AMERICAN UNIVERSITY OF BEIRUT

# TESTING A WATER MONITORING TOOL TO ENHANCE POTABLE WATER QUALITY AND SAFETY IN LEBANON


by
L'EMIRA SARAH L'EMIR NABIL CHEHAB


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Approved by:

Dr. Mey Jurdi, Professor — Advisor
ENVD & Coordinator of the Associate Research Unit on Potable Water Quality and Management (ARU PWQM)

Dr. Sami Ramia, Professor — Member of Committee
MLSP& PI, ARU PWQM)

Dr. Nabil Amacha, Associate Professor — Member of Committee
FAS, Lebanese University & PI, ARU PWQM

Dr. Joumana Nasr, Lecturer — Member of Committee
Co- PI ARU PWQM

Date of thesis/dissertation defense: December 15, 2016

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AN ABSTRACT OF THE THESIS OF

<u>L'Emira Sarah L'Emir Nabil Chehab</u> for <u>Master of Science in Environmental Sciences</u>

<u>Major</u>: Environmental Health

Title: Testing a Water Monitoring Tool to Enhance Potable Water Quality and Safety in Lebanon

This thesis develops and tests a valid Potable Water Quality Index (PWQI) to monitor the desirability, acceptability, and safety of distribution water supplies. It also assesses the quality of potable water distribution networks of Mount Lebanon, based on the developed PWQI, identifies problematic areas and recommends interventions.

The study methodology consisted of collecting 20-25 random water samples from the each of the six Qadaas in Mount Lebanon (Aley, El Chouf, Baabda, Jbeil, Kisirwan, and Al Matn). Samples were collected during 4 rounds reflecting on the wet and dry season .The physical, chemical and microbiological quality was determined in the laboratory, based on standard analytical methods and in line with LIBNOR standards. The statistical analytical scheme consisted of: (1) Calculation of the proposed PWQI based on the equation developed by the Canadian Council of Ministers of the Environment (CCME) in accordance with LIBNOR water quality standards; (2) Validation and factor analysis was conducted (3) Contribution of quality parameters; (4) Parameter sensitivity analysis; by simple Regression by using backwards method.

Results showed that the PWQI is more reflective of the water quality than the AWQI which only reflects on the acceptability of the water due to the unaccounted for microbiological profile, while the HWQI reflects only the health concern and does not reflect on water acceptability which is a major factor in determining water use by consumers. The UNEP WQI and the PWQI yield overall similar results in terms of water quality classification; still, the ranges seem to be more defined by the PWQI possibly as it includes parameters (TDS, total hardness, and free residual chlorine) that reflect more on the types of water sources, sources of pollution and the management of water supplies.

The regression analysis showed that for HWQI, UNEP WQI and PWQI, [F3], the amplitude (the extent to which the failed test exceeds the guideline, showing by how much each parameter exceeded the guideline, was the most driving factor; while the AWQI was driven by [F2] the frequency (the percentage of individual tests within each parameter that exceeded the guideline, showing how many times each parameter exceeded the guidelines).

Parameter contributions and correlation analysis showed that the quality parameters faecal coliforms, cadmium and lead, are the major contributors to the HWQI (88%, 7%, 5%, respectively); color and chlorides were the major contributors to the AWQI (73%); faecal coliforms, cadmium and lead, are the major contributors to the UNEP WQI (86%

11%, 1%, respectively); and manganese (22%), lead (22%), total hardness (13%), free residual chlorine (12%), and faecal coliform (10%) were the major contributors to the proposed PWQI.

Additionally, comparison between all exceeding contributing water quality parameters showed that in the HWQI the largest contributor is faecal coliform, the AWQI the largest contributor was iron. For the UNEP WQI the largest contributors is faecal coliform. Similarly for the PWQI the most contributing and the most significant parameter was the faecal coliform in addition to manganese, at acceptability levels, lead, free residual chlorine and total hardness.

Assessing the quality of the piped water supplies in Mount Lebanon, the main concerns were as follows: high mineral content of coastal ground water sources, and high chloride levels, deterioration of distribution networks evident from the high levels of manganese, lead and cadmium, faecal contamination, and inconsistent free residual chlorine concentrations. Recommendations were suggested accordingly.

In conclusion, the thesis recommends the use of the PWQI in all 4 Regional Water Establishments to determine quality and safety based LIBNOR standards, thus identify hot spots and set interventions. In addition, the PWQI should be coupled with water safety plans and screening quality of water sources feeding networks, minimally twice per year (peak of dry & wet seasons). The water quality parameters included in the calculation PWQI should be revised based on country specific needs.

# CONTENTS

# ILLUSTRATIONS

# TABLES

# ABBREVIATIONS

| | |
|---|---|
| ARU PWQM | Associate Research Unit on Potable Water Quality and Management |
| AUB | American University of Beirut |
| AWQI | Acceptability Water Quality |
| BMLWE | Beirut and Mount Lebanon Water Establishment |
| CCME | Canadian Council of Ministers of the Environment |
| CNRS | Lebanese National Council for Scientific Research |
| DWQI | Drinking Water Quality Index |
| ESCWA | United Nations Economic and Social Commission for Western Asia |
| GEMS/Water | Global Environment Monitoring System Water |
| HWQI | Health Water Quality Index |
| IWRM | Integrated Water Resource Management |
| JMP | Joint Monitoring Program for Water Supply and Sanitation |
| JPoI | Johannesburg Plan of Implementation |
| LAU | Lebanese American University |
| LU | Lebanese University |
| MDG | Millennium Development |
| MoEW | Ministry of Energy and Water |
| MoPH | Ministry of Public Health |
| NPS | Non-point sources |
| NSF | National Sanitation Foundation |
| PVC | Polyvinyl chloride |
| PWQI | Potable water Quality Index |
| RWEs | Regional Water Establishments |
| SDG | Sustainable Development Goals |
| TDS | Total Dissolved Solids |
| UNEP | United Nations Environment Programme |
| UNICEF | United Nations Children's Fund |
| WASH | Water Sanitation and Hygiene |
| WHO | World Health Organization |
| WQI | Water Quality Index |
| WRA | Water Resources Assessment |
| WSSD | World Summit on Sustainable Development |
| WWAP | United Nations World Water Assessment Program |

For my parents and grandparents

# CHAPTER 1

# INTRODUCTION

## 1.1 Overview of the Chapter

This section of the thesis presents the significance, the objectives and the research questions examined in this study.

## 1.2 Significance and Objectives of the Study

Water Resource monitoring is critical and has been emphasized by international efforts leading to the development of the Global Water Quality Monitoring Network (GEMS/Water) in 1978 (UNEP/WHO, 1996). Its role was especially significant in determining that the Millennium Development Goal (MDG) target 7.c was met, and that the post 2015 Sustainable Development Goal (SDG) target 6.1 of universal sustainable access to safe drinking water, will be met (WHO/UNICEF, 2015; UN, 2016 b). Further, it is a tool that allows stakeholders to confirm that the invested costs were used effectively and that water safety plans are in place (FAO, 2006; UNEP, 2016; WHO, 2005).

In Lebanon, as it is the case in other developing countries, sustaining safe water supply is mainly challenged by deficient water quality monitoring, water treatment and water management from source to distribution network to end-users taps. As a result the quality of water being supplied through the distribution networks is not properly determined. Therefore, no interventions are planned to upgrade quality (e.g. proper watershed management, planning and operating water treatment plants and managing distribution networks). The deficiency in water quality monitoring programs is mainly due to limited technical and financial resource. Hence, programs are undeveloped, and major efforts are needed to upgrade and sustain them (Jurdi et al., 2011).

Per se, the use of simple and valid water monitoring tools, such as the Water Quality Index (WQI), will enhance monitoring with relatively minimal resources. Such a tool is needed to evaluate quality and accordingly recommend proper quality management strategies. Additionally, it will help communicate potential risks to policy makers and end-users in a simple classified manner (poor, marginal, fair, good, excellent) avoiding scientific specifications and terminologies (UNEP, 2012).

Various drinking water quality monitoring indices have been reported in literature (Jasmine et al., 2014; Mohebbi et al., 2013; UNEP, 2012). Some of them such as the Drinking Water Quality Index (DWQI) require monitoring of all WHO guideline parameters (physical, chemical, microbiological and radiological) (WHO, 2011). This would entail lots of technical and monitory resources that are beyond the capacities of delivering units such as the Water Establishments in Lebanon.

Other indices focus only on quality parameters that have direct health impacts such as the Health Water Quality Index (HWQI). This index depends on monitoring arsenic, boron, chromium, copper, fluoride, lead, manganese, mercury, nitrate, nitrite and faecal coliform bacteria. Still, it is not sensitive to quality parameters that impact acceptability by end-users. This is critical issue to insure that the distributed water supply is accepted, and that alternative complementary sources of undefined quality and safety are not used (UNEP, 2012).

Moreover, the Acceptability Water Quality Index (AWQI), reflect only on the general acceptability parameters of ammonia, chloride, iron, pH, sodium, sulfate and zinc (UNEP, 2012; WHO, 2011). Such an index does not insure the safety of the distributed water supply and is highly limited in significance.

Currently various countries in Africa (e.g. Morocco, and South Africa), Asia (e.g. Japan, Republic of Korea), Europe (e.g. Belgium, Poland), and South American (e.g. Argentina) use both the HWQI, and the AWQI. Other countries such as the Unites States, Canada, Oceania, Cambodia, Iran and India use the extensive DWQI India (Jasmine et al., 2014; Mohebbi et al., 2013; UNEP, 2012). Still, additional studies are needed to prioritize quality parameters that should be included to sustain the monitoring of water quality and safety.

As such, this study will attempt to develop a simple, comprehensive, and valid Potable Water Quality Index (PWQI) that will reflect on water desirability, acceptability and safety in accordance with LIBNOR standards. Moreover, such index should be sensitive to the type of water (surface and ground), major sources of pollution (sewage, solid waste leachate, seawater infiltration, excessive use of fertilizers and pesticides, and industrial waste) and conditions of distribution networks.

## 1.3 Objectives

- Develop and test a valid Potable Water Quality Index (PWQI) to monitor the desirability, acceptability, and safety of distribution water supplies.
- Assess the quality of potable water distribution networks of Mount Lebanon, based on the developed index, to identify problematic areas and recommend interventions.

## 1.4 Research question

Is the proposed Potable Water Quality Index (PWQI) valid and sensitive in monitoring water quality and safety?

# CHAPTER 2

# BACKGROUND INFORMATION

## 2.1 Overview of the Chapter

This chapter focuses on water quality monitoring and its importance. It further presents water resource monitoring programs and their importance in implementing global water and sanitation initiatives. Then, the challenges to safe water supplies in developing countries would be tackled, and the importance of using simple water a monitoring tools to assess quality and safety and upgrade quality of services, will be presented.

## 2.2 Water Quality Monitoring: Significance and Importance

Water is a finite resource essential to sustain human life and development activities. This resource is being progressively degraded by human activities. Some of the major causes of the determined water quality are toxic discharge from industries, over pumping of aquifers, and contamination of water bodies with various physical, chemical and microbiological sources of pollution. As such, to ensure safe water supply for the various types of utilization (domestic, agricultural, industrial and recreational), the quality of water supplies should be continuously monitored for proper evaluation and the implementation of proper environmental interventions (WMO/ GMES/Water, 2012).

Water quality monitoring presents an understanding of the conditions of different types of fresh water bodies, and shows how they vary regionally and nationally. Monitoring also allows the changes in water that occur over time to be observed and documented. It reveals whether the fluctuations in water quality are due to natural changes or anthropogenic factors, and how such factors alter the water quality (WMO, 2013).

Monitoring consists of several steps leading to the assessment of the water quality. It begins with sampling followed by analytical testing, and finally recording the water characteristics. Hence, water quality monitoring is not just a short-term activity and should be instituted on continuous basis. As such, monitoring the physical, chemical, and biological characteristics indicates the water quality and safety of the water supply and directs the needed environmental management strategies (WMO/ GMES/Water, 2012).

### *2.2.1 Elements of a Water Quality Monitoring Program*

To ensure the implementation of a successful monitoring system, the following elements should be addressed: (1) the process for water quality monitoring starts off by setting the objectives. Then, (2) surveys and field monitoring operations are conducted to identify sampling locations; sampling locations should be determined in order to identify and evaluate natural and anthropogenic risk factors. Next, (3) the physical, chemical, and microbiological and radiological (where applicable) parameters to be monitored are selected in line with exposure to the various types of environmental hazards. Additionally, (4) the number of samples and sampling frequency should be determined based on international standards and guidelines, such as the WHO Guidelines for Drinking Water (WMO/ GMES/Water, 2012; WMO, 2013).

Moreover, (5) a quality assurance strategy should be developed to ensure the reliability of the analytical work. And, (6) samples are then analyzed based on the predetermined parameters and collected data is analyzed and findings reported (WMO, 2013).

### *2.2.2 Objectives of Water Quality Monitoring*

#### 2.2.2.1 Monitoring for Management

Monitoring water quality for proper water management is a main objective .The program should be able to meet short-term objectives, while still managing to achieve long-term objectives of sustaining water supplies. In addition, monitoring assists in generating data to determine and monitor water quality indices which helps assess water quality and safety. Such indices assess the quality of water on an annual basis, and thus yield reliable data for proper management and informed decision-making. The yielded data will also be of value for planning and setting policies and strategies for the integrated management of water resources (WMO/ GMES/ Water, 2012; WMO, 2013).

#### 2.2.2.2 Monitoring for Assessment

Water quality monitoring and assessment screen and evaluate current water quality and quantity and its fluctuation over a period of time. It assesses water quality parameters and determines the sources of pollutants, whether natural or induced by human activities.

As such, the sources and extent of pollution can also be pinpointed for proper risk assessment. Accordingly, proper risk management to control exposure to pollution and ensure proper water shed management can be determined. Management strategies as such should be based on proper water quality assessment, and the effectiveness of such strategies can later be assessed with continuous monitoring (WMO, 2013).

### *2.2.3 Global Water Resource Monitoring Programs*

#### 2.2.3.1 Joint Monitoring Program for Water supply and Sanitation

Water resource monitoring programs were established, globally, to ensure the safety and sustainability of water supplies. The Joint Monitoring Program for Water Supply and Sanitation (JMP) was established by the WHO/UNICEF in 1990. It monitored and tracked changes and improvements towards meeting the Millennium Development (MDGs) targets for over 25 years. Additionally, it collected data that pointed out the gap in inequalities between different regions of the world based on gender, and social status and quality of provided water and sanitation services. As such, the JMP monitored coverage on national, regional, and global levels, and established a vigorous database with analysis indicators even beyond the ones set by MDGs. Accordingly, the JMPs identified challenges that should be dealt with to help strengthen water governance and policy-making by countries. It also identified the Sustainable Development Goals (SDGs) that should be attained post-2015 Millennium Development Goals (UNICEF/WHO, 2015).

2.2.3.2 Global Water Quality Monitoring Network (GEMS/Water)

In addition to the JMP, the Global Environment Monitoring System (GEMS) Water Program was established way before in 1974 by the established by the United Nations (Gems/Water Programme, 2015; UNEP GEMS/Water Programme, 2016). It provides reliable and accessible water quality data and information. The data on water quality collected by GEMS/Water includes more than 4,100 stations, around 4.9 million records, and more than 100 parameters. In 2011, UNEP encouraged governments and organizations to provide data on water quality to be able to deliver financial support, capacity building, and technology needed for developing countries.  As such, GEMStat is the database that accumulates all the data from the water quality monitoring (surface and ground water) all over the world. It was restructured in 2014 to become more effective in monitoring and sharing global data by all stakeholders (UNEP, 2014).  And, this data is available for easy access (UNEP, 2016).

### *2.2.4 Significance of Water Quality Monitoring in Implementing Global Initiatives*

2.2.4.1 Water Sanitation and Hygiene (WASH)

International efforts directed towards instating water quality monitoring have also been instrumental in supporting Water Sanitation and Hygiene (WASH) services.  Led by UNICEF, the program has been working on improving water and sanitation services and basic hygiene, globally, over the past 15 years. By 2015, almost 14 million people were provided with clean water and over 11 million people with basic sanitation (toilets) (UNICEF, 2016).  The WASH framework aims at limiting the exposure of communities to pathogenic microorganisms that are caused by improper sanitation and hygiene related to waterborne, water-based, and water-related diseases (Montgomery et al, 2007).

A study by the Pacific Institute in 2002, projected that if no action is taken globally to address problems of water scarcity, deficient sanitation, and poor hygiene, then by 2020 a total of 135 million preventable deaths would take place. However, even if the millennium development goals water and sanitation targets were met between 34 and 76 million people will still succumb to water related diseases by 2020 (Gleick, 2002, Montgomery et al, 2007).

Currently, major challenge to WASH programs is the lack of sustainability as 30 - 50% of projects fail 2-5 years after implementation mainly due to poor governance (UNICEF, 2016).

#### 2.2.4.2 Integrated Water Resource Management (IWRM)

Water quality monitoring is also critical for proper water resources assessment which is an essential component of Integrated Water Resources Management (IWRM). As defined by the United Nations World Water Assessment Program (WWAP), DHI Water Policy and the UNEP-DHI Centre for Water and Environment, "IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems" (WWAP, DHI Water Policy, UNEP- DHI, 2009). And, as part of the Johannesburg Plan of Implementation

(JPoI) set at the World Summit on Sustainable Development (WSSD) in Johannesburg (2002), the target was to have all countries establish IWRM and water efficiency plans by 2005 while supporting developing countries throughout this process (UN, 2002).

2.2.4.3 Millennium Development Goal (MDG)

Water Quality monitoring efforts have also been crucial in tracking the progress towards achieving the water and sanitation millennium development targets (Water for Life Decade 2005-2015). Ensuring the provision of sustainable safe drinking water supplies remains a major challenge mostly for developing countries. The Millennium Development Goal (MDG) number 7, target 7.C aimed at decreasing by half the proportion of people without sustainable access to safe drinking water by 2015 (WHO, 2012). The target was later modified to improved water supply due to deficiency in water quality monitoring programs that would reflect on the safety of the water supplies. According to UNDP, the global population using improved drinking water sources has increased from 76% in 1990, to 91% in 2015 (UNICEF, 2016; UNDP, 2016). And, according to the WHO (World Health Organization) and the United Nations Children's Fund (UNICEF) Joint Monitoring Program for Water Supply and Sanitation (JMP), even though the world has met the aforementioned target, 5 years ahead of schedule, still 663 million people used unimproved drinking water sources in 2015, and 1.8 billion people still drink faecally contaminated water (UN, 2016 a; UNICEF, 2016; WHO/UNICEF, 2015, WHO, 2015).

So although the target was met, still, improved water sources should not be automatically categorized as safe drinking water and proper water quality monitoring should be instated to reflect on deficiencies and needed interventions (Bain et al., 2012). As such, installing improved water sources is a step forward; still, water quality monitoring to insure safety and sustainability of water supplies is a must (Bain et al., 2012).

#### 2.2.4.4 Sustainable Development Goals (SDG)

Currently, the importance of water quality monitoring is further emphasized as international efforts focused towards meeting the post 2015 Sustainable Development Goal 6 target 6.1, (UN, 2016).The 15-year plan aims at achieving universal access to safe drinking water by the year 2030. This goal ensures a clear intent on improving water management that would aid in protecting the ecosystems, as well as will guarantee its resiliency (UN, 2016).

## 2.3 Challenges to Safe Water Supply in Developing Countries

Globally, the major challenges to sustainable safe domestic water supplies in developing counties mostly relate to water scarcity and deficient sanitation (Montgomery et al, 2007; Vairavamoorthy, K et. al, 2011). Even though there has been noticeable improvement in the use of improved drinking water around the world, developing areas like sub-Saharan Africa and Oceania still face major problems (UN, 2015). According to UNICEF close to half the population of Sub Saharan Africa still remain without access to improved drinking water. Coverage and quality monitoring are still low, and countries are still struggling to meet the basic water and sanitation needs (Montgomery et al, 2007, UNICEF, 2015).

As such, challenges to safe adequate water supplies are still evident mostly in developing countries. For example, in a country like India, although 85% of the urban population in India have access to drinking water, still, 20% of water supplies comply with WHO guidelines (Vairavamoorthy, K et. al, 2011). And, additional examples of countries where around half the population does not have access to improved water are “Equatorial Guinea (48%), Chad (51%) and the democratic republic of the Congo (52 %)” (UNICEF, 2015).

Hence, diarrhea, a water-related disease is one of the primary causes of morbidity and mortality among children under the age of 5. Globally, diarrhea contributes to about 361, 000 deaths in children under 5 years (FAO, 2008b; WHO, 2014a). And, in Sub-Saharan Africa, alone, around 180,000 children under the age of 5 die every year (approximately 500 a day). As such, diarrheal diseases linked to inadequate safe water supplies and deficient sanitation are still taking a large toll in developing counties (UNICEF, 2015). This further emphasis the need for proper risk assessment by conducting routine water quality monitoring. Accordingly, proper informed management strategies can be developed and properly monitored.

