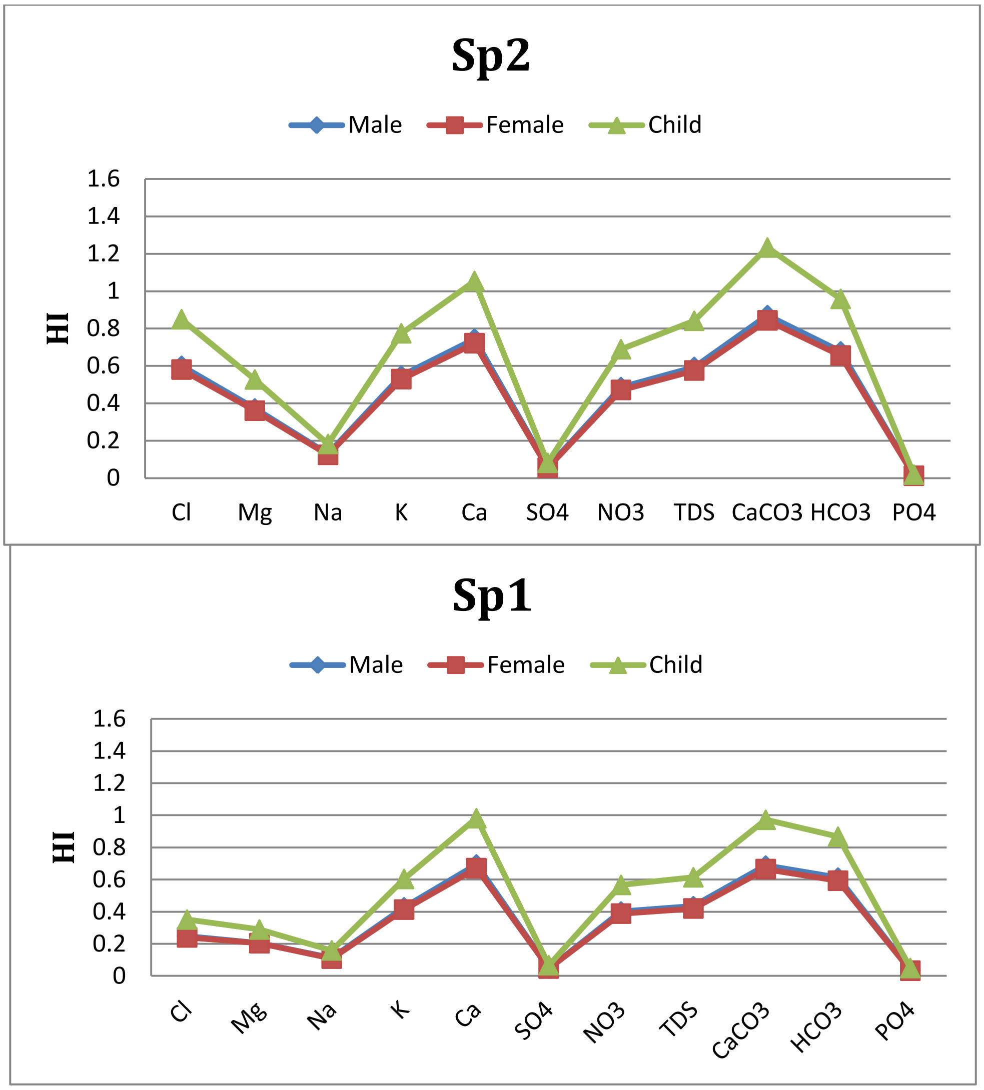


Figure 5.2: Comparison of HI between Adult Male, Adult Female, and Child for Each of the Tested Wells and Springs

5.3 Potential Future Risk

According to work of Duraidi (running master thesis, 2013), there is an increase in the concentrations of some heavy metals and organic compound in the Faria stream as described in **Table 5.4**.