## 2.4 Challenges to Safe Potable Water Supply in Lebanon

### *2.4.1 Exposure to Point and Non-point Sources of Pollution*

Point and non-point sources of pollutants highly impact water quality in Lebanon. Such sources mostly related to the discharge of untreated industrial wastewater effluents and deficient domestic wastewater (sewage) management. The industrial sector discharges untreated effluents along the coastal line, in surface water, and directly in sewerage systems impacting water quality and ecologic wellbeing. (MOE/EFL/ECODIT, 2012; CIH, 2013; EPA, 2016). Likewise, the improper management of wastewater remains a major challenge to be met. Even though there are 37 established wastewater treatment plants in Lebanon, only a few are properly operated and maintained. And, around one third of households are not connected to the sewerage network (mostly outside the Beirut and Mount Lebanon) as the sewage treatment capacity is still low (ESCWA, 2015; MoE/EU/UNDP, 2014, 2015).

As such, both domestic and industrial wastewater are mostly disposed without proper treatment (92% of generated wastewater). Further, wastewater generation by Syrian refugees is contributing to an increase of 34 to 56 MCM. This results in an increase of 8 to 14 % in wastewater generation corresponding to an increased pollution load estimated at 40,817 tons of BOD5 per year (27,930 tons per year of which is disposed on land and in water resources) (World Bank, 2011; MoE/EU/UNDP, 2014, 2015).

As for non-point sources (NPS) of pollution these mostly relate to agricultural and urban runoff, rainfall, and snowmelt (EPA, 2016). The agriculture sector in Lebanon was estimated to consume 61% of the water resources including irrigation and livestock uses (MOEW, 2010). Contributing agricultural activities include overgrazing, incorrect animal feeding methods, and improper and excessive fertilizer use and pesticide application (EPA, 2005). And, agricultural runoff contains fertilizers, pesticides, animal manure and other pollutants that contribute to the degradation of water quality (MoE/EU/UNDP, 2014, 2015; EPA, 2013; EPA, 2016 b). In addition to agricultural activities, urban runoff plays a major role in degrading water quality (EPA, 2003; MoE/EU/UNDP, 2014, 2015; UNHCR/WFP/ UNICEF, 2015).

To avoid exposure to point and non-point sources of pollution, watershed management is the most effective way. The watershed is a hydrologically defined approach that involves all stakeholders including both the public, private sector, and the community. It strategically address priority water resource goals and should be followed by the strategic watershed plans and water safety plans (EPA, 2016 c) Watershed management is a socio-political-ecological concept that is critical in addressing food, water, and economical security (Wani et al., 2009).

Additionally, overexploitation of ground water resources and over pumping to meet the increasing the water demand (8-12 %) further contributes to water quality degradation mostly along the coastline. Degradation in water quality is associated in the increase in water conductivity, sulfates, sodium, chlorides, carbonate and non-carbonate hardness, and calcium and magnesium ratios (Aulong et. al, 2009; Korfali et al., 2006; Nasr et.al, 2012). In 2012, Lebanon was using over 60% of the available water, compared to the 10-30% extracted in other regions of the world. This is causing depletion in the water quantity and degradation in water quality and is mostly evident in summer.

Further, the availability of limited water resources and power shortages, and wastage in distribution networks (up to 58 %) led to intermittent water distribution varying from 3 to 22 hours/ day, depending on the season of the year. This further exposes networks to external contaminants due to pipeline surroundings (Acra et. al, 2001; MoEW/ MOE, No Year; Chambers et. al, 2004; Le Chevallier et al., 2003; Korfali et al., 2006; MoEW/

MOE, 2015; World Bank, 2014). A study by Karim et al. (2003) in the Unites States of America showed the presence of total and faecal coliform bacteria, Enteroviruses, Norwalk and Hepatitis A in soil samples collected immediately adjacent to drinking water distribution networks in six states. The analysis demonstrates a clear indication of human faecal contamination immediately outside the pipe, and seeping of microbiological coliforms and viruses into the pipes and water after low or negative pressures (Karim et al, 2003).

As such, the domestic water supply is below capacity and sometimes drinking water that in compliance with National drinking water Standards which prompts consumers to depend on complementary water sources (e.g. water springs, private wells, water shops, cistern water..) of undetermined nor controlled quality (EU 2011; Jurdi et.al, 2013,15). Moreover, the decrease in water availability and increased exposure to sources of pollution is leading to a harsh rise in water borne diseases (UN, 2014; MOE/EU/UNDP, 2014; World Bank 2011).

### *2.4.2 Deficient Risk Assessment and Risk Management*

Faced with the presented water quality challenges, water quality monitoring in Lebanon is critical for proper risk assessment that would ensure the development of proper management strategies and their effective implementation. As such, water quality monitoring is essential to insures safety and sustainability of water supplies, monitor health outcomes, and reassure ecological wellbeing and viability (Jurdi, 2014; CIH, 2013). Hence, insuring sustainable access to safe drinking water and improved sanitation remains a major challenge that persists despite initiatives undertaken by various stakeholders (Water

Establishments, municipalities, USAID, NGOs, academic institutions and the National Council for Scientific Research) since 2000 (MOE/LEDO, 2001).

The domestic water sector in Lebanon is managed by many stakeholders including the MoEW, and the MoPH, Regional Water Establishments, and municipalities. Each stakeholder has a specific task, however, some tasks overlap, and require collaboration, which is absent in many cases.

Under the law 221, the Water Establishments are responsible for ensuring both the quality and safety of domestic water supplies from source to end-user (CIH, 2013; Jurdi, 2014; MOE/UNDP/ECODIT, 2011). Per se, Regional Water Establishments (RWEs) sustain water quality monitoring programs under the supervision of the Quality Control Department at the Ministry of Energy and Water (MoEW). However, this division is still unequipped with a functional laboratory for quality assurance. This factor limits the ability to sustain quality assurance, and ensure the effectiveness of the water quality monitoring programs and activities (CIH, 2013; Jurdi, 2014; MOE/UNDP/ECODIT, 2011).

Additionally, the MoEW Quality Control department works with ESCWA on supporting the MDGs and SDGs in the Arab countries; specifically SDG target 6 (water and sanitation). It also plays a role in contributing to the revision and update of the National Drinking Water Standards. Currently this ongoing activity is headed by LIBNOR as the national standards were last updated in 1996 (Jurdi, 2014; MoPH, 2014; LIBNOR, 1996).

In addition, MoPH maintains the health standards by monitoring the incidence of waterborne diseases and publishes all related epidemiological data for further referencing. In 2014, the MoPH in collaboration with MoEW and municipalities developed a new water quality-monitoring program. The program aims at enhancing the cooperation between the major players that conduct monitoring activities, as presented in figure 2.1, to achieve unified management of the domestic water supply (Jurdi, 2014; MoPH, 2014).

Still, the main challenges to proper water quality monitoring is the lack of resources (technical and monetary). The shortage in data and information systems makes it difficult to monitor and plan services to enhance water supply and sanitation services. Also, it delays water operators form taking rapid measures in case of any fault in the distribution network (CIH, 2013; Jurdi et. al 2012 Bekaa project). Additionally, poor governance, overlapping and uneven distribution of responsibilities, and the incoherent communication and coordination between all the players are further contributing factors (Jurdi et.al., 2012 Bekaa project).

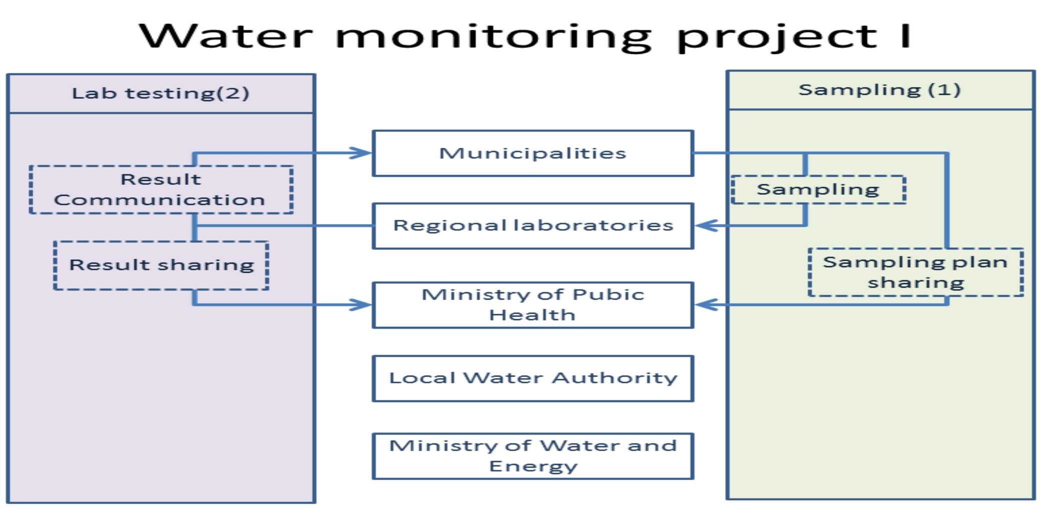


Figure 2.1: Schematic Process for Water Sampling and Result Communication (MoPH, 2014)

As such, strengthening risk assessment through proper water quality monitoring is critical for proper risk management and risk communication towards the provision of a sustainable safe water supply (Jurdi et.al., 2012 Bekaa project).

## 2.5 Importance and Significance of Surface Water Quality Indices (WQI) Monitoring Tool

### *2.5.1 Types and Significance of Water Quality Indices*

Developed in 1965 by the US based National Sanitation Foundation (NSF), the Water Quality Index (WQI) is a monitoring tool with a numerical value that reflects the quality of a water body. The WQI has been considered as a major measure for surface water classification. It is based on the use of standards for water characterization. (Sanchez et al, 2007).

The Water Quality Index compiles data about the physical, chemical and microbiological parameters and gives it a numerical value based on a mathematical equation. The score determined then shows if the water quality is excellent, good, marginal or poor. The higher scores indicate an excellent or good quality, while a lower score shows a degraded water body, thus having a marginal or poor quality as presented in Table 2.1 (Lumb et. al, 2011).

Table 2.1 WQI Designations (UNEP, 2012)

| Designation | Index value | Description |
|---|---|---|
| Excellent | 95-100 | All measurements are within objectives virtually all of the time |
| Good | 80-94 | Condition rarely depart from natural or desirable levels |
| Fair | 64-79 | Conditions sometimes depart from natural or desirable levels |
| Marginal | 45-64 | Conditions often depart from natural or desirable levels |
| Poor | 0-44 | Conditions usually depart from natural or desirable levels |

The WQI has been used globally to monitor the quality of surface waters. Different WQIs have been developed over the time to cater for the requirements in each country. The parameters for WQIs range from the bare minimum to the extreme maximum. Still, there is no globally accepted composite index of water quality. And, most developed indices rely on normalizing or standardizing of quality parameters based on the expected levels. Parameters are often then weighted according to their perceived importance to overall water quality and the index is calculated as the weighted average of all observations of interest/importance (Pesce and Wunderlin, 2000; Stambuk-Giljanovic, 1999; Sargaonkar and Deshpande, 2003; Liou *et al*., 2004; Tsegaye et *al*., 2006).

Accordingly a large number of water quality indices have been developed at the national and global levels since 1999. Among these are the following:

- The Canadian Water Quality index for Freshwater Life (CCME, 2001); assesses the quality of inland water in reference to guidelines for fresh water life.

- The Environmental Performance Index (Levy et al, 2006; Prescott-Allen. 2001); assesses human health parameters against ecosystem viability parameters.
- Overall Index of Pollution (Sargaonkar and Deshpande, 2003); assesses river health by assessment and classification of a number of water quality parameters.
- Index of River Water Quality (Liou et al. 2004); assesses river heath using multiplicative aggregate function of standardized scores for a specific number of water quality parameters.
- The Scatter-score Index; assesses water quality; assesses water quality by monitoring spatially increase and decrease of selective water quality parameters.
- The Chemical Water Quality Index (Tsegaya et al, 2006); assesses quality of lake basins by determining the determining a number of water quality parameters and standardizing each observation against the maximum concentration of each parameter.
- The Fuzzy Water Quality Index (FWQI) (Lermontovet et al, 2009; Sanchez, et. al., 2007); assesses river water quality by using fuzzy logic and interferences to analyze a set of 27 water quality parameters.
- The Aquatic Water Quality Index ( Santos Simões et. al, 2007); assesses levels of pollution in aquatic bodies by monitoring 3 quality parameters of turbidity, total phosphorus and dissolved oxygen.
- The River Water Quality Index (Sanchez et al, 2007); assesses WQI and compares it to the oxygen deficit (high linear relationship was found). This allowed the WQI to be estimated through the calculation of the oxygen deficit.

### *2.5.2 Benefits of Computing a Water Quality Index*

The major benefits of computing the water quality index can be summarized in terms of saving needed resources for extensive monitoring, and enhancing risk analysis.

2.5.2.1 Saving resources

WQI is an extreme scientific tool for achieving scientific accuracy, thus making the maximum use of monitoring data (Walsh, 2012). It is a simple tool that allows water to be classified according to quality and based on standards. In addition, due to minimum quality parameters that need to be determined, it does not require excessive resources, both monetary and technical. This can be very useful in developing countries with limited resources. As such, computing a WQI is cost-effective. Furthermore, it helps in allocating resources to the sectors in need, avoiding resource misallocation, and wasting resources. Resources are usually directed to repair indicators with the lowest values, thus resulting in large increases in WQIs (Walsh, et al, 2013; Sanchez et al, 2007; Pesce and Wundelin, 2000).

2.5.2.2 Enhancing Risk Analysis

Being an easy conveying tool aimed at policy makers, WQI helps in making decisions about the sustainability and use of water body. The integrated effect of each variable and its importance gives an overall idea about that water body. It helps in making quick decisions, simply based on the overall WQI. As such, the enhancing risk assessment with relatively less technical and monitoring resources will lead to informed decisions on water management (Jurdi et. al 2014; Bhargava, D., 1985; Walsh, et al, 2013). The index was used in many countries, and polished for improvement (Lumb et. al, 2011). USA and Canada have numerous official WQIs. In the USA alone, different states have different national WQIs. On the other hand, most countries have only one national WQI, while other countries do not still have any (Abbasi et. al, 2012).

Moreover, the use of WQI has been evaluated as one of the easiest and most effective leading ways to communicate information about water quality from the experts to the policy makers, and the general public (Landwehr et al, 1976; Walsh, 2012). It combines complex data and information from several sources, analyzes them, and then combines them into one single value with a description reflecting the quality of a water body; making it easier, and quicker for the public to understand (Kent, 2005; Walsh, 2012). As such, it enhances the integrated management of water bodies by all stakeholders.

## 2.6 Types of Drinking Water Quality Indices: Advantages and limitations

### *2.6.1 Drinking Water Quality Index ( DWQI)*

Numerous issues still arise when assessing water quality. Some of the primary concerns are related to assuring safe drinking water supplies. A priority to assure the safe drinking water supplies is to protect the water source. A tool that could achieve a global assessment of water quality is the Drinking water quality (DWQI). This DWQI is significant because it is tool that can be conducted on a global scale, and uses the WHO drinking water guidelines as a baseline for the water assessment, and GEMS/Water program database as reference.

In addition the DWQI is composed of both the AWQI, and the HWQI. Thus it is a comprehensive tool to show the water quality as a whole, and it is significant to both human health and acceptability from the end users. One aspect that signifies the DWQI from other WQIs is its ability to identify the overall quality of the water, and to indicate the effect of each parameter on the overall water quality (Abtahi et. al, 2015; UNEP, 2012; WHO, 2011).

The DWQI allows both the assessment of water quality changes and over time, and the evaluation of the any national and international efforts to protect the water sources, such as MDGs and SDGs. In addition, the index gives an idea about the treatment process that should follow, based on the category each sample's index belong to (UNEP, 2012).

The DWQI was used in Pakistan, where the water pipes are deteriorating. The water was analyzed for physio-chemical parameters, resulting in pinpointing the numerous factors that are responsible for the water quality deterioration. Weights were assigned to each parameter depending on their significance in drinking water. In addition the DWQI helped highlight the sources of pollution that were organic pollutants, agricultural run-off and urban land use. Due to the accuracy of this scientific tool, misinterpretation is avoided, and the information is beneficial to water quality monitoring agencies (Nazir et al, 2015).

Between the years 2009 – 2013, the DWQI was used to assess the drinking source in rural communities in Iran.  However, assigning the weight factors, modifying the excursion for carcinogens and bio accumulative pollutants, and lastly removing the effect of unequal measurements of input parameters modified the DWQI. Even though DWQIs usually use all the WHO guidelines; however in this case, researchers decided a minimum of 7 parameters (out of 24 selected parameters) would be measured at least four times per year, following the Iranian drinking water quality standard. This study also found the quality of the ground water to be better than the surface water in both the health and the acceptability quality aspects (Abtahi et. al, 2015).

Hence, even though the DWQI is a comprehensive tool, however it is overly exhaustive, since it includes all the WHO parameters. Some agencies such as UNEP (2012), who wanted to adapt the index, selected the most common parameters, and then reported the index accordingly. These parameters still included a variety of the health parameters, and the acceptability parameters that only reflect on the aesthetics of water.

### *2.6.2 Health Water Quality Index (HWQI)*

Following the DWQI is a more specific index that is the Health Water Quality Index (HWQI). This index is reflective of the health perspective of the water quality. It includes the chemical and microbiological parameters that have direct or adverse human health impacts, based on the WHO Guidelines for Drinking-water Quality. The adverse health effects can be due to water-borne microorganisms and harmful chemicals (Abtahi et. al, 2015; UNEP, 2012; WHO, 2011). For example, a stringent guideline of 0 coliforms per 100 ml is set for the faecal coliforms, is set by WHO (WHO, 2011).

The HWQI does not include any parameters that reflect on the water's acceptability. It includes parameters with direct health effects such as Nitrate – Nitrogen, Nitrite – Nitrogen, Manganese, Copper, Lead, Zinc, Nickle, Cadmium, Faecal coliform (Table 2.2).

With a WHO guideline of 0 coliforms/ 100ml for drinking water (WHO, 2011), faecal coliforms, are important predictors of the quality of water (UNEP, 2012).

Table 2.2 Health Water Quality Parameters based on the WHO Drinking Water Guidelines 2011 (WHO, 2011)

| **HWQI Health Parameters** | **WHO Guideline** | **If parameter exceeds guideline** |
|---|---|---|
| Nitrate | 11 mg/l as nitrate-nitrogen | • Methaemoglobinaemia,<br>• Blue-baby syndrome |
| Nitrite | 0.9 mg/l as nitrite-nitrogen | • Methaemoglobinaemia |
| Manganese | 0.4 mg/l | •Neurological effects (Extended exposures of very high levels in drinking water) |
| Copper | 2 mg/L | •Gastrointestinal irritation<br>•Copper homeostasis |
| Lead | 0.01 | •Accumulates in the skeleton<br>•Interferes with calcium & vitamin D metabolism<br>•Neurological and behavioral effects |
| Nickle | 0.07 | • Carcinogenic ( Inhalation) |
| Cadmium | 0.003 | •Cadmium accumulates primarily in the kidneys → cadmium toxicity. |
| Faecal coliform | 0 coliforms/100 ml | •Gastroenteritis<br>•Diarrhea |

One of the main contributors to the HWQI is the faecal coliform bacteria, which exclusively accounts for 76.06% of all the exceedances in the HWQI therefore beaming a major driver of the HWQ (UNEP, 2012).

The drawback with such in index the inability to show the water quality as a whole, yet it only shows the quality based on the health implications.

### *2.6.3 Acceptability Water Quality Index ( AWQI)*

The other index that is more specific than the DWQI is the Acceptability Water Quality Index (AWQI). This index reflects solely on the acceptability and aesthetic dimension of the water quality, while it does not reflect on any health issues. It takes into consideration the objectionable taste or odor in the water, and the appearance of water (Abtahi et. al, 2015; UNEP, 2012; WHO, 2011). The index is driven by the end-users' perception of the water, since water can be rejected by the end-user if the water has questionable color, turbidity, taste or odor. It leads the consumer to believe that the water is unsafe for drinking. This AWQI does not include any microbiological (faecal coliforms) parameters in the assessment since these are purely health related (UNEP, 2012).

The AWQI includes parameters such as: color, turbidity, TDS, pH, total hardness, chlorides, ammonia, sulfates, and sodium (Table 2.3).

Table 2.3: Acceptability Water Quality Parameters based on the WHO Drinking Water Guidelines 2011 (WHO, 2011)

| AWQI Acceptability Parameters | WHO Guideline | If parameter exceeds guideline |
|---|---|---|
| Color | Color above 15 TCU can be detected in a glass of water | Rejected because of the color of the water for aesthetic reasons |
| Turbidity | 5 NTU | Visible cloudiness |
| Total Dissolved Solids (TDS) | 600 mg/l | • Becomes unpalatable when TDS exceeds 1000 mg/l |

| | | |
|---|---|---|
| | | • Causes excessive scaling in water pipes, heaters, boilers and household appliances. |
| Total hardness | 200 mg/l | • Causes precipitation of soap scum<br>• Need for excess use of soap when<br>• Taste<br>• Scaling when heating |
| Chlorides | 200 mg/l | • Salty taste |
| Ammonia | • Odor: 1.5 mg/L<br>• Taste: 35 ml/L | • Odor<br>• Taste |
| Sulfates | 250 mg/l | • Taste<br>• Laxative effects |
| Sodium | 200 mg/l | • Salty Taste |

## 2.7 Advantages and limitations of Types of WQIs

### *2.7.1 Discussion & analysis of Types of WQIs*

The development of the three indices the DWQI, HWQI, and AWQI discussed in the UNEP CCME report allowed the assessment of water quality across different regions and countries (UNEP, 2012). A summary of the 3 indices is presented in table 2.4, it shows the description and the parameters used in each index.

Table 2.4: Summary table of the 3 types of indices used by the UNEP

| **Index** | **Description** | **Parameters** |
|---|---|---|
| Drinking Water Quality Index (DWQI) | Overview of the water quality including all parameters | Includes all WHO guideline parameters |
| Health Water Quality Index (HWQI) | Includes physical and chemical that only parameter have potential | Only health guideline parameters |

| | | |
|---|---|---|
| | direct health impacts | |
| Acceptability Water Quality Index (AWQI) | Acceptability Guidelines that do not necessarily have any health impacts;<br>Water is rejected by the consumer, because it leads them to feel that the water is unsafe | Only acceptability guideline parameters |

Preliminary reported studies show that DWQI and HWQI are influenced by how much each quality parameter surpasses the guideline, as opposed to how many parameters fail. On the other hand, AWQI is influenced by the number of parameters that fail and frequency of noncompliance. Many different countries used both the HWQI and the AWQI in the year 2002 (UNEP, 2012). Some used both indices such as Morocco, Argentina, the Republic of Korea, Japan, Belgium, Poland and Switzerland. Other countries used only the AWQI. Examples of these countries include South Africa, India, Pakistan, and the Russian Federation.  Most of the stations ranked excellent for the HWQI, while for the AQWI, most ranked Fair. Others countries, use only the extensive DWQI such as the Unites States, Canada, Oceania, Cambodia, Iran and India (Jasmine et al., 2014; Mohebbi et al., 2013; UNEP, 2012).

A study in Iran ran the modified DWQI, the HWQI, and the AWQI for network water based on the Canadian (CCME) DWQI. It specified a weight for each parameter, as opposed to the CCME DWQI. It found the AWQI was better than the HWQI in many cases. The AWQI (91) got the highest average of scores, followed by the DWQI (85) and last the HWQI (79). (The water was treated before entering the distribution networks.) Hence, they concluded that the acceptability quality of the water was superior to the health-based quality. In that study they also concluded that, in the province with the lowest DWQI, the parameter that exceeded the Iranian guidelines the most was the nitrates for the health related indicators and magnesium for the acceptability indicators. While for the normalized sum of excursions (nse), it was fluorides and also magnesium respectively. When the fluorides and magnesium were removed during the sensitivity analysis, the DWQI significantly improved. (Mohebbi et al., 2013).

However, another stud in India, concluded the opposite. When comparing the HWQI, and AWQI for pond samples, the HWQI was overall better than he AWQI, with half the samples scoring excellent, while the AWQI had half the samples in Poor (Reddi, 2015).

A worldwide study used the CCME GDWQI to state of water quality worldwide, over 31 years, from 1978 to 2008. The study used GEMS/Water as the database. However, the study found many discrepancies in GEMS/Water in the data on groundwater. The study covered 20% of the countries worldwide, and both surface and groundwater in Africa, the Americas, Asia, Europe and Oceania. All countries had to report their monitoring findings and results to GEMStat. To obtain a global index, the study calculates the DWQI, HWQI, and the AWQI; they were reported by decade. Generally, the DWQI improved with time. The HWQI also tended to improve over time, except in Africa, where the index decreased over time. However, in most cases, acceptability decreased over time. The AWQI in Africa decreased by 20% over the decades. Other continents showed stability, or slight improvement when it came to AWQI. This indicates that parameters inferring human health have contributed to improving water quality over the last decades (Costa Silva and Dubé, 2013).

According to the UNEP (2012) report and their analysis using Pearson's correlation matrix, in the HWQI and AWQI all indices were significantly correlated, regardless of which parameter was removed. This shows that the combination of all the parameters that drive the index, and not one single parameter (UNEP, 2012).

The flaws in each of the above mentioned quality indicators lead to the conclusion of developing a new index. This new index should be comprehensive, concise, and should cover both the acceptability and the health issues simultaneously. In addition a global index will not tend to the needs of each country, meanwhile this index should be reflective of the problematic areas of each country individually, such as corrosion in distribution networks, improper watershed management, or high salinity in waters.

This thesis aims are developing a valid, comprehensive water quality index, the Potable water Quality Index (PWQI), that fits the criteria mentioned above.

# CHAPTER 3

# STUDY METHODOLOGY

## 3.1 Overview of the Chapter

This chapter presents an overview of the study area, data sources, study design, sample collection and transportation, laboratory analytical assessment and statistical analysis. It also presents the study limitations.

## 3.2 Study Area

This study assessed the quality of distributed potable water supplies (piped water supplies) of Mount Lebanon. Administratively, Lebanon is divided into major divisions, also known as Mouhafazat: Beirut, Mount Lebanon, North Lebanon, Bekaa, South Lebanon, and Nabatiyye (CAS, 2013). Mount Lebanon, also known as the western mountain range in Lebanon, has a total length of 160 km (CAS, 2010). Covering 47% of the Lebanese area, itis the largest and most definitely the most densely populated area (40%) of the population (ECODIT, 2015). The reported population (including Southern Beirut suburbs Lebanon) in 2007 was 1,484,474 people or about 39.49% of the Lebanese population (MOE/UNDP/ECODIT, (2011). Additionally, Mount Lebanon hosts 23.9% of the Syrian refugees influx (Alley: 4.99%; Baabda 7.88%; El Chouf: 4.68; and El Maten: 4.84) (MoE/EU/UNDP, 2014; MoE/EU/UNDP, 2015).

The average household in Mount Lebanon spends around 28.3% of the total household expenditure on housing, network water, electricity, gas, and other fuels (CAS, 2012). However, this expenditure does not include the cost of complementary water sources, where 40% of households buy gallons of treated water, and 12%-15% buy commercial bottled water (ECODIT, 2015).

Mount Lebanon also hosts 49.8% of the industrial establishments of the country (MOI/UNIDO/ALI, 2010). And, all the economic and domestic sectors of Mount Lebanon receive their water supply from the Beirut and Mount Lebanon Water Establishment (BMLWE) as presented in figure 1.

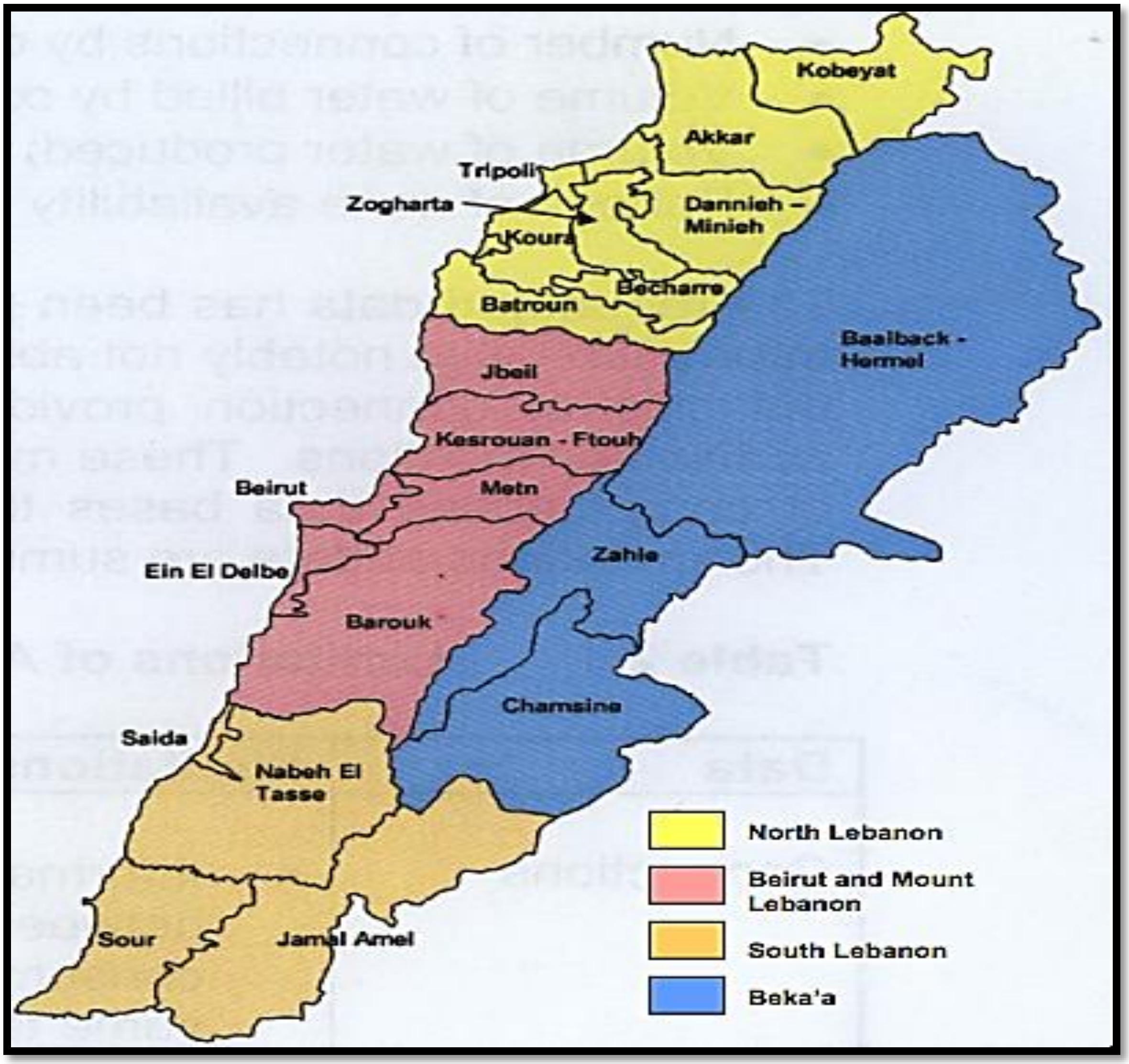


Figure 3.1: Areas Served by the Four Water Establishments of Lebanon (World Bank, 2010)

### 3.3 Data Sources

The data Sources of this study include the results of the water quality analysis of samples collected from distribution networks of Mount Lebanon. Analysis was conducted at the laboratory of the Associate Research Unit on Potable Water Quality and Management

(ARU PWQM), funded by the Lebanese National Council for Scientific Research, The American University of Beirut, The Lebanese American University and the Lebanese University (CNRS/AUB/LAU/LU) and located at the Environmental Health Department of the Faculty of Health Sciences at the American University of Beirut.

## 3.4 Study Design

The study design is divided into two main sections (1) environmental sampling (water sample collection and laboratory analysis) and (2) statistical analysis and determination of the Potable Water Quality Index (PWQI).

### *3.4.1 Environmental Sampling Design*

#### 3.4.1.1 Sampling Stations

Random water sampling of the Mount Lebanon distribution networks was initiated in summer 2015 as part of the research activities of ARU PWQM. All six Mount Lebanon water distribution areas of Aley (Figure 3.2), El Chouf (Figure 3.3), Baabda (Figure 3.4), Jbeil (Figure 3.5), Kisirwan (Figure 3.6), and Al Matn (Figure 3.7) were covered. 20-25 samples were collected from each of the distribution areas (Qadas) (totaling 500 samples), at each of the 4 rounds reflecting on the start of the dry season ( June 2015), the peak of the dry season (September 2015) ; the start of the wet season ( January 2016) and the end of the wet season (April 2016) as presented in table 1.

Table 3.1: Number of Proposed and Collected Samples from the 6 Qadaas of Mount Lebanon

| Qadaa in Mount Lebanon | Number of samples / round (proposed) | Total Number of samples proposed | Number of Samples collected | | | | Total Number of samples (collected) |
|---|---|---|---|---|---|---|---|
| | | | Round 1 | Round 2 | Round 3 | Round 4 | |
| Matn | 25 | 100 | 23 | 22 | 18 | 23 | 86 |
| Kesserwan | 25 | 100 | 24 | 19 | 16 | 24 | 83 |
| Jbeil | 25 | 100 | 23 | 21 | 20 | 23 | 87 |
| Aley | 25 | 100 | 19 | 12 | 15 | 19 | 65 |
| Baabda | 25 | 100 | 20 | 15 | 18 | 20 | 73 |
| Chouf | 25 | 100 | 21 | 12 | 12 | 18 | 63 |
| Total | 150 | 600 | 130 | 101 | 99 | 127 | 457 |

Due to excessive water rationing the number of collected samples was less than the proposed but still exceeded the World Health Organization (WHO) recommended sample size of 312 for monitoring distribution networks for (based on a population size of 1,145,458; 12 samples for each 1 00,000 population).

The choice of the sampling points was based on the distribution lines as documented by the Ministry of Energy and Water. In addition, the sampling frequency is based on the “four by four” rule, which states that samples should be taken no less than four times per year, providing four sets of parameter, in order to calculate an accurate index sensitive to seasonal fluctuations in water quality.

And, GPS coordinates were recorded for each sampling point, to be able to plot WQI and highlight the “problematic” water quality hotspots.