Table 5.4: Heavy Metals and Organic Compound Concentrations in the Faria Stream

Parameter	Concentration	Palestinian Standards 41-2005	EPA Standards 2012
		MCL (mg/L)	
Ni	1.69 (mg/L)	0.05	0.1
Cr	0.2 (mg/L)	0.05	0.1
Cu	1.2 (mg/L)	1	1
CH_3Br	0.03 (ppb)	-	-

By comparing the concentrations of the heavy metals to the Palestinian and EPA drinking water standards, it was found that all the concentrations are above EPA and the Palestinian MCL.

The hydrogeological conditions of the area enhance the wadi-aquifer interaction in the Faria catchment (Abboushi, 2013). Therefore, there is a great potential that these pollutants may reach and pollute the groundwater aquifers in the catchment, if their concentrations did not decrease by the time they reach the aquifers.

Fortunately, studies have demonstrated that metals are generally retained in the upper soil layers via adsorption to solid particles, and they ultimately dilute before reaching the groundwater. However, eventual breakthrough can occur due to the finite sorption capacities of the soil media. The ranking of adsorption potential for some common heavy metals to soil particles is, Pb>Cu>Ni>Zn>Cd, with lead having the highest potential (Weiss et al., 2008).

On the other hand, bromomethane (CH_3Br) which is a volatile organic compound (VOC), and by comparison with other organic compounds, VOCs may be transported for relatively long distances in groundwater, as a result of their relatively weak sorption affinity and their resistance to degradation (Wang et al., 2013).

Thus, the chronic daily intake was calculated for each of the heavy metals and the organic compound for adult male, adult female, and child as described in **Table 5.5**.

Table 5.5: Chronic Daily Intake of the Heavy Metals and Organic Compound

Parameter (mg/L)	Male	Female	Child
	CDI (mg/kg.day)		
Ni	0.065	0.063	0.091
Cr	0.008	0.007	0.011
Cu	0.046	0.044	0.065
CH_3Br	0.001	0.001	0.002

The described heavy metals and the organic compound are considered non-carcinogen. In order to find the potential non-carcinogen toxicity for the heavy metals, HI was found as shown in **Table 5.6**.

Table 5.6: Potential Non-Carcinogen Toxicity of the Heavy Metals and Organic Compound.

Parameter (mg/L)	RfD (mg/kg.day)	Male	Female	Child
		HI		
Ni	0.020	3.220	3.120	4.570
Cr	0.005	1.527	1.480	2.160
Cu	0.040	1.145	1.108	1.620
CH_3Br	0.001	1.145	1.109	1.162
Total HI		7.040	6.820	9.510

The results indicate a very high potential risk of non-carcinogen toxicity for each of the heavy metals and the organic compound, as all the values of HI are above unity. Consequently, there might be a high potential of adverse health effects on the general population of the Faria catchment, if these pollutants have been proven to reach the drinking water resources in the catchment.

5.4 Risk Management Options

The goal of risk management is to reduce or eliminate risks and the negative consequences associated with risks. Risk can be managed using many different strategies and is most effective when it is informed through risk characterization. The identification and evaluation of risk management strategies on the basis of cost and effectiveness are integral parts of the process. However, a number of other factors influence risk management decisions including social, political, economic, and public health considerations (CAMRA, 2013).

In this research, the microbial risk characterization and the comparison of water quality data with the local and international standards, indicates the potential of high fecal contamination risk in the Faira catchment. Some possible sources of fecal contamination include: agricultural runoff from areas contaminated with pet manure, wildlife that uses the water as their natural habitat, untreated wastewater discharge, and using cesspits for wastewater disposal due to lack of sewerage systems in the catchment.

However, and in order to mitigate the risk associated with microbial contamination, some management practices should be considered as follows; installing sanitation systems to provide treatment and proper disposal of wastewater for all villages that use cesspits for wastewater disposal, and an a wastewater treatment plant for the untreated wastewater discharge coming from Nablus city should be considered. This in turn will stop the leakage of untreated wastewater into the groundwater aquifers and accordingly minimize the potential associated risk.