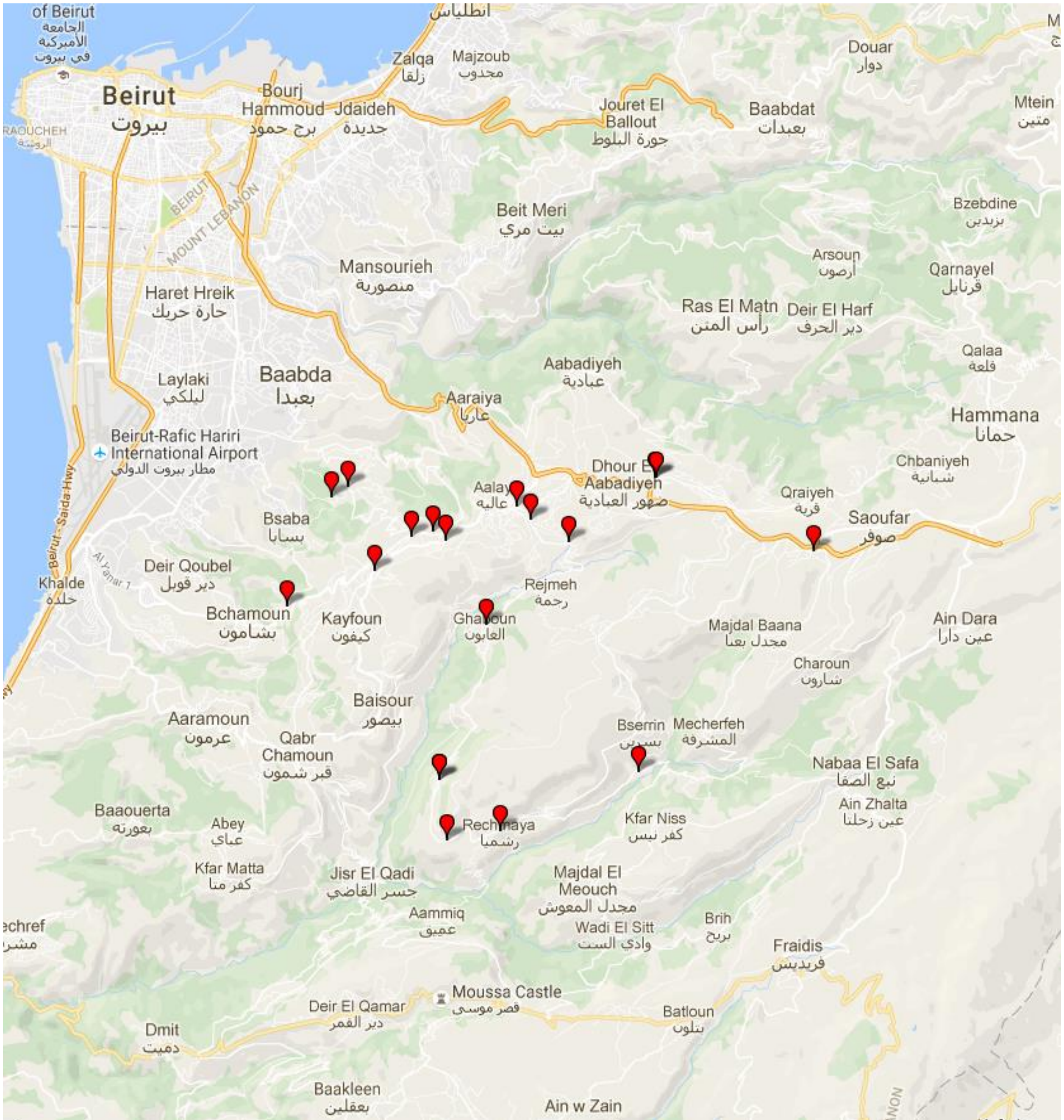


Figure 3.2: Location of samples stations for Aley Distribution Area

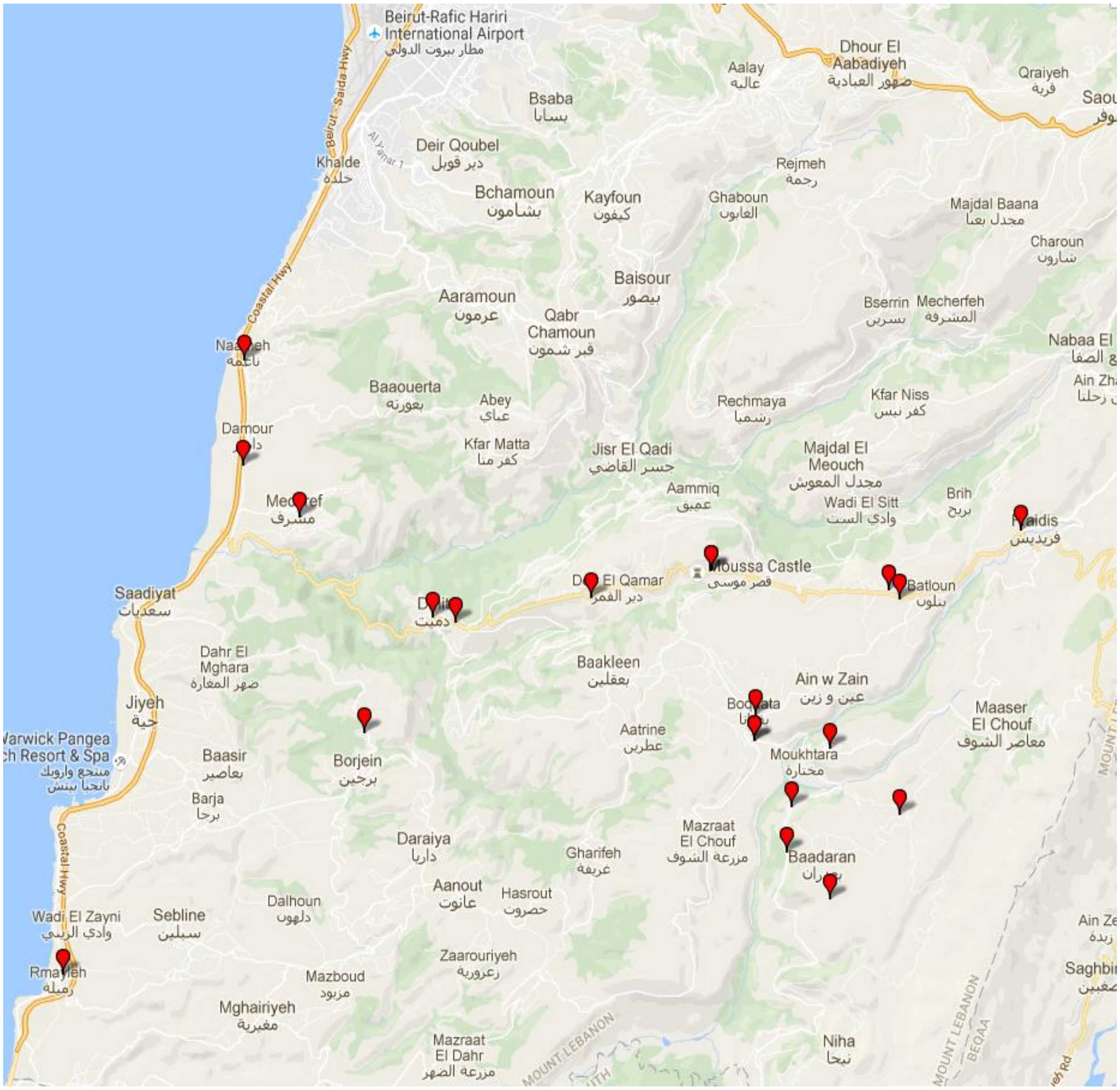

Figure 3.3 Location of sampling stations for the El Chouf Distribution Area

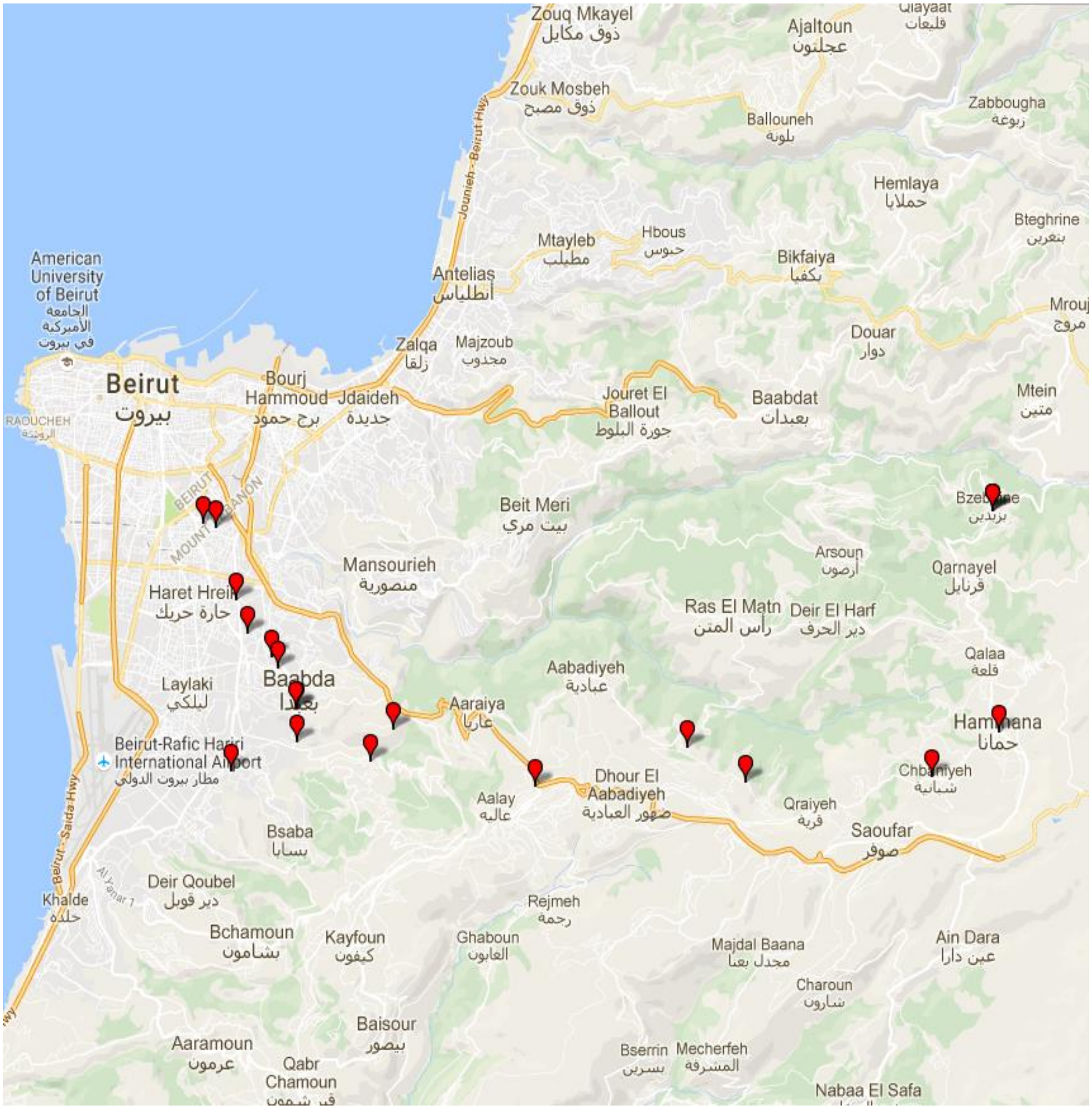


Figure 3.4: Location of sampling stations for the Baabda distribution Area

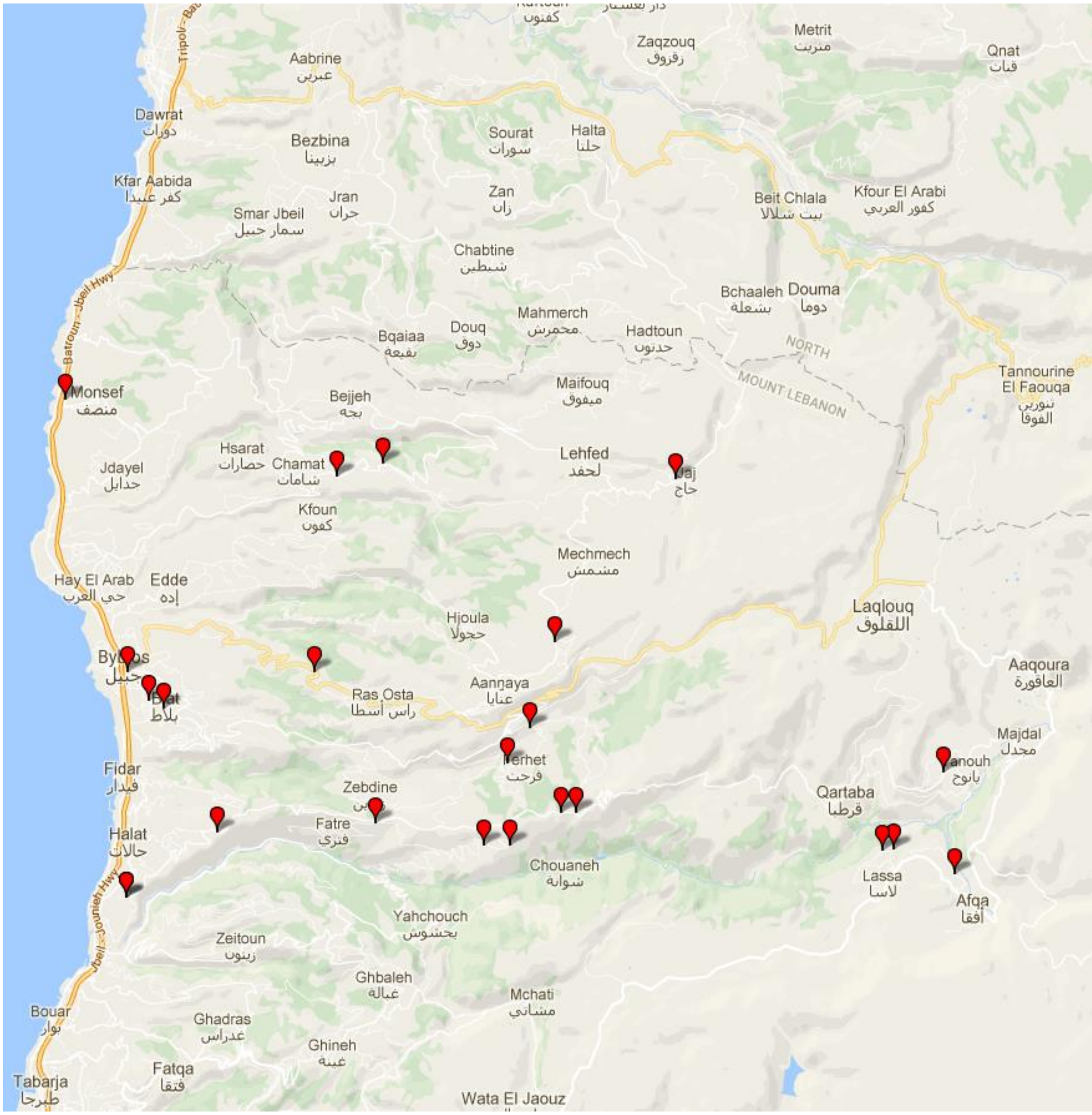

Figure 3.5: Location of sampling stations for the Jbeil Distribution Area

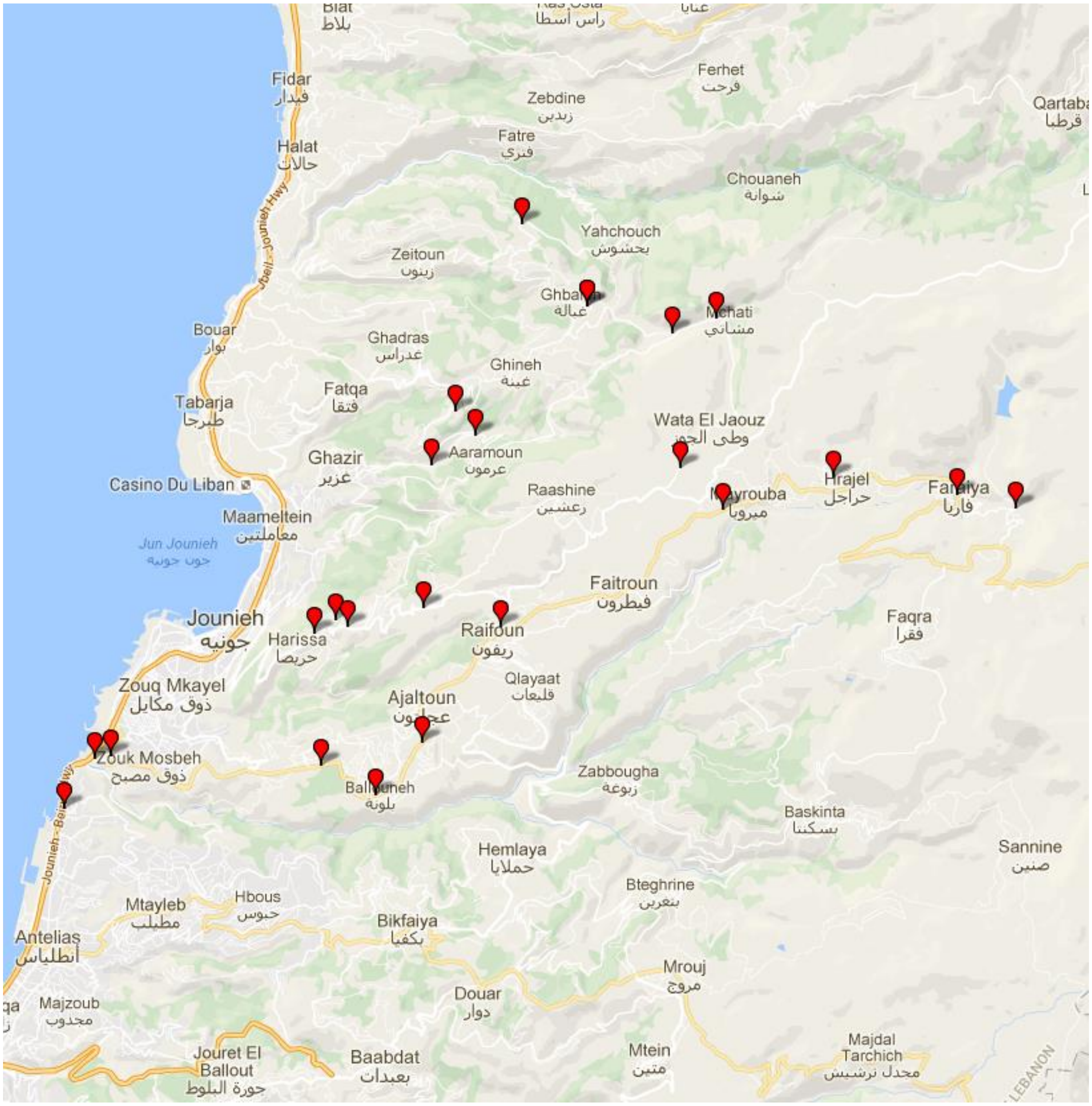


Figure 3.6: Location of sampling stations for the Kisirwan Distribution Area

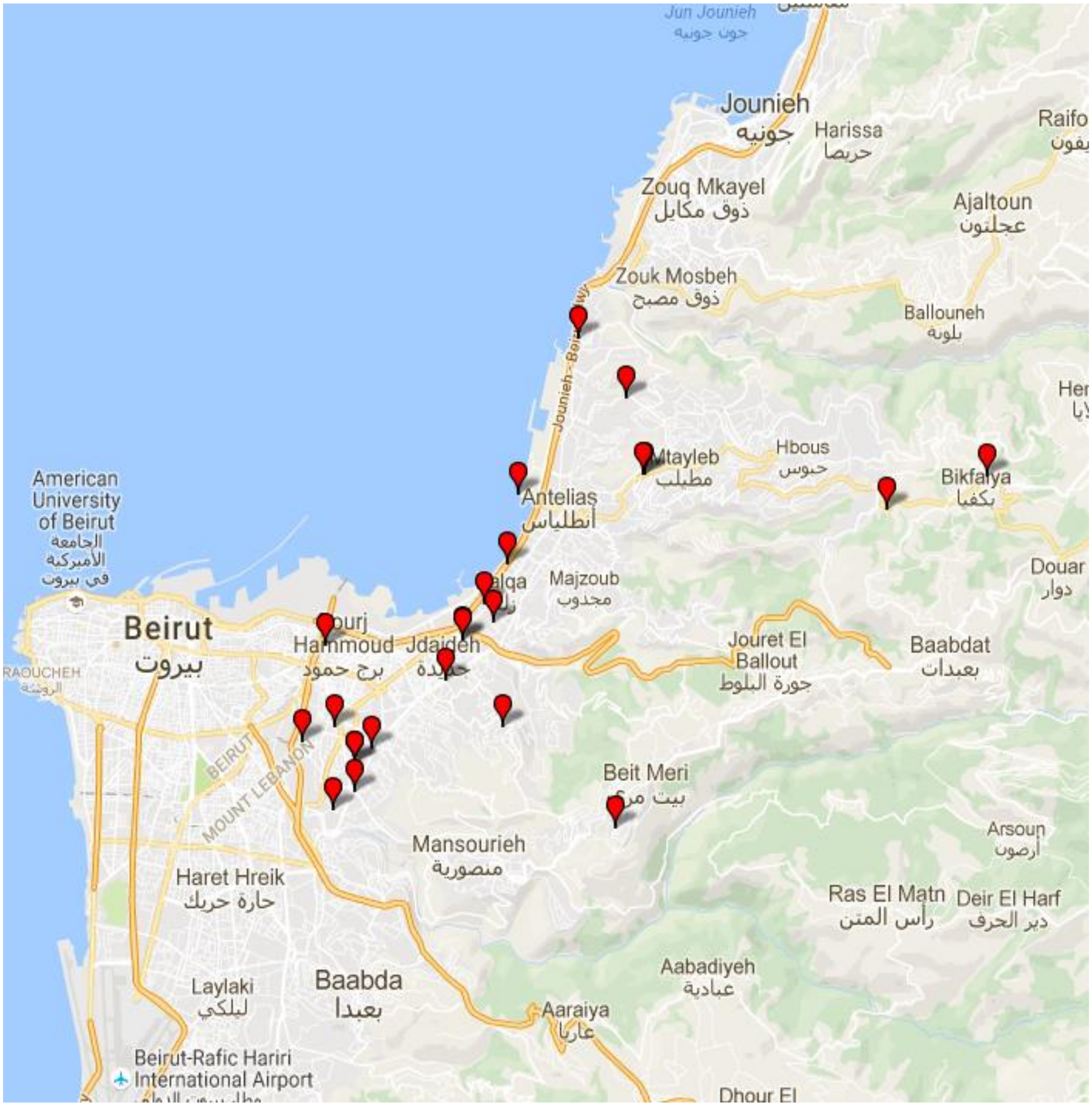


Figure 3.7: Location of sampling stations for Al Matn Distribution Area

3.4.1.2 Samples Collection, Transportation, and Storage

Sampling was done in accordance with standard methods recommended by the American Public Health Association, the American Water Works Association, and the Water Environment Federation (APHA/AWWA/WEF, 2012).

Water samples for physical and chemical analysis were collected in polyethylene bottles that were presoaked overnight in 10% (v/v) nitric acid and then rinsed with distilled water. For microbiological testing, samples were collected in sterile borosilicate 300 ml bottles. Sodium thiosulfate was added to the glass bottles (APHA/AWWA/WEF, 2012).

All grab water samples were collected following standard methods and procedures, in appropriate sampling bottle (APHA/AWWA/WEF, 2012). Samples were randomly collected from taps fed by distribution networks. And, to reflect on the quality of the distribution networks, samples were not collected from water in storage (household water reservoir). This is critical due to the prevailing intermittent water distribution.

Post collection, samples were transported in ice boxes back to the laboratory within the same day. And, all the samples were stored at 4°C prior throughout the entire analysis period (APHA/AWWA/WEF, 2012).

### *3.4.2 Laboratory Analysis*

All Physio-chemical and microbiological analysis were done in accordance with Standard Methods for the Examination of Water and Wastewater, recommended by the

American Public Health Association, the American Water Works Association, and the Water Environment Federation (APHA/AWWA/WEF, 2012).

3.4.2.1 Physical Parameters

The physical quality assessment included parameters of color, turbidity, electrical conductivity and total dissolved solids (TDS). The color was determined using the Platinum-Cobalt Standard Method. The turbidity was determined using the Nephelometric Method. And, the electrical conductivity and total dissolved solids were determined by the Electrical Conductivity Method as presented in table 2.

3.4.2.2 Chemical Parameters

The chemical parameters analyzed to reflect on the chemical water quality of piped water supplies are presented in Table 2. The pH was determined using the Potentiometric method. Additionally, the macro-chemicals (Nitrate-Nitrogen, Nitrite-Nitrogen, Ammonia-Nitrogen, Sulfates, Iron, and Manganese) were determined using the Cadmium Reduction Method, Diazotization Method, Nesslerization Method, SulfaVer 4 Turbidimetric Method, 1-10 Phenanthroline Method, and the PAN Method, respectively. Further, the flame photometric technique was used to determine sodium levels.

And, the Alkalinity, Total Hardness and Chlorides were determined using the standard burette titration method. As for trace metals (Copper, Cadmium, Nickle, lead and Zinc) levels were determined by Atomic Absorption as presented in table 3.2.

The analysis of all chemical parameters was done in the laboratory except for the Free Residual Chlorine that was determined onsite (the Pocket Colorimeter II) using the DPD method as this parameter is highly unstable.

3.4.2.3 Microbiological Parameters

Total and faecal coliforms were determined to reflect on the microbiological quality of the piped water supplies. The membrane filtration technique (abiding by aseptic techniques) was followed for the microbiological testing as presented in table 2. The m-Endo media was used for the total coliforms (incubated at 35˚C for 24 hours) determination, while m-FC media was used for faecal coliforms (incubated at 44.5 ˚C for 24 hours) (APHA, 2012).

Table 3.2: Analytical Methods and Techniques (APHA/AWWA/WPCF, 2012)

| **Analytical Parameter** | **Standard Analytical Method** | **Type of Analytical Equipment** |
|---|---|---|
| Color | Platinum-Cobalt Standard Method | DR 2800 HACH Spectrophotometer |
| Turbidity | Nephelometric Method | HACH Turbidimeter 2100 p |
| Electric conductivity | Electrical Conductivity Method | HQ40D Conductivity Probe: Model CDC40101 |
| Total Dissolved Solids | Electrical Conductivity Method | HQ40D Conductivity Probe: Model CDC40101 |

| | | |
|---|---|---|
| pH | Potentiometric method | HQ40D Refillable pH Probe: Model PHC30101 |
| Alkalinity | Standard Acid Titration Method using Sulfuric Acid (0.02N) | Burette Titration |
| Total Hardness | Standard EDTA Titration Methods | Burette Titration |
| Calcium & Magnesium | Standard EDTA Titration Methods | Burette Titration |
| Chlorides | Standard Mercuric Nitrate Titration Method | Burette Titration |
| Ammonia-Nitrogen | Nesslerization Method | DR 2800 HACH Spectrophotometer |
| Nitrite-Nitrogen | Diazotization Method | DR 2800 HACH Spectrophotometer |
| Nitrate-Nitrogen | Cadmium Reduction Method | DR 2800 HACH Spectrophotometer |
| Phosphates | PhosVer 3 (Ascorbic Acid) Method | DR 2800 HACH Spectrophotometer |
| Sulfates | SulfaVer 4 Turbidimetric Method | DR 2800 HACH Spectrophotometer |
| Iron | 1-10 Phenanthroline Method | DR 2800 HACH Spectrophotometer |
| Manganese | PAN method | DR 2800 HACH Spectrophotometer |
| Free Residual Chlorine | Free Chlorine method | HACH Pocket Colorimeter II |
| Sodium &Potassium | Flame Photometry | JENWAY Flame Photometer |
| Trace Metals: Cr, Cd, Cu, Hg, Ni, Pb and Zn etc. | Atomic Absorption | Atomic Absorption Spectrophotometer – Thermo Scientific |
| T. Coliform, Faecal Coliform | Membrane Filter Technique | Millipore Filtration Apparatus |

## 3.5 Statistical Analysis

The Statistical Analytical Scheme included the calculation of the HWQI, AWQI, UNEP WQI, and the proposed PWQI, testing and validation, and determining the contribution of each of the quality parameters to the 4 indices.

### *3.5.1 Calculation of the Proposed PWQI*

The Potable Water Quality Index (PWQI) was adapted based to the UNEP WQI. It reflects on acceptability and safety of potable piped water supplies of Mount Lebanon. In addition, the quality of the distribution networks of Mount Lebanon can be inferred. The PWQI summarizes complex scientific data into a simple form, thereby smoothing risk assessment and communication. This type of water quality evaluation allows it to be used as a screening tool, facilitating water quality monitoring, which our country lacks due to shortages in technical and financial resources.

Additionally, the PWQI reflects on the fluctuations in the water quality, between seasons, and according to sampling point. In addition, it show the magnitude of deviation of each parameter from the LIBNOR sampling point. Also, it is an important tool for pinpointing the problematic areas, and facilitating the interventions needed.

The PWQI includes quality parameters that relate to the potable water acceptability of included desirability, safety and conditions of distribution networks. The parameters are: color, turbidity, total dissolved solids, pH, hardness, chlorides, ammonia, nitrite, nitrates, sulfates, sodium, iron, manganese ( at the acceptability levels), zinc, copper, lead, nickel, cadmium, free residual chlorine, and faecal coliforms.

The PWQI did not include fluoride and mercury levels in the calculation of the index due to their minimal levels in the water supply (based of determined data base 2009-12). On the other hand, since ground water is masterly used as potable water in Lebanon hence total hardness was added.

The PWQI assessment of the quality safety of the piped water supply in Mount Lebanon falls in accordance to the Lebanese national standards for drinking water (LIBNOR 1999). The LIBNOR standards do not include levels for the Ammonia parameter. Hence, the WHO drinking water guideline was used ammonia (1.5 mg/L) (WHO, 2011).

The calculation of the proposed PWQI was based on the equation developed by the Canadian Council of Ministers of the Environment (CCME) as presented in figure 3.8 and in accordance with the national standard for drinking water set by LIBNOR (LIBNOR, 1999).

$$\mathrm{WQI} = 100 - \left(\frac{\sqrt{\mathrm{F1}^2 + \mathrm{F2}^2 + \mathrm{F3}^2}}{1.732}\right)$$

F1 represents the <u>Scope</u>: The percentage of parameters that exceed the guideline

$$\mathrm{F1} = \left(\frac{\text{\# failed parameters}}{\text{total \# of parametrs}}\right) \mathrm{X}\ 100$$

F2 represents the <u>Frequency</u>: The percentage of individual test within each parameter that exceeded the guideline

$$\mathrm{F2} = \left(\frac{\text{\# of failed tests}}{\text{total \# of tests}}\right) \mathrm{X}\ 100$$

F3 represents <u>Amplitude</u>: The extent (excursion) to which the dialed test exceeds the guideline. This is calculated in three stages. First, the excursion is calculated

$$\text{excursion} = \left(\frac{\text{failed test value}}{\text{guideline value}}\right) - 1$$

NB: in the case of pH where a minimum and maximum guideline is gives, the excursion equation must be run as above as well as in reverse i.e. guideline value/failed test value.

Second, the normalized sum of excursions (nse) is calculated as follows:

$$\text{nse} = \left(\frac{\sum \text{excursion}}{\text{total \# of tests}}\right)$$

F3 is then calculated using a formula that scaled the nse to range between 1 and 100:

$$\text{F3} = \left(\frac{\text{nse}}{0.01\text{nse} + 0.01}\right)$$

Figure3.8: Method for Calculating the Proposed Water Quality Index (CCME, 2005)

### *3.5.2 Testing and Validation*

Validation and sensitivity analysis was conducted to assess whether the developed index is impacted by (1) how much each parameter exceeds the guideline level F3, (2) how many times it exceeds the guideline F2 and (3) how many parameters exceed guideline at each sampling point at each round F1. This was be done by multiple regression analysis by using forced entry method.

### *3.5.3 Determining Contribution of Quality Parameters*

Determining the contribution of each of the quality parameters was done by Simple Regression using backwards method (20 Simple Regressions using backwards method). This was done to quantify the magnitude and the unique contribution of every parameter to the original index.

### 3.6 Study Limitations

The major limitation of the study was collecting the proposed number of water samples over the four indicted rounds. The main problem faced was with Round 3 (January 2016) in the Qadaas of Baabda, Aley and El Chouf. Even though this was not expected for the wet season, however many areas either had major problems with the water distribution networks, or with minimal water distribution frequency due to the increased population density resulting from the influx of Syrian residents) and the progressive cut-off in electricity.

Due to the above problems and since the calculation of PWQI requires that each sampling point is tested 4 times (the 4x4 rule), the incomplete data sets were dropped and the total number of sample included in the computation of the PWQI was 457, as presented in Table 1.Still, this sample size, even after the drop of sample points, exceeded the World Health Organization (WHO) recommended sample size of 312 for monitoring distribution networks for (based on a population size of 1,145,458; 12 samples for each 1 00,000 population) as indicated before.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Overview of the chapter

This chapter will evaluate of the water quality of the piped water supplies of Mount Lebanon (all 6 Qadaas) based on a proposed Potable Water Quality Index (PWQI) and accordingly, identify problematic areas where the water quality is not in compliance with LIBNOR Standards. It will further determine statistically whether the proposed PWQI is driven by F1, F2, or F3. Moreover, the contribution of each of the quality parameters to the determined index will be presented. Additionally, the sensitivity of the different indices: Health Quality Index (HWQI), Acceptability Water Quality Index (AWQI), UNEP Water Quality Index (UNEP WQI), and the Potable Water Index (PWQI) will be determined to identify the optimal one to be recommended for routine potable water quality monitoring.

## 4.2 Assessment of Piped Water Supplies of Mount Lebanon Based on Quality Indices

### *4.2.1 Qadaa Aley*

The main physical, chemical and microbiological water quality parameters of the piped water supply of Qadaa Aley are presented in tables 4.1a and 4.1b. Evaluating the water quality based on the indicated parameters show minimal variability between the wet and dry seasons of the year; this is mainly reflective of the use of spring and well water sources.

Overall, TDS levels were less than 500 mg/l and did not exceed the LIBNOR standard as presented in table 4.1a. And, even though high levels of TDS do not have direct health impacts, levels above 1000 mg/L could be associated with irritation of the gastrointestinal tract. Additionally, such levels are concomitant with unpleasant taste and lead to excessive scaling in water pipes, heaters, boilers and household appliances (WHO, 2011).

Moreover, hardness levels were moderate reflective of ground water sources and the levels of non-carbonate hardness were relatively minimal (26-38 mg/L) indicating minimal exposure to pollution.

The chloride levels were also below the LIBNOR standard of 200 mg/L; the highest detected concentration was 45 mg/L (Table 4.1a). High levels of chlorides exceeding the WHO guideline of 250 mg/L are associated with a salty taste that is rejected by consumers (WHO, 2011).

Additionally, high sulfate levels exceeding the LIBNOR standard of 250 mg/L were also not detected (Table 4.1a). High concentrations of sulfates might cause laxative affects and noticeable taste in the water thus, affecting the water acceptability by end-users.

Further, the nitrates levels were minimal and did not exceed the standard of 10mg/L as nitrate-nitrogen as presented in table 4.1a. Monitoring nitrate levels is critical as high levels expose infants to methemoglobinemia, or blue baby syndrome (WHO, 2011).

The pH of the water mostly ranged between 7.6 and 8.5 which is expected for ground water supplies and are within the acceptable range of 6.5-8.5 (Table 4.1a). As for trace metals, the levels of copper, nickel, zinc and manganese were all below the health LIBNOR

Standards /WHO Guideline levels (LIBNOR/ of 1 mg/L, 0.02 mg/L, and 5 mg/L, 0.4 mg/l, respectively. Still, lead levels in rounds 3 and 4 (January and April 2016), exceeded the LIBNOR standard (0.01 mg/L) in all piped water supplies thus raising a warning flag (Table 4.1a).

Sources of lead can either be natural, or due to the corrosion of distribution networks and household plumbing systems. Polyvinyl chloride (PVC) pipes also contain lead and can result in leaching based on the water pH levels. The quantity of lead dissolved from the distribution networks depends on, and is increased by acidic pH, water softness, and the standing time of the water in the networks (WHO, 2011). Accordingly, lead leaching may have been enhanced by precipitation (rainy season).

Exposure to high levels of lead is associated with several health risks in children under the age of 6 and pregnant women and their fetus. It affects the central nervous system resulting in neurological and behavioral effects, and is associated with acute lead intoxication (headaches, muscle tremor, abdominal cramps, kidney damage, hallucinations, and loss of memory) (WHO, 2011).

Further, cadmium levels were above the standard (0.005 mg/L) in the 1st round (May- June 2015). High cadmium levels can either be due to the exposure of water sources feeding the distribution networks to agricultural runoff, or are an indicator of the corrosion of the distribution networks. The amount of cadmium dissolved in water from distribution networks is also impacted by low pH and water softness. Prolonged exposure to cadmium targets the kidneys and leads to cadmium toxicity (WHO, 2011).

Still, although the levels of manganese did not exceed the health standard (WHO guideline of 0.4mg/L, it is impacting water acceptability based on the 0.05mg/L LIBNOR standard.

This is will further degrade networks by coating the pipes leading to a black precipitate at high levels of 0.2mg/L (WHO, 2011)

Microbiologically, only 16% of the piped water supplies were contaminated with faecal organisms as presented in table 4.1b. This could be reflective on deficient chlorination and/or insufficient levels of free residual chlorine that should be maintained to protect the microbiological safety of water supply throughout the distribution network.

This can be further confirmed by minimal levels of free residual chorine of less than 0.1 mg/L in 42 % of the piped water supplies of Qadaa Aley as presented in Table 4.1b.

Table 4.1a: Mean Levels of Critical Physical and Chemical Water Quality Indicators for Qadaa Aley Piped Water Supplies

| Sampling Round | pH | TDS | | $NO_3$-N | $SO_4^{2-}$ | $Cl^-$ | Pb | Cd |
|---|---|---|---|---|---|---|---|---|
| | | mg/L | | mg/L as | mg/L | mg/L | mg/L | mg/L |
| | % <6.5 & > 8.5 | % > 500 mg/L | % > 1000 mg/L | % > 10 mg/L | % > 250 mg/L | % > 200 mg/L | > 0.01 mg/L | > 0.005 mg/L |
| Round 1 | 0% | 0% | 0% | 0% | 0% | 0% | 18% | 90% |
| Round 2 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Round 3 | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% |
| Round 4 | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% |
| Mean | 0 | 0% | 0% | 0% | 0% | 0% | 55% | 23% |
| EPA | 6.5-8.5 | 500 | | 10 | 250 | 250 | 0.015 | 0.005 |
| WHO | 6.5-8.5 | 1000 | | 50 | 250 | 250 | 0.01 | 0.003 |
| LIBNOR | 6.5-8.5 | 500 | | 45 | 250 | 200 | 0.01 | 0.005 |

Table 4.1b: Mean Levels of Microbiological Water Quality Indicators and Free Residual Chlorine for Qadaa Aley Piped Water Supplies

| Sampling Round | Free Residual Chlorine | F. Coliforms |
|---|---|---|
| | mg/L | / 100 ml |

| | % > 0.3 mg/L | % < 0.1 mg/L | % = 0 mg/L | % positive |
|---|---|---|---|---|
| Round 1 | 37% | 37% | 0% | 18% |
| Round 2 | 0% | 83% | 0% | 18% |
| Round 3 | 18% | 28% | 0% | 9% |
| Round 4 | 37% | 21% | 0% | 18% |
| Mean | 23% | 42% | 0% | 16% |
| EPA | | | | - |
| WHO | | | | - |
| LIBNOR | 0.3 | | | - |

Evaluating the water quality of the piped water supplies of Qadaa Aley based on the HWQI, AWQI, UNEP WQI and the proposed PWQI (Tables 4.1- 4.2 and figure 4.1), the following can be noted:

- Based on the calculated PWQI (Tables 4.1a&b - 4.2 and Figure 4.1), 82% of supplies are of good quality that is mostly in compliance with LIBNOR standards. Still, 9% are of marginal quality that is often noncompliant with standards. Additionally, 9% is of poor quality that is mostly noncompliant with standards (Tables 4.2-4.3).
- Based on the AWQI, the quality of all the piped water supplies are all classified as excellent (Tables 4.2-4.3, Figure 4.1). This gives false positives as the levels of the all acceptability parameters (color, turbidity, ammonia, chlorides, iron, pH, sodium, sulfate, and zinc) were within LIBNOR standards. Moreover, the microbiological quality is not indicated masking the inferiority of the water supplies and making it difficult to identify problematic areas.
- Based on the HWQI, 55% of the piped water supplies are of good water quality. This is also non-reflective of the overall quality since the quality classification

automatically drops to poor (18%) once faecal coliforms are present. This is mainly due to the high contribution of the microbiological quality parameter to the index due to the limited number of parameters that are monitored (faecal coliforms, nitrates, nitrites, manganese, lead, cadmium, and copper). However, in cases where no faecal coliforms were present, the HWQI quality classification was similar to that of the PWQI (Figure 4.2). Still, the HWQI reflects only on the health aspects and doesn't address water acceptability; a major cause that would lead consumers to reject the water supplies increasing the dependence on unsafe complementary water sources.

- Based on the UNEP WQI, 82% of piped water supplies are of excellent quality. However, only 9% are of marginal water quality and 9% are of poor water quality that is mostly noncompliant with LIBNOR Standards (Table 4.2). As indicated in the methodology, the UNEP WQI includes both health and acceptability parameters (color, turbidity, faecal coliforms, pH, ammonia, nitrates, nitrites, sulfate, chlorides, sodium, iron, manganese, lead, cadmium, and copper) and as such is more reflective of the water quality in comparison to the AWQI and the HWQI.
- The PWQI (Figure 4.2) is more reflective of the water quality than the AWQI which only reflects on the acceptability of the water by consumers. The AWQI does not reflect the health aspect of the water quality due to the unaccounted for microbiological profile. Thus, the AWQI gave false positives by inflating the water quality classification to excellent for all the piped water supplies of Qadaa Aley (Figure 4.2).
- The HWQI is also non-reflective on the water quality, since it automatically drops the index to a poor quality when faecal coliforms are present. As such, the HWQI yielded

the lowest quality classification among the 4 computed indices. This is, as indicated before, due to the high contribution of the faecal coliform parameter to the HWQI that monitors limited quality parameters. Moreover, it does not take into consideration parameters of water acceptability which are major factors in determining water use (Figure 4.2).

➢ The UNEP WQI and the PWQI yield overall similar results in terms of water quality classification.

Table 4.2: Quality of Piped Water Supplies of Qadaa Aley based on determined Indices

| | | HWQI | | AWQI | | UNEP WQI | | PWQI | |
|---|---|---|---|---|---|---|---|---|---|
| Qadaa ALEY | A2 | 85.3 | Good | 100.0 | Excellent | 90.9 | Good | 92.0 | Good |
| | A3 | 88.9 | Good | 98.4 | Excellent | 88.4 | Good | 92.6 | Good |
| | A4 | 41.5 | Poor | 100.0 | Excellent | 42.1 | Poor | 41.7 | Poor |
| | A5 | 72.6 | Fair | 100.0 | Excellent | 83.3 | Good | 81.9 | Good |
| | A6 | 89.3 | Good | 100.0 | Excellent | 92.2 | Good | 87.9 | Good |
| | A9 | 89.1 | Good | 100.0 | Excellent | 92.1 | Good | 89.7 | Good |
| | A10 | 72.8 | Fair | 100.0 | Excellent | 81.8 | Good | 85.2 | Good |
| | A11 | 85.5 | Good | 100.0 | Excellent | 90.9 | Good | 91.4 | Good |
| | A15 | 40.6 | Poor | 100.0 | Excellent | 45.3 | Marginal | 45.7 | Marginal |
| | A18 | 89.3 | Good | 100.0 | Excellent | 92.2 | Good | 92.6 | Good |
| | A19 | 69.1 | Fair | 100.0 | Excellent | 82.0 | Good | 84.0 | Good |

Table 4.3: Classification of the Quality of Qadaa Aley Piped Water Supplies based on determined indices

| | | HWQI | AWQI | UNEP WQI | PWQI |
|---|---|---|---|---|---|
| Qadaa ALEY | Excellent | 0% | 100% | 82% | 82% |
| | Good | 55% | 0% | 0% | 0% |
| | Fair | 27% | 0% | 0% | 0% |
| | Marginal | 0% | 0% | 9% | 9% |
| | Poor | 18% | 0% | 9% | 9% |

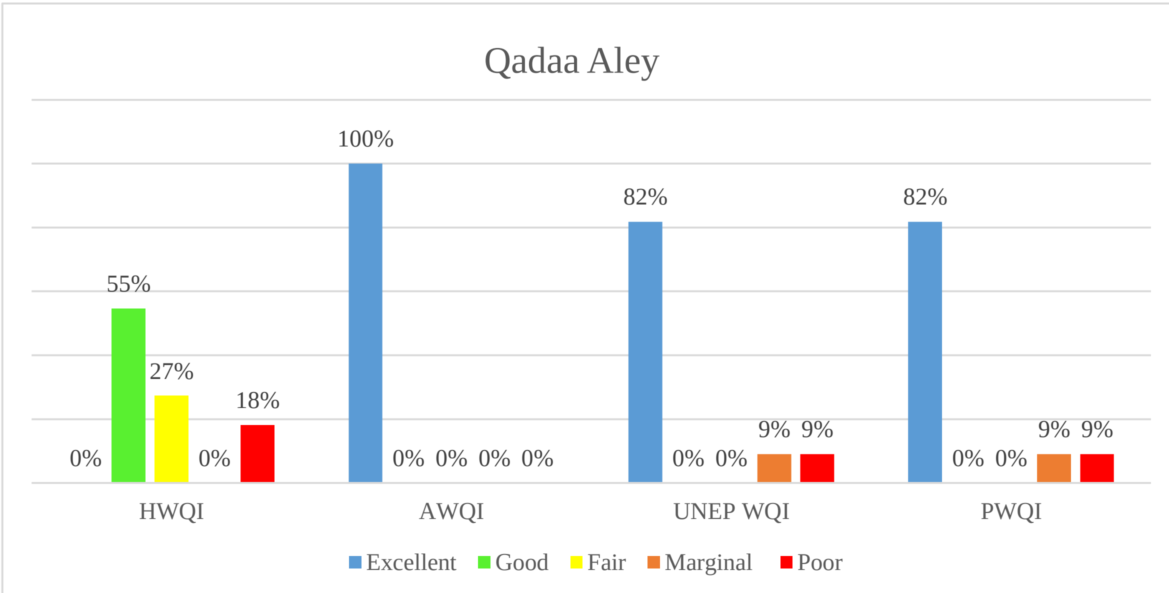


Figure 4.1: Bar Chart showing the Classification of the Quality of Qadaa Aley Piped Water Supplies based on the determined indices

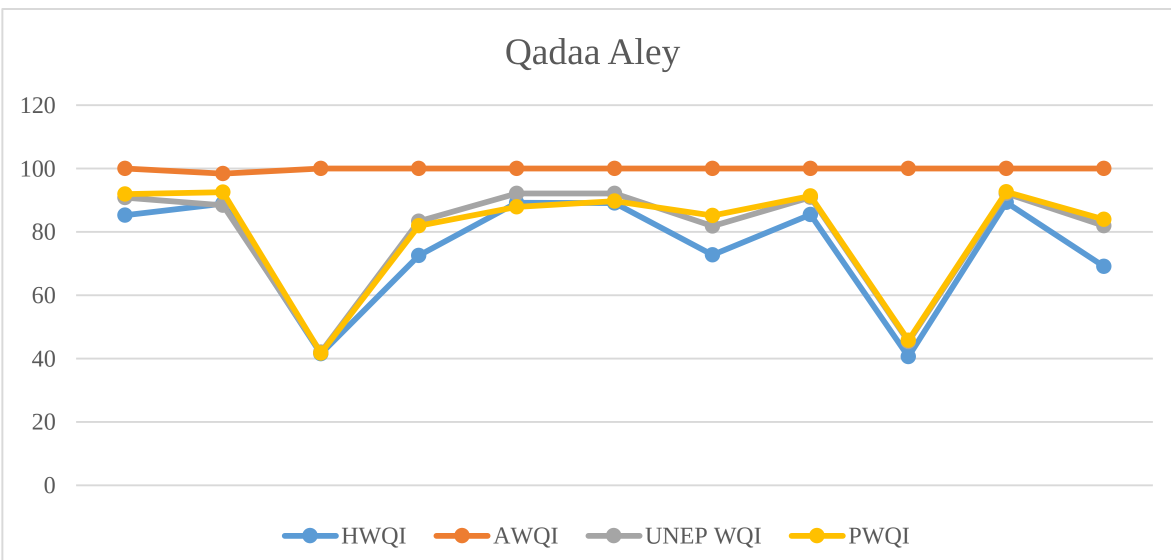


Figure 4.2: Sensitivity of Computed Water Quality Indices

### *4.2.2 Qadaa El Chouf*

The main physical, chemical and microbiological water quality parameters of the piped water supplies of Qadaa of El Chouf are presented in tables 4.4aand 4.4b. Evaluating the water quality based on the indicated parameters, shows major variability between the wet and dry seasons of the year. This is mostly due to the excessive use and overexploitation of groundwater sources along the coastal zone (mainly during the dry season) that enhances seawater infiltration.