Moreover, the use of chlorine as disinfectant agent is very effective for the deactivation of pathogenic microorganisms. Thus, more attention should be made for monitoring and using the right amounts of chlorine for disinfecting the drinking water at the catchment water resources. Also, regular microbial tests on Faria water resources (domestic and agricultural wells, and springs) should be made, to make sure that they are free from highly risky pollutants.

On the other hand, the results of chemical risk characterization showed that, all the tested chemicals do not pose any adverse health effects individually, but may cause non-carcinogen toxicity due to bioaccumulation of all the chemicals in long-term exposure, with higher potential hazard on children more than adults.

In order to mitigate any potential risk caused by the presence of chemicals and organic compounds in the drinking water; agricultural practices must be controlled by using the proper amount of fertilizers and pesticides needed for each crop. In addition, the use of untreated wastewater for irrigation must be stopped. However, regular monitoring and testing of chemicals in Faria water resources should be continued. Consequently, water treatment plant is recommended to be considered to reduce the concentrations of any pollutants to meet the drinking water standards, in order to mitigate the potential risks in the future.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Based on the chemical and microbial analysis of the drinking water quality of the tested wells and springs in the Faria catchment, it was noticed that there is a deterioration of the drinking water quality due to microbial contamination and bioaccumulation of chemicals in the long-term exposure.

The following are the main research conclusions:

1. The comparison between the obtained water quality data with the Palestinian and EPA water quality standards showed that, most of the chemical parameters are below the Palestinian and EPA MCL;

2. The values of FC and turbidity, where both above the Palestinian and EPA MCL, due to water contamination by the uncontrolled use of fertilizers and the discharge of untreated wastewater;

3. The risk assessment of chemical parameters indicates that, the potential of non-carcinogen toxicity by each parameter individually is negligible;

4. The microbial risk assessment revealed that there is a potential risk of microbial contamination in the Faria water resources, and a chance of at least one person out of one thousand people, to get sick due to the presence of E.coli in the drinking water.

5. The potential future risk associated with the presence of heavy metals and organic compound in the Faria stream, indicates a high risk of non-carcinogen toxicity that may cause adverse health effects, if these pollutants have been proven to reach the drinking water resources in the catchment.

6. Risk management options were considered in order to mitigate the risk associated with microbial and chemical contamination.

6.2 Recommendations

Based on the outcome of this research, the following can be recommended:

1. Villages' councils should seek financial aid from the government or the donors to install sanitation systems for all villages in the catchment which use cesspits for wastewater disposal.
2. Nablus municipality is recommended to construct a wastewater treatment plant in the eastern part of the city, to get rid of the adverse impact of the ongoing discharge of untreated wastewater to the Faria catchment.
3. The villages' councils and the ministry of health should pay more attention and monitor the amount of chlorine used for disinfecting the drinking water at the catchment water resources, since the amount which is used is relatively small.

4. The ministry of health should continue monitoring and testing chemicals and microbes of all daily water resources in the catchment including the agricultural wells. Moreover, due to high concentrations of turbidity and FC, additional water quality tests should be conducted for more chemicals and microbes such as heavy metals, organic compounds, viruses, and other pathogens.
5. Minimize the potential chemical risk caused by the excessive use of fertilizers and pesticides, by organizing training programs and preparing guidelines for the farmers to control the agricultural practices should use for each crop.
6. Enforcement of laws that prohibit farmers from using untreated wastewater for irrigation.
7. More studies should be conducted to describe the transport and fate of heavy metals and organic compounds through Faria stream to the groundwater aquifers.
8. Advising consumers to disinfect the water by using various methods such as boiling the water or using water filters, especially if it is used for drinking or making baby formulas, since there is a higher risk on children to catch waterborne diseases more than adults.

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Annexes

Annex A: Water Quality Data from the Period of December 2010 and July 2012

Annex B: Questions of the Structured Interviews

Annex A: Water Quality Data from the Period of December 2010 and July 2012.

Site ID	Sampling Date	SO_4 (mg/L)	PO_4 (mg/L)	NO_3 (mg/L)	HCO_3 (mg/L)	Cl (mg/L)	Mg (mg/L)	Ca (mg/L)	Na (mg/L)	K (mg/L)	TDS (mg/L)	pH	EC (µs/cm)	Turbidity (NTU)	$CaCO_3$ (mg/L)	FC (cfu/100 ml)
SP1	14/12/2010	16.7	0.03	17.7	330	48.0	4.9	82.0	15.9	8.5	323	9.4	505	14.5	225	240
SP1	27/12/2010	6.3	0.01	18.3	271	48.3	3.6	70.0	15.3	2.3	333	7.5	520	6.4	190	700
SP1	31/1/2011	16.3	0.08	18.5	263	46.7	6.1	80.0	15.5	1.9	339	7.6	530	6.0	225	3000
SP1	28/2/2011	1.5	0.14	17.7	266	52.2	19.0	83.3	15.9	2.3	310	7.7	484	25.0	287	3000
SP1	4/3/2011	5.9	0.03	13.3	237	34.4	13.0	60.0	17.6	1.3	320	7.6	500	12.0	203	30
SP1	25/4/2011	18.1	0.05	18.5	260	52.2	13.4	82.0	17.2	3.0	326	7.8	510	7.0	260	3000
SP1	29/5/2011	3.3	0.05	16.4	251	47.8	13.4	73.3	17.0	2.6	282	7.9	440	6.0	282	7600
SP1	28/6/2011	3.6	0.03	20.2	247	44.4	14.6	80.0	17.0	2.5	358	8.1	560	2.5	260	7
SP1	31/7/2011	9.8	0.31	14.6	262	44.4	18.6	72.0	15.1	5.5	358	8.0	560	25.0	257	4
SP1	22/8/2011	5.9	0.03	12.0	267	47.2	18.2	72.7	16.2	5.2	307	7.7	480	1.8	257	7000
SP1	25/9/2011	7.4	0.05	18.0	255	45.5	10.1	85.3	16.3	5.2	314	8.0	490	1.6	255	500
SP1	30/10/2011	0.3	0.05	13.9	239	44.4	18.2	82.0	16.0	2.1	365	8.1	570	3.3	280	300
SP1	30/11/2011	5.6	0.03	14.8	270	45.5	8.1	86.0	19.6	1.7	384	7.9	600	4.3	248	350
SP1	27/12/2011	5.6	0.03	14.8	270	45.5	31.2	61.3	19.1	2.1	365	7.8	570	0.9	282	400
SP1	30/1/2012	9.3	0.03	18.5	256	39.4	19.0	86.0	18.1	3.7	310	8.0	485	0.8	293	500
SP1	28/2/2012	8.6	0.02	18.0	256	55.0	16.2	77.3	18.2	4.4	256	7.4	400	1.8	260	800