Overall the TDS of 29% of the piped water supplies exceeded the national standard recommended by LIBNOR of 500 mg/L. Additionally, 24% had high mineral contents above the 1000mg/L WHO guideline level as presented in table 4.4a. And, even though high levels of TDS do not have direct health impacts, still it could be associated with irritation of the gastrointestinal tract. In addition, it results in unpleasant water taste and leads to excessive scaling in water pipes, heaters, boilers and household appliances (WHO, 2011).

Moreover, hardness levels were relatively high reflective of ground water sources and exposure to pollution. Accordingly, the levels of non-carbonate hardness were moderate (154-176 mg/L) confirming exposure to pollution induced by seawater infiltration.

Additionally, the mean chloride levels exceeded the LIBNOR standard of 200 mg/l in 20% of supplies (Table 4.4a). Supplies with high concentrations of chlorides are mostly located along the costal line. This is concurrent with earlier reported studies that identified seawater intrusion as a major source of pollution for many coastal cities (Korfali and Jurdi, 2010). Chloride levels that exceed the WHO guideline of 250 mg/L give a salty taste to water, and as such are rejected by consumers (WHO, 2011). On the other hand, sulfate levels did not exceed the LIBNOR standard of 250 mg/L (Table 4.4a). High concentrations of sulfates would cause laxative affects and noticeable taste in the water affecting water acceptability. Additionally, nitrate levels were not high and did not exceed the LIBNOR standard of 10mg/L as nitrate- nitrogen (Table 4.4a).

The pH of the piped water supplies ranged between 7.6 and 8.4; within the acceptable range of 6.5-8.5 and mostly reflective of the use of ground water sources (Table 4.4a). As for trace metals, the levels of copper, nickel, zinc and manganese were all below the health LIBNOR Standards /WHO Guideline levels (LIBNOR/ of 1 mg/L, 0.02 mg/L, and 5 mg/L, 0.4 mg/l, respectively. However, lead levels of round 4 (April 2016) exceeded the guideline level for all distribution areas thus raising a warning flag (Table 4.4a). And, as indicated before, lead leaching may have been enhanced by precipitation (rainy season). Moreover, 18% of the cadmium levels, as presented in table 4.4a, exceeded the standard in the 1st sampling round (May - June 2015) further reflecting on the deterioration of the distribution networks (WHO, 2011 Cadmium).

Still, although the levels of manganese did not exceed the health standard (WHO guideline of 0.4mg/L, it is highly impacting water acceptability based on the 0.05mg/L LIBNOR standard. This is will further degrade networks by coating the pipes leading to a black precipitate at high levels of 0.2mg/L (WHO, 2011).

Microbiologically, 55% of the piped water supplies were faecally contaminated as (Table 4.4b). This could be attributed to deficient chlorination and/or insufficient levels of free residual chlorine that should be maintained to protect the microbiological safety of the distributed water especially under conditions of intermittent flow and deficient operation and maintenance. And, this is further confirmed by the levels of free residual chorine of less than 0.1 mg/L in 74 % of supplies, as presented in table 4.4b. Still, none of the piped water supplies had the recommended 0.3 mg/L free residual chlorine level, and 36% of the supplies had no free residual chlorine levels as presented in table 4.4b.

Table 4.4a: Mean Levels of Critical Physical and Chemical Water Quality Indicators for Qadaa El Chouf Piped Water Supplies

| Sampling Round | pH | TDS mg/L | | $NO_3$-N mg/L | $SO_4^{2-}$ mg/L $^-$ | $Cl^-$ mg/L | Pb mg/L | Cd mg/L |
|---|---|---|---|---|---|---|---|---|
| | % <6.5 & > 8.5 | % > 500 mg/L | % > 1000 mg/L | % > 10 mg/L | % > 250 mg/L | % > 200 mg/L | > 0.01 mg/L | > 0.005 mg/L |
| Round 1 | 0% | 24% | 24% | 0% | 0% | 19% | 9% | 18% |
| Round 2 | 0% | 33% | 25% | 0% | 0% | 25% | 0% | 0% |
| Round 3 | 0% | 36% | 27% | 0% | 0% | 36% | 9% | 0% |
| Round 4 | 0% | 21% | 21% | 0% | 0% | 0% | 100% | 0% |
| Mean | 0% | 29% | 24% | 0% | 0% | 20% | 30% | 5% |
| EPA | 6.5-8.5 | 500 | | 10 | 250 | 250 | 0.015 | 0.005 |
| WHO | 6.5-8.5 | 1000 | | 50 | 250 | 250 | 0.01 | 0.003 |
| LIBNOR | 6.5-8.5 | 500 | | 45 | 250 | 200 | 0.01 | 0.005 |

Table 4.4b: Mean Levels of Microbiological Water Quality Indicators and Free Residual Chlorine for Qadaa El Chouf Piped Water Supplies

| Sampling Round | Free Residual Chlorine mg/L | | | F. Coliforms / 100 ml |
|---|---|---|---|---|
| | % > 0.3 mg/L | % < 0.1 mg/L | % = 0 mg/L | % positive |
| Round 1 | 0% | 38% | 43% | 73% |
| Round 2 | 0% | 100% | 100% | 55% |
| Round 3 | 0% | 81% | 0% | 73% |
| Round 4 | 0% | 76% | 0% | 18% |
| Mean | 0% | 74% | 36% | 55% |
| EPA | | | | - |
| WHO | | | | - |
| LIBNOR | 0.3 | | | - |

Evaluating the water quality based on the HWQI, AWQI, UNEP WQI and the PWQI as presented in tables 4.4a&b-4.6 and figure 4.4, the following can be noted:

- Based on the calculated PWQI, 18% of the piped water supplies are of good quality that rarely depart from LIBNOR standards. In addition, 55% are of fair quality that sometimes departs from standards. Moreover, 27% are of marginal quality that is mostly noncompliant with national standards (Table 4.5 & 4.6).
- Based on the AWQI, 64% of the piped water supplies are of excellent quality. And, 36% are of good quality that rarely depart from LIBNOR standards. As such, the AWQI highly boasts the water quality classification, as explained before in section 4.2.1, due to the unaccounted for microbiological quality (Tables 4.5- 4.6).
- Based on the HWQI index, only 9% of piped water supplies are o excellent quality, 18% are of good quality and 9% are fair in quality. The majority of the piped water supplies fall under 64% that often noncompliant with LIBNOR Standards (Table 4.5 & 4.6). The variability in HWQI results of Qadaa El Chouf is due to different exceedances of parameters.

This is mainly due to the significant contribution of the faecal coliform parameter to the overall index due to the limited number of monitored parameters, as indicated in section 4.2.1. Hence, in supplies where faecal coliforms are present the HWQI drops automatically to a lower quality classification (Table 4.5 & 4.6).

- Based on the UNEP WQI, 27% of the piped water supplies are of good quality that rarely depart from standard levels. However, 45% of supplies are of fair quality that sometimes depart from LIBNOR Standards. And, 27% are of marginal quality that is often noncompliant with national standards (Tables 4.5-4.6).

- The PWQI is more reflective of water quality than the AWQI which only reflects on the acceptability of the water. The AWQI does not reflect the health aspect due to the unaccounted for microbiological profile. This gave false positive results by boosting the water quality classification to excellent for all the piped water supplies (Figure 4.4).
- The HWQI is also non-reflective on the actual water quality since it automatically drops the index quality classification to marginal when faecal coliforms are present. As before, the HWQI yielded, relatively, the lowest water quality classification among the 4 computed indices.

This is due, as explained earlier, to the high contribution of the faecal coliform parameter to the overall index. Moreover, the HWQI does not address water acceptability which is a major factor in determining water use by consumers. Thus, the PWQI is still more reflective than the HWQI (Figure 4.4).

- The UNEP WQI and the PWQI yield overall similar results in terms of water quality classification; still, the ranges seem to be more defined by the PWQI possibly as it includes parameters that reflect more on the types of water sources, sources of pollution and the management of water supplies (Figure 4.3). As, such, the UNEP WQI seems to boast minimally the water quality classification as it constitute 5 water quality parameters (arsenic, boron, chromium, fluorides, and mercury) that are below detection limits.

Table 4.5: Quality of Piped Water Supplies of Qadaa El Chouf based on determined Indices

| | | HWQI | | AWQI | | UNEP WQI | | PWQI | |
|---|---|---|---|---|---|---|---|---|---|
| Qadaa El CHOUF | C1 | 97.8 | Excellent | 87.1 | Good | 89.7 | Good | 78.5 | Fair |
| | C2 | 53.0 | Marginal | 80.1 | Good | 57.9 | Marginal | 57.2 | Marginal |
| | C3 | 70.2 | Fair | 88.9 | Good | 75.5 | Fair | 71.9 | Fair |
| | C5 | 61.2 | Marginal | 100.0 | Excellent | 73.1 | Fair | 75.8 | Fair |
| | C6 | 80.0 | Good | 100.0 | Excellent | 88.2 | Good | 89.4 | Good |
| | C7 | 47.3 | Marginal | 100.0 | Excellent | 58.1 | Marginal | 61.2 | Marginal |
| | C8 | 61.0 | Marginal | 100.0 | Excellent | 73.3 | Fair | 70.0 | Fair |
| | C14 | 58.2 | Marginal | 100.0 | Excellent | 70.0 | Fair | 73.1 | Fair |
| | C16 | 80.1 | Good | 100.0 | Excellent | 88.2 | Good | 85.0 | Good |
| | C17 | 61.0 | Marginal | 100.0 | Excellent | 73.2 | Fair | 71.7 | Fair |
| | C19 | 46.1 | Marginal | 91.7 | Good | 51.0 | Marginal | 48.9 | Marginal |

Table 4.6: Classification of the Quality of Qadaa Chouf Piped Water Supplies based on the determined Indices

| | | HWQI | AWQI | UNEP WQI | PWQI |
|---|---|---|---|---|---|
| Qadaa El Chouf | Excellent | 9% | 64% | 0% | 0% |
| | Good | 18% | 36% | 27% | 18% |
| | Fair | 9% | 0% | 45% | 55% |
| | Marginal | 64% | 0% | 27% | 27% |
| | Poor | 0% | 0% | 0% | 0% |

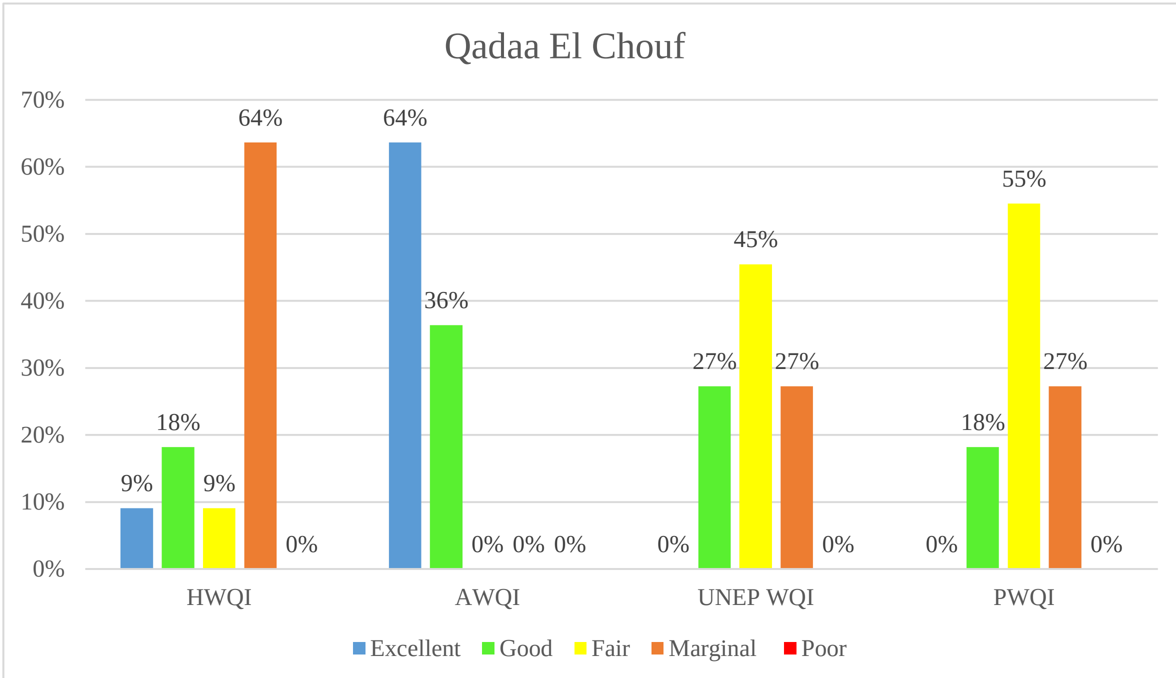


Figure 4.3: Bar chart showing the Classification of the Quality of Qadaa El Chouf Piped Water Supplies based on the determined indices

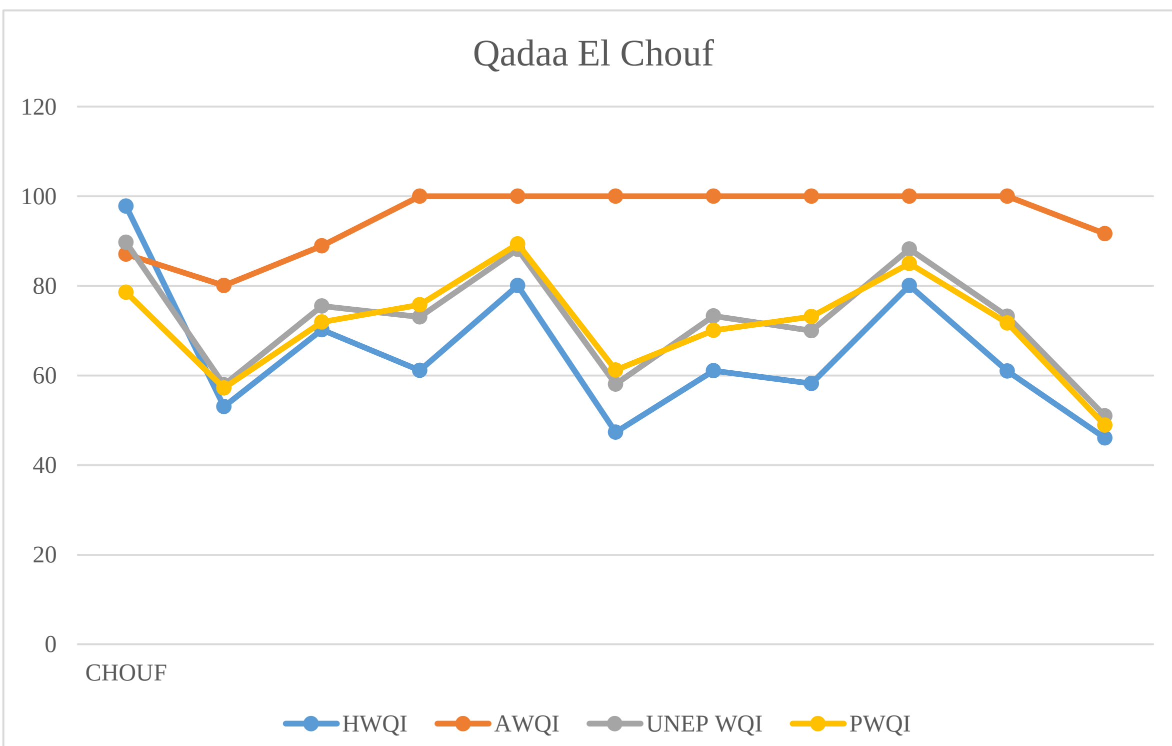


Figure 4.4: Sensitivity of Computed Water Quality Indices

### *4.2.3 Qadaa Baabda*

The main physical, chemical and microbiological water quality parameters of the piped water supplies of Qadaa Baabda are presented in tables 4.7a and 4.7b. Evaluating the water quality based on the indicated parameters, show moderate quality variability between the wet and dry seasons of the year. Overall, only 3% of piped water supplies had TDS levels more than 500 mg/l and did exceed the LIBNOR standard (Table 4.7a). Additionally, 3% of supplies had TDS levels higher than the WHO Guideline level of 1000mg/L. Even though high levels of TDS, as indicated before, do not have direct health impacts concentrations higher than 1000 mg/L may be associated with irritation of the gastrointestinal tract, unpleasant taste and excessive scaling in water pipes, heaters, boilers and household appliances (WHO, 2011).

Moreover, hardness levels were relatively high reflective on ground water sources and exposure to pollution. And, the non-carbonate hardness levels were relatively moderate (80- 214mg/l) mostly indicative to sea water infiltration in coastal wells and exposure to sources of pollution. Further, the chloride levels in 3% of supplies exceeded the LIBNOR standard of 200 mg/L (Table 4.7a); with the highest detected level of 1530 mg/L. The high levels of chlorides occurred during the peak of the dry season, in Round 2, due to sea water infiltration. Still, sulfate levels did not exceed the LIBNOR standard of 250 mg/L (Table 4.7a). And, the nitrate levels were below the LIBNOR standard of 10mg/L as nitrate-nitrogen (Table 4.7a).

The pH of the piped water supplies mainly ranged between 7.54 and 8.56. All levels were within the acceptable range of 6.5-8.5 reflective of ground water supplies (Table 4.7a). As for trace metals, the levels of copper, nickel, zinc and manganese were all below the health LIBNOR Standards /WHO Guideline levels (LIBNOR/ of 1 mg/L, 0.02 mg/L, and 5 mg/L, 0.4 mg/l, respectively. However, the levels of lead in round 3 exceeded the guidelines in all piped water supplies, and in 26% of the supplies in round 4 (April 20016) (Table 4.7a). Accordingly, lead leaching may have been enhanced by precipitation (rainy season). Additionally, cadmium concentrations were above the standard (0.005 mg/L) in the 1st round, May - June 2015 (Table 4.7a). And, still, although the levels of manganese did not exceed the health standard (WHO guideline of 0.4mg/L, it is impacting water acceptability based on the 0.05mg/L LIBNOR standard. This is will further degrade networks by coating the pipes leading to a black precipitate at high levels of 0.2mg/L (WHO, 2011)

Microbiologically, 30% of the piped water supplies were contaminated with faecal organisms. This reflects on insufficient levels of free residual chlorine that should protect the microbiological safety of the distribution network. And, this is further evident by the minimal detected levels of free residual chorine of less than 0.1 mg/l in 63 % of piped water supplies as presented in Table 4.7b.

Table 4.7a: Mean Levels of Critical Physical and Chemical Water Quality Indicators for Qadaa Baabda Piped Water Supplies

| Sampling Round | pH | TDS mg/L | | $NO_3$-N mg/L | $SO_4^{2-}$ mg/L - | $Cl^-$ mg/L | Pb mg/L | Cd mg/L |
|---|---|---|---|---|---|---|---|---|
| | % <6.5 & > 8.5 | % > 500 mg/L | % > 1000 mg/L | % > 10 mg/L | % > 250 mg/L | % > 200 mg/L | > 0.01 mg/L | > 0.005 mg/L |
| Round 1 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 100% |
| Round 2 | 0% | 13% | 13% | 0% | 0% | 13% | 0% | 13% |
| Round 3 | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Round 4 | 0% | 0% | 0% | 0% | 0% | 0% | 33% | 0% |
| Mean | 0% | 3% | 3% | 0% | 0% | 3% | 33% | 28% |
| EPA | 6.5-8.5 | 500 | | 10 | 250 | 250 | 0.015 | 0.005 |
| WHO | 6.5-8.5 | 1000 | | 50 | 250 | 250 | 0.01 | 0.003 |
| LIBNOR | 6.5-8.5 | 500 | | 45 | 250 | 200 | 0.01 | 0.005 |

Table 4.7b: Mean Levels of Microbiological Water Quality Indicators and Free Residual Chlorine for Qadaa Baabda Piped Water Supplies

| Sampling Round | Free Residual Chlorine | | | F. Coliforms |
|---|---|---|---|---|
| | mg/L | | | / 100 ml |
| | % > 0.3 mg/L | % < 0.1 mg/L | % = 0 mg/L | % positive |
| Round 1 | 0.0% | 65% | 0% | 40% |
| Round 2 | 0.0% | 66% | 0% | 20% |
| Round 3 | 20% | 66% | 0% | 13% |
| Round 4 | 0.0% | 53% | 0% | 47% |
| Mean | 4% | 63% | 0% | 30% |
| EPA | | | | - |
| WHO | | | | - |
| LIBNOR | 0.3 | | | - |

Evaluating the water quality based on the HWQI, AWQI, UNEP WQI and the proposed PWQI (Tables 4.8 & 4.9 and figure 4.5), the following can be noted:

- Based on PWQI, 33% of the piped water supplies are of good quality. Still, 20% are of fair quality and 27% are marginal in quality. Additionally, 20% receive poor water quality where which is usually noncompliant with LIBNOR Standards (Tables 4.8-4.9).
- Based on the HWQI index, 33% of piped water supplies are of good quality. Moreover, 33% of supplies are classified as marginal in quality and 33% as poor; mostly noncompliant with LIBNOR Standards (Table 4.8 & 4.9). The variability in HWQI

results for Qadaa Baabda is due to different exceedances of parameters mainly due to the major contribution of the faecal coliform parameter to the overall index as presented earlier. Hence, in areas where faecal coliforms are detected, the HWQI quality classification automatically dropped to either fair or poor.

- Based on the AWQI, 87% of the piped water supplies are of excellent quality and 13% are of good quality (Table 4.8 & 4.9). The drop to good quality classification is mainly due to high levels of chlorides in a few areas where the sources feeding the distribution networks are exposed to sea water infiltration.
- Based on UNEP WQI, around 33% of the piped water supplies are of good quality. Additionally, 20% fair quality, 27% marginal water, and 20% poor quality that is mostly noncompliant with LIBNOR Standards (Tables 4.8-4.9).
- The PWQI is more reflective of the quality on the water than the AWQI which only reflects on the acceptability of the water due to the unaccounted for microbiological profile as explained before. Hence, the AWQI gives false positives by inflating the water quality classification to excellent for all the distribution areas (Figure 4.6)
- The HWQI is also non-reflective on the actual water quality since it automatically drops the index classification to poor when faecal coliforms are present. Also as explained before, the HWQI mostly yielded the lowest scores among the 4 computed indices. This is due to the high contribution of the faecal coliform parameter to the calculated index. Moreover, the index neglects water acceptability which is a major factor for water use by consumers (Figure 4.6).
- The UNEP WQI and the PWQI yield overall similar results in terms of water quality classification; (Figure 4.5).

Table 4.8: Quality of Piped Water Supplies of Qadaa Baabda based on determined Indices

| | | HWQI | | AWQI | | UNEP WQI | | PWQI | |
|---|---|---|---|---|---|---|---|---|---|
| Qadaa BAABDA | B1 | 94.9 | Good | 100.0 | Excellent | 92.4 | Good | 91.5 | Good |
| | B2 | 94.4 | Good | 100.0 | Excellent | 92.4 | Good | 94.5 | Good |
| | B5 | 57.3 | Marginal | 100.0 | Excellent | 66.9 | Fair | 69.5 | Fair |
| | B6 | 94.9 | Good | 98.4 | Excellent | 88.8 | Good | 94.6 | Good |
| | B8 | 89.0 | Good | 100.0 | Excellent | 92.1 | Good | 88.3 | Good |
| | B9 | 64.3 | Marginal | 100.0 | Excellent | 75.2 | Fair | 77.1 | Fair |
| | B10 | 89.2 | Good | 100.0 | Excellent | 92.2 | Good | 86.1 | Good |
| | B11 | 41.3 | Poor | 92.8 | Good | 40.4 | Poor | 42.2 | Poor |
| | B12 | 41.3 | Poor | 90.3 | Good | 39.1 | Poor | 42.1 | Poor |
| | B13 | 44.6 | Poor | 100.0 | Excellent | 48.5 | Marginal | 49.2 | Marginal |
| | B15 | 41.6 | Poor | 100.0 | Excellent | 42.3 | Poor | 42.5 | Poor |
| | B16 | 41.3 | Poor | 100.0 | Excellent | 46.9 | Marginal | 47.4 | Marginal |
| | B17 | 48.5 | Marginal | 100.0 | Excellent | 59.3 | Marginal | 61.0 | Marginal |
| | B18 | 45.5 | Marginal | 100.0 | Excellent | 50.2 | Marginal | 52.0 | Marginal |
| | B19 | 60.4 | Marginal | 100.0 | Excellent | 71.5 | Fair | 73.4 | Fair |

Table 4.9: Classification of the Quality of Qadaa Baabda Piped Water Supplies based on the determined Indices

| | | HWQI | AWQI | UNEP WQI | PWQI |
|---|---|---|---|---|---|
| Qadaa BAABDA | Excellent | 0% | 87% | 0% | 0% |
| | Good | 33% | 13% | 33% | 33% |
| | Fair | 0% | 0% | 20% | 20% |
| | Marginal | 33% | 0% | 27% | 27% |
| | Poor | 33% | 0% | 20% | 20% |

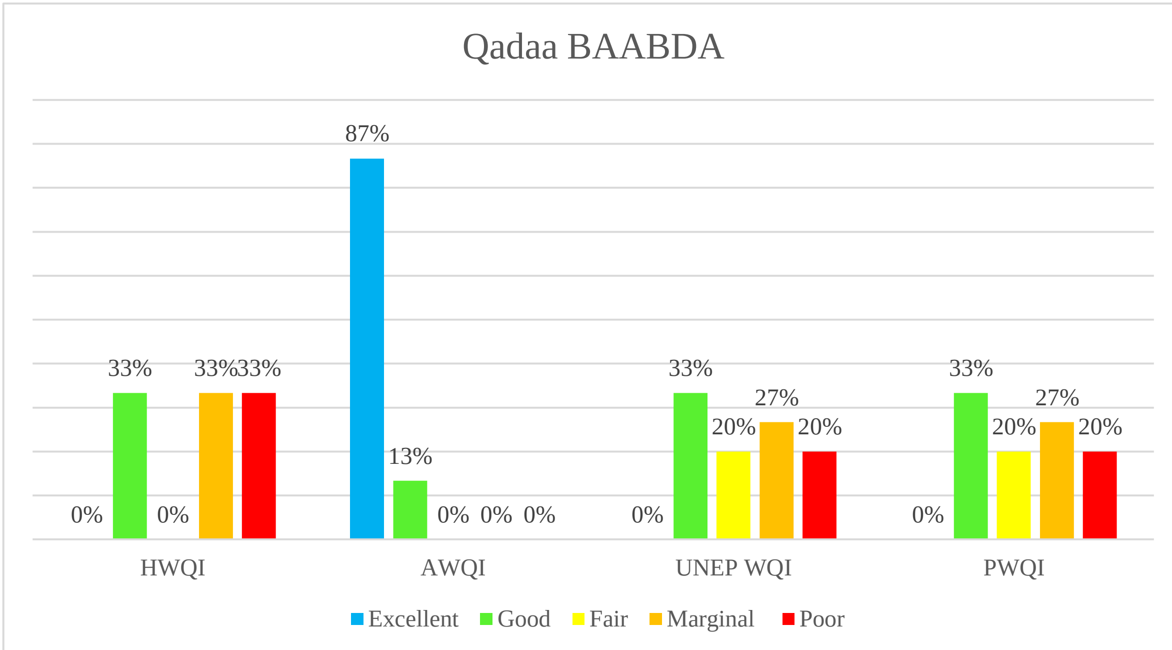


Figure 4.5: Bar Chart showing the Classification of the Quality of Qadaa Baabda Piped Water Supplies based on the determined Indices

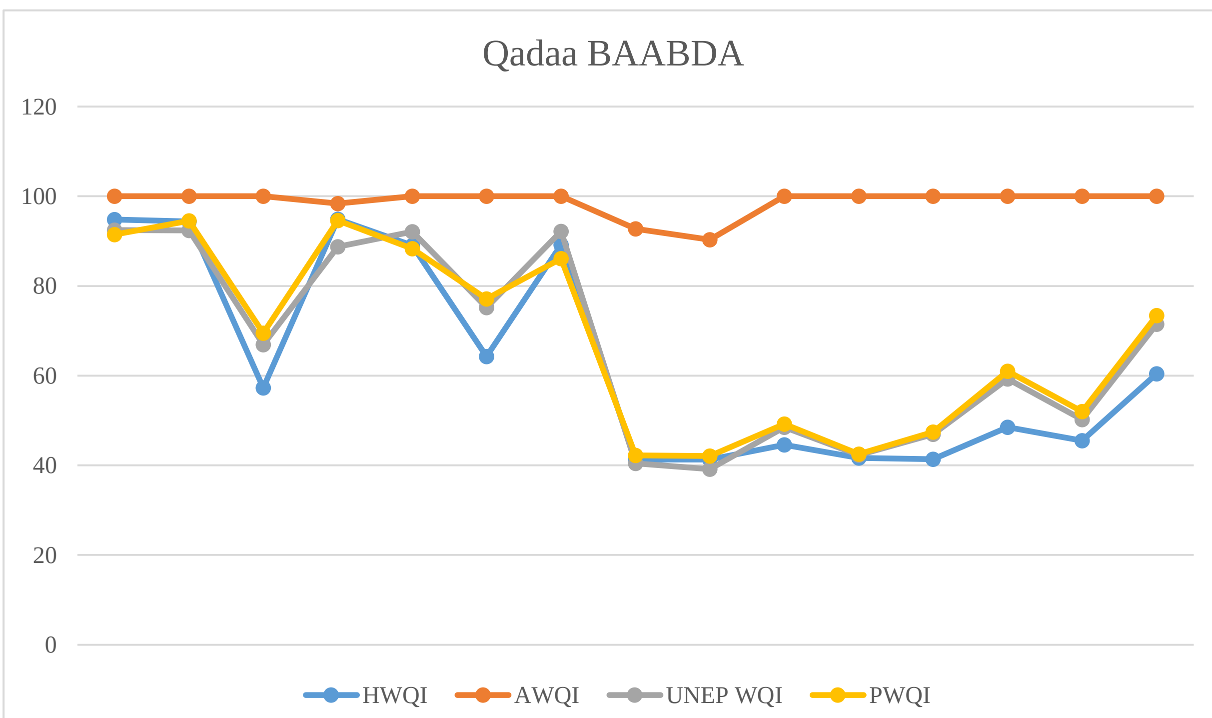


Figure 4.6: Sensitivity of Computed Water Quality Indices

### *4.2.4 Qadaa Jbeil*

The main physical, chemical and microbiological water quality parameters of the piped water supply of Qadaa Jbeil are presented in tables 4.10a and 4.10b. Evaluating the water quality based on the indicated parameters, show minimal variability between the wet and dry seasons of the year; mainly reflective of the use of spring and well water sources.

Overall, none of the piped water supplies had TDS levels over 500 mg/L (LIBNOR Standard) as presented in table 4.10a. Moreover, hardness levels were moderate reflective on groundwater sources. Additionally, the levels of the non-carbonate hardness were relatively low (20-46 mg/L) reflective of minimal exposure to sources of pollution. Also, the chloride levels were all well below the LIBNOR standard of 200 mg/L (Table 4.10a). And, the sulfate levels also did not exceed the LIBNOR standard. Additionally, nitrate levels did not exceed the standard of 10mg/L as nitrate-nitrogen (Table 4.10a).

The pH of the piped water supplies mainly ranged between 7.3 and 8.5, falling within the acceptable range set by LIBNOR (Table 4.10a). As for trace metals, the levels of copper, nickel, zinc , cadmium and manganese were all below the health LIBNOR Standards /WHO Guideline levels (LIBNOR/ of 1 mg/L, 0.02 mg/L, and 5 mg/L, 0.4 mg/l, respectively.

Still, lead levels for Rounds 3 (January 2016) exceeded the LIBNOR standard (0.01 mg/L) by 100% and by 47% for Round 4 (April 2016) thus raising a warning flag (Table 4.10a). Accordingly, as explained before, lead leaching may have been enhanced by precipitation (rainy season). And, although the levels of manganese did not exceed the health standard (WHO guideline of 0.4mg/L, it is impacting water acceptability based on the 0.05mg/L LIBNOR standard.  This is will further degrade networks by coating the pipes leading to a black precipitate at high levels of 0.2mg/L (WHO, 2011)

Microbiologically, 16.5% of the piped water supplies were faecally contaminated as presented in table 4.10b. This could be attributed to insufficient levels of free residual chlorine that should be maintained throughout the distribution network to insure the microbiological safety. This is further confirmed by levels of free residual chorine that are less than 0.1 mg/l in 36 % of the piped water supplies as presented in table 4.10b. The chlorination problem needs to be addressed in order to properly determine the chlorine demand and insure sufficient free residual chlorine levels throughout the network.

Table 4.10a: Mean Levels of Critical Physical and Chemical Water Quality Indicators for Qadaa Jbeil Piped Water Supplies

| Sampling Round | pH | TDS mg/L | | $NO_3$-N mg/L | $SO_4^{2-}$ mg/L | $Cl^-$ mg/L | Pb mg/L | Cd mg/L |
|---|---|---|---|---|---|---|---|---|
| | % <6.5 & > 8.5 | % > 500 mg/L | % > 1000 mg/L | % > 10 mg/L | % > 250 mg/L | % > 200 mg/L | > 0.01 mg/L | > 0.005 mg/L |
| Round 1 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Round 2 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Round 3 | 4% | 0% | 0% | 0% | 0% | 0% | 100% | 0% |
| Round 4 | 0% | 0% | 0% | 0% | 0% | 0% | 47% | 0% |
| Mean | 1% | 0% | 0% | 0% | 0% | 0% | 37% | 0% |
| EPA | 6.5-8.5 | 500 | | 10 | 250 | 250 | 0.015 | 0.005 |
| WHO | 6.5-8.5 | 1000 | | 50 | 250 | 250 | 0.01 | 0.003 |
| LIBNOR | 6.5-8.5 | 500 | | 45 | 250 | 200 | 0.01 | 0.005 |

Table 4.10b: Mean Levels of Microbiological Water Quality Indicators and Free Residual Chlorine for Qadaa Jbeil Piped Water Supplies

| Sampling Round | Free Residual Chlorine | | | F. Coliforms |
|---|---|---|---|---|
| | mg/L | | | / 100 ml |
| | % > 0.3 mg/L | % < 0.1 mg/L | % = 0 mg/L | % positive |
| Round 1 | 34% | 16% | 6% | 34% |
| Round 2 | 10% | 65% | 37% | 16% |
| Round 3 | 9% | 28% | 6% | 6% |
| Round 4 | 10% | 35% | 0% | 10% |
| Mean | 16% | 36% | 12% | 16.5% |
| EPA | | | | - |
| WHO | | | | - |
| LIBNOR | 0.3 | | | - |

Evaluating the water quality based on the HWQI, AWQI, UNEP WQI and the proposed PWQI (Tables 4.11-4.12 and Figure 4.7), the following can be noted:

- Based on the PWQI, 37% of the piped water supplies of Qadaa Jbeil are of excellent quality and 37% are of good quality. Still, 11% are of fair quality and 16% are marginal in quality where conditions often depart from LIBNOR Standards (Tables 4.11-4.12).
- Based on the HWQI index, 47% of piped water supplies are of excellent quality, while 16% are of good water quality. Still, 11% are of fair quality, 26 % are marginal quality that is often noncompliant with LIBNOR Standards as presented in tables 4.11-4.12. The variability in HWQI for Qadaa Jbeil is due to different exceedances of parameters attributed to the large contribution of the faecal coliform parameter to the overall index as explained before. Hence, in 22% of supplies that are faecally contaminated the quality classification automatically drops to marginal (Table 4.10b).

- Based on the AWQI, 95% of the piped water supplies are classified as excellent in quality and only 5% as good (Tables 4.11- 4.12). This is highly misleading as it is mostly due to the fact that the levels of the acceptability water quality parameters are all in compliance with LIBNOR standards. And, the minor exceptions in few piped water supplies where levels of color and chlorides exceed the standards, lead to a drop in the index classification to good.
- Based on UNEP WQI, 42% of the piped water supplies are of excellent quality, and 32% are of good quality. Still, 5% are of fair quality and 21% are of marginal quality that is mostly noncompliant with LIBNOR Standards (Tables 4.11-4.12).
- The PWQI is more reflective of the water quality than the AWQI which only reflects on the acceptability of the water. The AWQI does not reflect the health aspect of the water quality due to the unaccounted for microbiological profile. Hence, it gives false positives by inflating the water quality to excellent for all the distribution areas (Figure 4.8).
- The HWQI is also non-reflective on the actual water quality since it automatically drops the index classification to marginal when faecal coliforms are present (16.5%) (Table 4.10b). And, as explained before, this is due to the high influence of the faecal coliform parameter on the computation of the index. Moreover, this index disregards water acceptability which is a major factor in determining water use by consumers (Figure 4.8).
- The UNEP WQI and the PWQI yield overall similar results in terms of water quality classification; still, the ranges seem to be more defined by the PWQI possibly as it includes parameters that reflect more on the types of water sources, sources of pollution

and the management of water supplies (Figure 4.8). As, such, the UNEP WQI seems to boast minimally the water quality classification as it constitute 5 water quality parameters (arsenic, boron, chromium, fluorides, and mercury) that are below detection limits.