SP1	28/3/2012	4.4	0.00	18.5	233	50.0	18.6	86.0	16.4	3.2	269	8.0	420	3.0	292	700
SP1	29/4/2012	2.4	0.00	21.3	225	50.8	19.4	83.3	17.5	1.4	314	7.8	490	1.5	288	2000
SP1	29/5/2012	4.7	0.02	14.6	225	41.1	24.7	75.3	16.3	2.2	336	8.4	525	2.1	248	2400
SP2	27/12/2010	10.1	0.08	22.9	393	142.2	25.5	90.0	21.1	6.3	649	7.7	1013	1.9	330	1600
SP2	31/1/2011	1.2	0.01	24.7	308	105.5	20.7	80.0	18.9	11.3	493	7.1	770	0.2	285	1000
SP2	28/2/2011	1.5	0.01	23.6	281	106.6	19.0	83.3	19.7	2.4	310	7.7	484	25.0	287	250
SP2	4/3/2011	9.8	0.06	17.7	319	111.1	13.0	60.0	19.0	2.8	320	7.6	500	12.0	203	120
SP2	25/4/2011	1.8	0.01	28.4	304	109.4	13.4	82.0	19.8	3.2	326	7.8	510	7.0	260	60
SP2	29/5/2011	0.6	0.01	19.2	308	110.5	13.4	73.3	19.6	2.9	282	7.9	440	6.0	282	40
SP2	28/6/2011	18.8	0.00	20.4	301	106.1	34.8	72.7	19.6	3.0	550	7.8	860	0.5	325	40
SP2	31/7/2011	7.2	0.01	19.6	298	108.9	18.6	110.7	19.1	5.7	512	7.2	800	1.0	353	150
SP2	22/8/2011	3.8	0.01	17.4	287	110.5	36.9	85.3	19.1	5.7	477	7.6	745	1.0	365	290
SP2	25/9/2011	1.0	0.02	16.5	294	106.6	35.6	82.0	19.2	5.8	477	7.2	745	0.2	352	270
SP2	30/10/2011	7.3	0.09	23.9	286	103.9	39.7	77.3	19.2	3.1	557	7.0	870	0.3	357	20
SP2	30/11/2011	24.7	0.00	19.4	302	112.2	42.5	82.7	16.9	2.0	506	7.2	790	0.3	382	300
SP2	27/12/2011	6.3	0.02	18.8	293	109.4	32.8	86.0	19.9	2.6	550	6.9	860	0.1	350	12
SP2	30/1/2012	8.2	0.01	19.9	302	103.9	36.1	90.7	20.2	3.9	310	7.0	715	0.3	375	35
SP2	28/2/2012	36.3	0.01	18.6	317	135.0	43.3	81.3	20.7	3.9	467	7.1	730	0.8	382	40
SP2	28/3/2012	12.3	0.00	16.7	298	116.6	40.0	97.3	19.9	3.7	448	7.0	700	0.4	407	12

SP2	29/4/2012	1.1	0.00	20.5	296	115.0	13.0	78.7	16.5	2.6	243	7.7	380	5.0	250	50
SP2	29/5/2012	3.7	0.01	19.5	290	107.2	24.7	90.0	19.2	2.9	525	7.2	820	0.2	327	35
W1	13/2/2011	3.3	0.00	20.5	302	110.5	7.3	82.0	18.9	2.1	526	7.3	822	0.4	235	20
W1	20/3/2011	7.9	0.00	25.1	316	117.7	29.6	100.7	19.6	2.1	512	7.1	800	0.3	373	40
W1	25/4/2011	3.8	0.01	22.9	323	122.7	39.7	86.7	19.1	2.7	518	7.4	810	1.1	380	8,000
W1	29/5/2011	0.9	0.01	25.4	324	126.1	32.8	90.7	20.0	2.5	461	7.3	720	0.6	362	200
W1	28/6/2011	7.3	0.00	25.8	296	117.7	31.2	100.7	19.6	2.6	621	7.7	970	1.6	380	2
W1	31/7/2011	5.8	0.01	23.0	306	125.5	38.1	78.0	19.0	5.2	544	7.4	850	6.6	352	55
W1	22/8/2011	4.8	0.02	12.7	296	126.1	38.5	86.0	19.3	5.2	525	7.7	820	0.2	373	270
W1	25/9/2011	3.3	0.01	20.7	298	117.7	35.2	101.3	19.0	5.0	490	7.3	765	0.6	398	70
W1	30/10/2011	4.0	0.06	25.3	296	120.0	40.9	90.7	19.1	2.5	582	6.9	910	0.7	395	10
W1	30/11/2011	1.9	0.14	11.5	267	44.4	42.1	83.3	19.2	1.5	666	7.3	1,040	2.8	382	400
W1	30/1/2012	2.1	0.05	20.0	302	104.4	28.8	102.0	20.1	2.7	461	7.1	720	5.9	373	0
W1	28/2/2012	22.3	0.05	20.7	317	125.0	38.5	91.3	20.4	3.0	474	7.2	740	3.0	387	12
W1	28/3/2012	5.3	0.00	25.1	294	125.0	31.2	102.0	20.1	3.4	448	6.9	700	1.2	383	12
W1	29/4/2012	6.3	0.00	20.7	290	125.0	24.3	102.0	19.2	1.4	435	7.7	680	0.5	355	31
W1	29/5/2012	6.7	0.02	19.3	300	125.5	20.7	112.7	19.2	1.9	570	7.1	890	0.2	367	500
W2	20/3/2011	0.0	0.00	22.0	316	92.8	30.8	94.0	18.9	2.1	467	7.1	730	0.2	362	10

W2	25/4/2011	3.8	0.03	22.7	316	89.4	26.7	84.7	20.1	2.7	454	7.4	710	0.1	322	20
W2	29/5/2011	2.0	0.01	21.9	328	91.1	38.1	78.0	19.4	2.6	397	7.3	621	0.1	352	140
W2	28/6/2011	7.6	0.00	18.2	306	83.3	23.9	87.3	19.5	2.6	538	7.8	840	0.1	317	110
W2	31/7/2011	4.3	0.05	21.6	319	102.8	36.1	88.0	19.3	5.8	554	7.3	865	0.6	368	200
W2	22/8/2011	3.9	0.00	29.4	325	114.4	41.3	84.7	19.5	5.4	519	7.7	811	3.6	382	1,000
W2	25/9/2011	9.1	0.03	18.3	317	87.2	39.3	79.3	18.9	4.8	429	7.4	670	0.6	360	680
W2	30/10/2011	0.0	0.06	21.6	323	83.3	43.3	68.7	19.0	1.9	512	7.0	800	0.6	350	10
W2	30/11/2011	6.3	0.04	18.8	310	90.5	36.5	83.3	18.5	2.1	634	7.2	990	0.5	358	200
W2	27/12/2011	6.3	0.04	18.8	310	90.5	30.8	88.0	16.8	2.0	525	7.5	820	1.4	347	220
W2	30/1/2012	6.3	0.02	17.7	314	83.9	36.1	82.7	20.1	3.2	422	7.1	660	4.8	355	0
W2	28/2/2012	8.0	0.00	16.7	329	115.0	19.0	86.0	20.7	3.3	467	7.2	730	0.8	367	60
W2	28/3/2012	25.6	0.00	23.2	304	105.8	38.1	98.7	19.7	3.3	442	7.0	690	0.1	403	7
W2	29/4/2012	2.2	0.00	22.5	298	103.3	29.2	86.0	19.0	1.9	410	7.9	640	2.1	335	6
W2	29/5/2012	9.3	0.01	23.0	302	91.1	28.0	88.0	18.7	2.2	518	7.7	810	0.3	335	16

Annex B: Questions of the Structured Interviews.

Municipalities:

1. What are the sources of water supply?

a) Rainwater (cisterns)

b) Groundwater (springs)

c) Groundwater (1. Domestic wells 2. Agricultural wells)

d) Surface water (stream)

2. Have you ever tested the water quality of your source?

a) Yes b) No

If you did, what kind of tests have you made? _____and how frequent?

3. Have these tests showed any kind of water problems?

a) Yes b) No

If yes, explain these problems? ______

4. Have you done anything to solve these problems?

a) Yes b) No

If yes, what have you done? ______

5. Do you know any sources of either ground or surface water contamination in the area?

a) Yes b) No

If you do, what kind of contamination are they? _____and have you done anything to prevent it? _____

6. Do you have wastewater network in your area?

a) Yes b) No

If not, how do people dispose their wastewater?

a) Cesspits.

b) Septic tanks.

7. Is there any water contamination caused by wastewater in the area?

a) Yes b) No

If yes, have you done anything to prevent this contamination? ______

8. Are there any problems in the water network pipes, such as?

a) Leakage

b) Corrosion

c) Illegal connections.

d) Old age pipes

What have you done to solve these problems? _____

9. What is the percentage of chlorine you add to water? ______

Swimming Pools Owners:

10. Since when have you owned these swimming pools? _______

11. What is the source of your pools water?

a) Rainwater (cisterns)

b) Groundwater (springs)

c) Groundwater (1. Domestic wells 2. Agricultural wells)

d) Surface water (stream)

12. How frequently do the people of this area swim? ______

13. For how many hours do they frequently stay? ______

14. What is the percentage of chlorine you add to the swimming water?

15. Do you make regular checks for the chlorine percentage in water?

a) Yes b) No

If yes, how frequent do you make these checks? ______

Health Centers:

16. In the past few years how many medical cases of waterborne diseases have been recorded? ______

17. Is there any waterborne disease in particular has high rate records?

a) Yes b) No

If yes, what is it? _____

18. What are the chemicals and microbes in water that caused such diseases?

______

19.How many Amoeba disease cases do you record a year? ______

20. Is the percentage of Amoeba disease:

a) Increase b) Decrease

And at what percentage? ______

21.How many times a week do people usually take a shower? _____

Farmers:

22.Do you own an agricultural land or a garden?

A. Yes B. No

23. How many times a day do you irrigate it? ______

24.What is your water source for irrigation?

a) Rainwater (cisterns)

b) Groundwater (springs)

c) Groundwater (1. Domestic wells 2. Agricultural wells)

d) Surface water (stream)

25. Have you ever tested the water quality of your source?

a) Yes b) No

If you did, what kind of tests have you made? _______

26.Have these tests showed any kind of water problems?

a) Yes b) No

If yes, explain these problems? ______

27.Have you done anything to solve these problems?

a) Yes b) No

If yes, what have you done? ____

جامعة النجاح الوطنية

كلية الدراسات العليا

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إعداد

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إشراف

د . سمير شديد

د . عبد الفتاح حسن

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة المياه والبيئة في كلية الدراسات العليا في جامعة النجاح الوطنية في نابلس– فلسطين.

2014

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د . عبد الفتاح حسن

الملخص

تقييم المخاطر هي عملية تهدف إلى تقدير الخطر على هدف معين ، بعد التعرض لعامل معين. وتبدأ هذه عملية بتحديد المشكلة، وتتضمن أربع خطوات إضافية : 1) تحديد المخاطر، 2) تقييم السمية، 3) تقييم التعرض 4) توصيف المخاطر. وتهدف هذه الأطروحة لتصف المخاطر الميكروبيولوجية و الكيميائية على عامة سكان حوض الفارعة، ووضع دراسة لإدارة المخاطر من اجل تخفيف الخطر الناتج من المكونات الميكروبيولوجية و الكيميائية في الحوض. يعتبر حوض الفارعة واحدا من أهم الاحواض في الضفة الغربية، ولكن هنالك محدودية في مصادر المياه التي إما أن تكون عبارة عن، مياه جوفية والتي عادة ما تستخدم من خلال الينابيع والآبار، أو مياه سطحية (المياه الجارية). ان تدفق مياه الصرف الصحي غير المعالجة والاستخدام غير المتوازن للأسمدة والمبيدات الحشرية، ساعد في تلوث مصادر المياه المحدودة في الحوض لكلا المياه الجوفية و المياه السطحية. وهذا قد يسبب آثارا خطيرة ضارة بالصحة على عامة السكان، وانتشار الأمراض التي تنقلها المياه مثل الإسهال والكوليرا و الدوسنتاريا والتيفود.

تم الحصول على بيانات مياه الشرب لمواد كيميائية وميكروبات، وبعض خصائص المياه الفيزيائية, لآبار و ينابيع مختارة في حوض الفارعة من خلال معهد المياه والبيئة بالتعاون مع مشروع UWIRA الذي يتناول أثر المياه العادمة غير المعالجة على المسطحات المائية الطبيعية. والمشروع هو عبارة عن مشروع بحثي متعدد الأطراف يعمل في حوض الفارعة ويتضمن

جامعة النجاح الوطنية وجامعة بيرزيت وسلطة المياه الفلسطينية بالتنسيق مع مؤسسة الينسكو. وقد تم تحليل نتائج نوعية المياه ومقارنتها مع معايير مياه الشرب المحلية والدولية. حيث أظهرت النتائج أن جميع التركيزات الكيميائية هي أقل من الحد المسموح به في المعايير الفلسطينية و وكالة حماية البيئة، في حين أن العكارة وبكتيريا القولون البرازية كلاهما اعلى من الحد المسموح به.

كما تم عمل مقابلات تضمن اسئلة مفتوحة في أحد عشر قريه تقع داخل حوض الفارعة، من أجل تحديد مصادر التعرض و مآخذ المواد الكيميائية ، والتي ساعدت في تحديد المعايير اللازمة في معادلات الخطر المستخدمة.

من أجل تقدير المخاطر الميكروبية والكيميائية في مياه الشرب في حوض الفارعة، تم استخدام الخطوات الأساسية لتقييم المخاطر، بما في ذلك تقييم السمية، تقييم التعرض، وتوصيف المخاطر. أدى تقييم السمية الى اختيار المواد الكيميائية الأكثر شيوعا و الميكروبات التي يتم اختبارها في مصادر مياه الشرب والتي هي، الأيونات الرئيسية (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}, HCO_3^{-}, PO_4^{3-}, and NO_3^{-}) ، العسره الكلي، والعدد الكلي لبكتريا القولون البرازية . تم وصف وتقييم التعرض للمواد الكيميائية باستخدام معادلات التحصيل اليومي المزمن لمسارات مختلفة من التعرض. واستخدمت جميع البيانات التي تم جمعها من التعرض و عمليات تقييم السمية في خطوة توصيف المخاطر. باستخدام المحلل QMRA Wiki تم توصيف المخاطر الميكروبية، حيث أظهرت النتائج ان احتمال الخطر الناتج من جرعات ال E.coli يدل على أن هنالك شخص واحد على الأقل من ألف شخص، سوف يتعرض لمرض ناتج من وجود E.coli في مياه الشرب في الحوض. اما لتوصيف مخاطر المواد الكيميائية، فقد تم استخدام مؤشر الخطر للعثور على السمية المحتملة في الذكور البالغين، والإناث البالغين، والأطفال. وأظهرت النتائج أنه لا يوجد أي احتمال سمية غير مسرطنة من قبل كل عنصر كيماوي بشكل فردي، ولكن تراكم الكيماويات على المدى الطويل قد يؤدي الى اضرار صحية.

كما تم تقدير المخاطر المحتملة المستقبلية لبعض المعادن الثقيلة والمركبات العضوية الموجودة في مجرى مياه حوض الفارعة باستخدام معادلات المخاطر الكيميائية. وقد أشارت النتائج إلى أن هناك إمكانات كبيرة من سمية غير مسرطنة إذا ثبت وصول هذه الملوثات إلى موارد مياه الشرب في حوض الفارعة.

تم تحديد مجموعة من ممارسات إدارة المخاطر مثل تركيب أنظمة صرف صحي والمراقبة المستمرة للمواد الكيميائية والميكروبات في الموارد المائية لحوض الفارعة من أجل التخفيف من أي مخاطر محتملة ناجمة عن وجود المواد الكيميائية والميكروبات في مياه الشرب، وذلك من اجل تحسين نوعية المياه في حوض الفارعة.