Table 4.11: Classification of the Quality of Qadaa Jbeil Piped Water Supplies based on the determined Indices

| | | HWQI | | AWQI | | UNEP WQI | | PWQI | |
|---|---|---|---|---|---|---|---|---|---|
| Qadaa JBEIL | J2 | 97.0 | Excellent | 95.2 | Excellent | 88.5 | Good | 83.6 | Good |
| | J3 | 97.1 | Excellent | 100.0 | Excellent | 96.2 | Excellent | 95.8 | Excellent |
| | J4 | 97.3 | Excellent | 100.0 | Excellent | 96.2 | Excellent | 97.5 | Excellent |
| | J6 | 79.7 | Fair | 100.0 | Excellent | 88.0 | Good | 86.1 | Good |
| | J7 | 97.1 | Excellent | 100.0 | Excellent | 96.2 | Excellent | 97.5 | Excellent |
| | J8 | 97.0 | Excellent | 100.0 | Excellent | 96.2 | Excellent | 98.3 | Excellent |
| | J9 | 97.1 | Excellent | 100.0 | Excellent | 96.2 | Excellent | 92.0 | Good |
| | J10 | 97.0 | Excellent | 100.0 | Excellent | 96.2 | Excellent | 96.3 | Excellent |
| | J11 | 97.0 | Excellent | 92.1 | Good | 91.8 | Good | 92.3 | Good |
| | J12 | 46.5 | Marginal | 100.0 | Excellent | 56.3 | Marginal | 59.1 | Marginal |
| | J13 | 97.3 | Excellent | 98.4 | Excellent | 92.5 | Good | 97.7 | Excellent |
| | J14 | 47.2 | Marginal | 100.0 | Excellent | 58.0 | Marginal | 58.6 | Marginal |
| | J15 | 90.3 | Good | 98.4 | Excellent | 92.2 | Good | 93.0 | Good |
| | J18 | 90.5 | Good | 100.0 | Excellent | 95.8 | Excellent | 96.3 | Excellent |
| | J19 | 90.5 | Good | 100.0 | Excellent | 95.8 | Excellent | 93.5 | Good |
| | J20 | 51.7 | Marginal | 100.0 | Excellent | 65.0 | Marginal | 68.3 | Fair |
| | J21 | 66.7 | Fair | 100.0 | Excellent | 81.5 | Good | 82.6 | Good |
| | J22 | 46.7 | Marginal | 100.0 | Excellent | 57.1 | Marginal | 60.0 | Marginal |
| | J23 | 61.6 | Marginal | 98.4 | Excellent | 75.2 | Fair | 78.5 | Fair |

Table 4.12: Classification of the Quality of Qadaa Jbeil Piped Water Supplies based on the determined Indices

| | | HWQI | AWQI | UNEP WQI | PWQI |
|---|---|---|---|---|---|
| Qadaa Jbeil | Excellent | 47% | 95% | 42% | 37% |
| | Good | 16% | 5% | 32% | 37% |
| | Fair | 11% | 0% | 5% | 11% |

| | | | | | |
|---|---|---|---|---|---|
| | Marginal | 26% | 0% | 21% | 16% |
| | Poor | 0% | 0% | 0% | 0% |

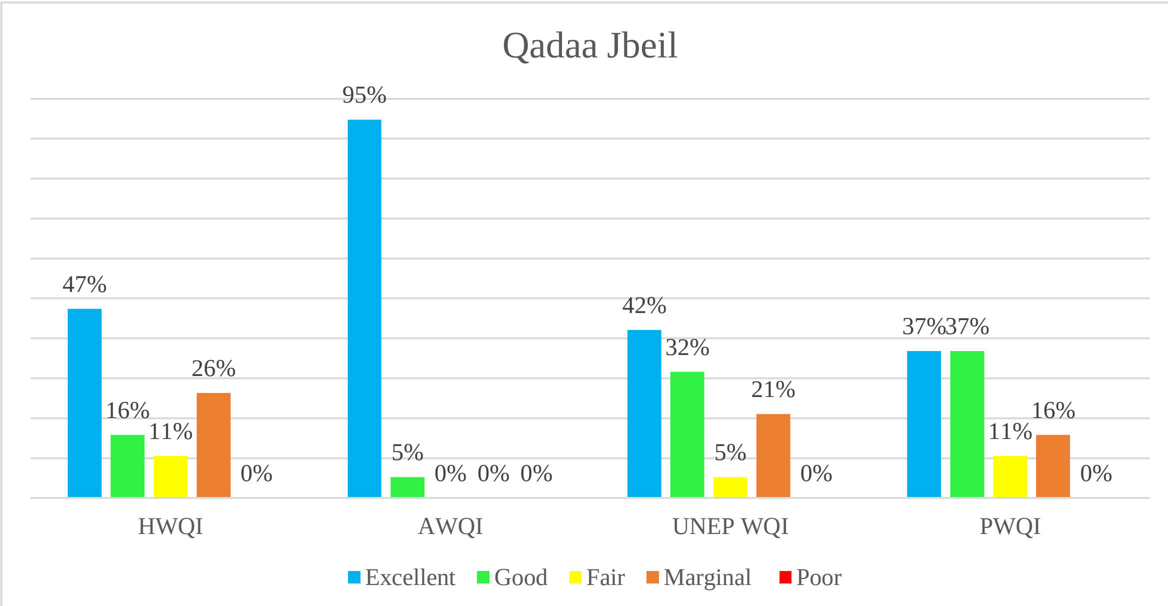


Figure 4.7: Bar Chart showing the Classification of the Quality of Qadaa Jbeil Piped Water Supplies based on the determined indices

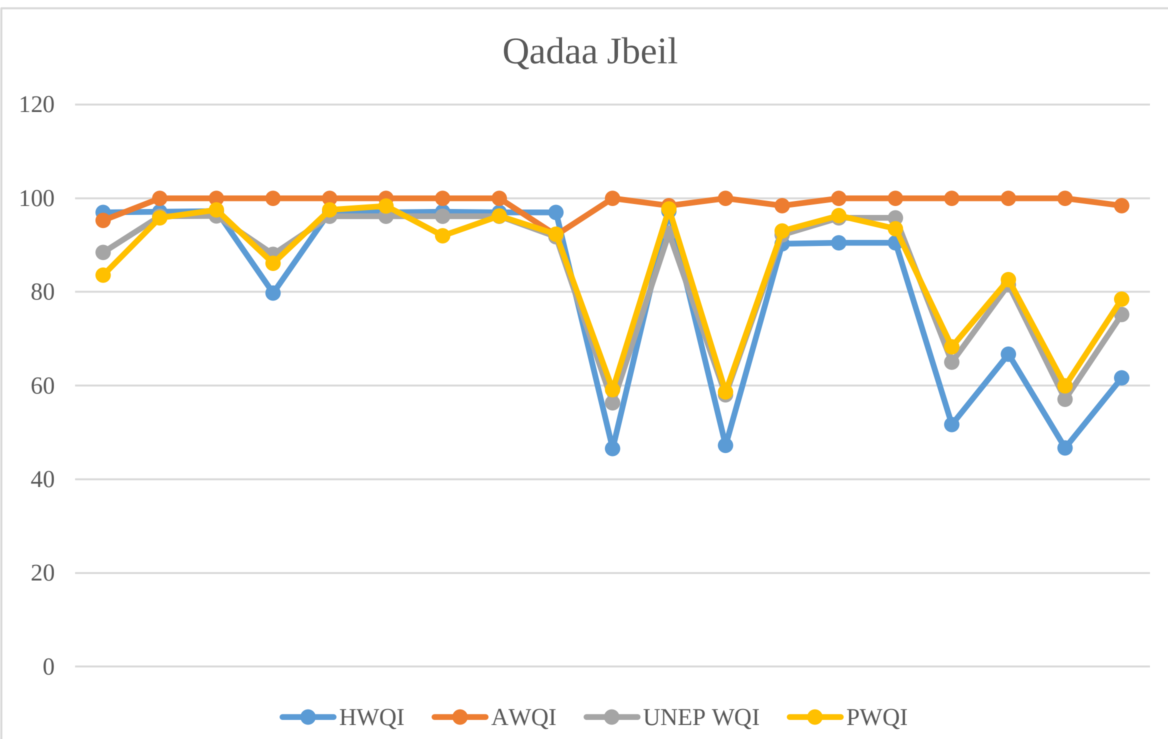


Figure 4.8: Sensitivity of Computed Water Quality Indices

### *4.2.5 Qadaa Kesserwan*

The main physical, chemical and microbiological water quality parameters of the piped water supplies of Qadaa of Kesserwan are presented in tables 4.13a and 4.13b. Evaluating water quality based on the indicated quality parameters, shows minimal variability (wet and dry seasons) which is mainly reflective of the use of spring and well water sources. Overall, all TDS levels were less than 500 mg/L and did not exceed the national standard recommended by LIBNOR (Table 4.13a). Moreover, hardness levels were moderate reflective of ground water sources. And, the levels of noncarbonated hardness were relatively low (20-46 mg/L) reflective of minimal exposure to pollution. The chloride levels were also well below the LIBNOR standards of 200 mg/L, with the highest determined level of 45 mg/L. Moreover, sulfate levels were low and the nitrate levels did not exceed the standard of 10mg/L as nitrate-nitrogen (Table 4.13a).

The pH of the piped water supplies mainly ranged between 7.3 and 8.5 (Table 4.13a). All levels were within the acceptable range of 6.5-8.5 reflective of ground water supplies. The levels of cadmium, copper, nickel, zinc and manganese were all below the LIBNOR standards/WHO Guidelines of 0.005mg/L, 1 mg/L, 0.02 mg/L, 5 mg/L, and 0.4mg/L, respectively. Still, the levels of lead for rounds 1, 3 and 4 (June 2015, and January & April 2016) exceeded the LIBNOR standards (0.01 mg/L) in 59% of the supplies (Table 4.13a) and this is really alarming. Still, although the levels of manganese did not exceed the health standard (WHO guideline of 0.4mg/L, it is impacting water acceptability based on the 0.05mg/L LIBNOR standard. This is will further degrade networks by coating the pipes leading to a black precipitate at high levels of 0.2mg/L (WHO, 2011)

Microbiologically, 11% of the piped water supplies were faecally contaminated as presented in table 4.13b. This reflects possibly the exposure of the distribution network to faecal contamination. And, this is clearly confirmed by levels of free residual chorine of less than 0.1 mg/l in 25 % of water supplies (Table 4.13b). Still, 45% of the piped water supplies had free residual chlorine levels higher than 0.3 mg/L. High levels of free residual chlorine are also rejected by consumers due to undesirable odor and taste (WHO, 2011). As such, the need to properly control the process of disinfection by chlorination and instate chlorine re-dosing along the network is evident.

Table 4.13a: Mean Levels of Critical Physical and Chemical Water Quality Indicators for Qadaa Keserwan Piped Water Supplies

| Sampling Round | pH | TDS | | $NO_3$-N | $SO_4^{2-}$ | $Cl^-$ | Pb | Cd |
|---|---|---|---|---|---|---|---|---|
| | | mg/L | | mg/L | mg/L | mg/L | mg/L | mg/L |
| | % <6.5 & > 8.5 | % > 500 mg/L | % > 1000 mg/L | % > 10 mg/L | % > 250 mg/L | % > 200 mg/L | > 0.01 mg/L | > 0.005 mg/L |
| Round 1 | 0% | 0% | 0% | 0% | 0% | 0% | 42% | 0% |
| Round 2 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| Round 3 | 0% | 0% | 0% | 0% | 0% | 0% | 100% | 0% |
| Round 4 | 0% | 0% | 0% | 0% | 0% | 0% | 95% | 0% |
| Mean | 0% | 0% | 0% | 0% | 0% | 0% | 59% | 0% |
| EPA | 6.5-8.5 | 500 | | 10 | 250 | 250 | 0.015 | 0.005 |
| WHO | 6.5-8.5 | 1000 | | 50 | 250 | 250 | 0.01 | 0.003 |
| LIBNOR | 6.5-8.5 | 500 | | 45 | 250 | 200 | 0.01 | 0.005 |

Table 4.13b: Mean Levels of Critical Microbiological Water Quality Indicators for Qadaa Keserwan Piped Water Supplies

| Sampling Round | Free Residual Chlorine | F. Coliforms |
|---|---|---|
| | mg/L | / 100 ml |

| | % > 0.3 mg/L | % < 0.1 mg/L | % = 0 mg/L | % positive |
|---|---|---|---|---|
| Round 1 | 54% | 13% | 0% | 8.7% |
| Round 2 | 37% | 31% | 0% | 10.5% |
| Round 3 | 47% | 42% | 0% | 16% |
| Round 4 | 42% | 16% | 0% | 16% |
| Mean | 45% | 25% | 0% | 13% |
| EPA | | | | - |
| WHO | | | | - |
| LIBNOR | 0.3 | | | - |

Evaluating the water quality based on the HWQI, AWQI, UNEP WQI and the proposed PWQI (Tables 4.14-4.15 and Figure 4.9), the following can be noted:

- Based on the calculated PWQI, 16% of the piped water supplies are of excellent quality and 58% of good quality. Still, 26% are of fair quality where conditions sometimes depart from standards (Tables 4.14-4.15).
- Based on HWQI, 5% of the piped water supplies are of excellent water quality, and 42% are of good water quality. Still, 26% are or fair quality and 11% are of marginal quality (Tables 4.14-4.15).The variability in HWQI results is due to different exceedances of parameters; mainly due to the large contribution of the faecal coliform parameter to the overall HWQI as explained before in section 4.2.1.
- Based on the AWQI, 63% of the piped water supplies receive excellent water quality and 32% receive good water quality (Tables 4.14-4.15). The AWQI gave the best water quality classification ranging between good and excellent since in most cases the levels of the acceptability parameters (color, turbidity, ammonia, chlorides, iron, pH, sodium, sulfate, and zinc) were in compliance with LIBNOR standards. The supplies classified

as good had high levels of color, turbidity and chlorides in addition to a spike in iron levels in rounds 3 and 4 (January & April 2016).

- Based on the UNEP WQI, 26% of the piped water supplies are of excellent water quality, 47% of the piped water supplies receive good water quality, and 26% receive fair quality water (Tables 4.14-4.15).
- The PWQI is more indicative of the water quality than the AWQI which only reflects on the acceptability of the water due to the unaccounted for microbiological profile, as explained before. The AWQI thus inflated the water quality evaluation to excellent for all the distribution areas (Figure 4.10).
- The HWQI is also non-reflective of the actual water quality, since it automatically drops the index classification to marginal when faecal coliforms are present (Figure 4.10). As before, the HWQI water quality classification were mostly the lowest among the 4 computed indices. This is also due to the high contribution of the feacal coliform parameter to the HWQI that monitors only 7 parameters as explained before. Moreover, this index does not account for water acceptability which is a major factor in determining water use by consumers.
- The UNEP WQI and the PWQI yield overall similar results in terms of water quality classification; still, the ranges seem to be more defined by the PWQI possibly as it includes parameters that reflect more on the types of water sources, sources of pollution and the management of water supplies (Figure 4.9). As, such, the UNEP WQI seems to boast minimally the water quality classification as it constitute 5 water quality parameters (arsenic, boron, chromium, fluorides, and mercury) that are below detection limits.

Table 4.14: Quality of Piped Water Supplies of Qadaa Keserwan based on determined Indices

| | | HWQI | | AWQI | | UNEP WQI | | PWQI | |
|---|---|---|---|---|---|---|---|---|---|
| Qadaa KESERWAN | K2 | 97.6 | Excellent | 97.7 | Excellent | 92.4 | Good | 92.2 | Good |
| | K3 | 90.5 | Good | 100.0 | Excellent | 95.9 | Excellent | 95.3 | Excellent |
| | K4 | 90.7 | Good | 100.0 | Excellent | 95.9 | Excellent | 96.4 | Excellent |
| | K5 | 90.7 | Good | 100.0 | Excellent | 95.9 | Excellent | 89.8 | Good |
| | K6 | 58.2 | Marginal | 100.0 | Excellent | 72.9 | Fair | 76.2 | Fair |
| | K8 | 90.6 | Good | 91.3 | Good | 88.0 | Good | 86.1 | Good |
| | K10 | 89.6 | Good | 81.2 | Good | 85.0 | Good | 80.2 | Good |
| | K11 | 89.5 | Good | 100.0 | Excellent | 95.4 | Excellent | 95.9 | Excellent |
| | K12 | 90.6 | Good | 90.9 | Good | 87.8 | Good | 85.4 | Good |
| | K13 | 53.6 | Marginal | 97.4 | Excellent | 65.8 | Fair | 69.4 | Fair |
| | K14 | 66.8 | Fair | 97.8 | Excellent | 79.4 | Fair | 81.8 | Good |
| | K16 | 89.5 | Good | 90.7 | Good | 87.4 | Good | 83.7 | Good |
| | K17 | 89.6 | Good | 100.0 | Excellent | 95.4 | Excellent | 92.7 | Good |
| | K18 | 89.4 | Good | 97.1 | Excellent | 91.6 | Good | 91.8 | Good |
| | K19 | 90.1 | Good | 90.6 | Good | 87.5 | Good | 66.5 | Fair |
| | K21 | 74.5 | Fair | 100.0 | Excellent | 87.7 | Good | 86.4 | Good |
| | K22 | 67.1 | Fair | 90.4 | Good | 75.7 | Fair | 74.8 | Fair |
| | K23 | 67.3 | Fair | 78.1 | Fair | 70.9 | Fair | 70.4 | Fair |
| | K24 | 73.6 | Fair | 100.0 | Excellent | 87.3 | Good | 83.5 | Good |

Table 4.15: Classification of the Quality of Qadaa Keserwan Piped Water Supplies based on the determined Indices

| | | HWQI | AWQI | UNEP WQI | PWQI |
|---|---|---|---|---|---|
| Qadaa Keserwan | Excellent | 5% | 63% | 26% | 16% |
| | Good | 58% | 32% | 47% | 58% |
| | Fair | 26% | 5% | 26% | 26% |
| | Marginal | 11% | 0% | 0% | 0% |
| | Poor | 0% | 0% | 0% | 0% |

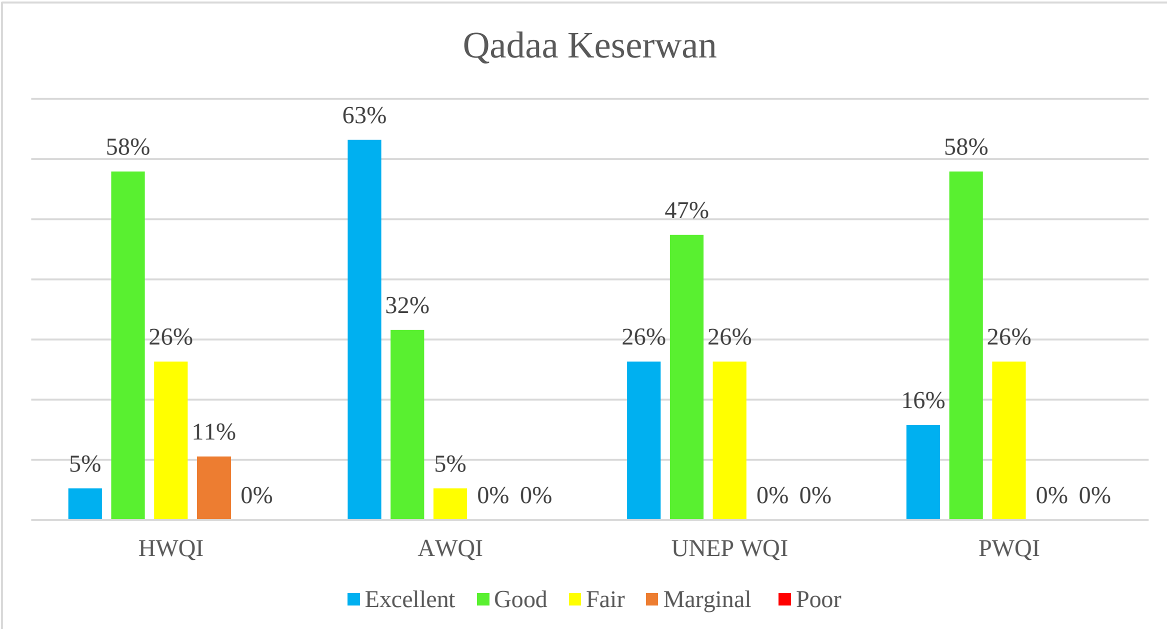


Figure 4.9: Bar Chart showing the Classification of the Quality of Qadaa Kesserwan Piped Water Supplies based on determined indices

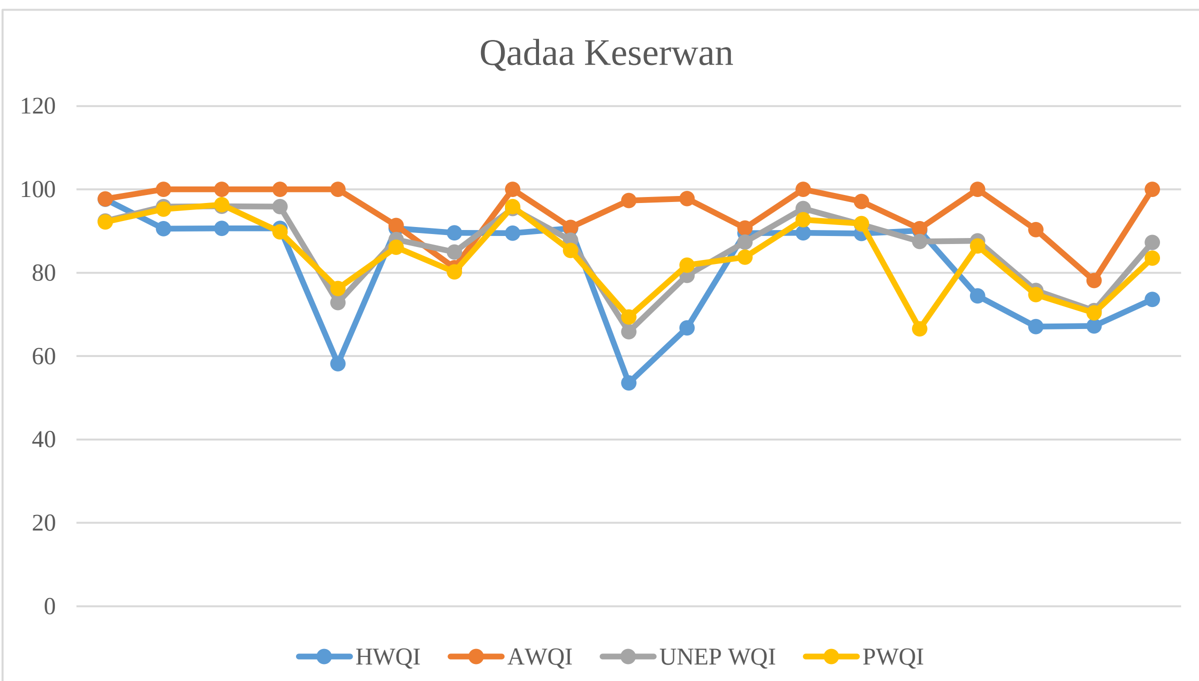


Figure 4.10: Sensitivity of Computed Water Quality Indices

### *4.2.6 Qadaa El Matn*

The main physical, chemical and microbiological water quality parameters of the piped water supply of Qadaa El Matn are presented in tables 4.16a and 4.16b. Evaluating the water quality based on the indicated water quality parameters, show minimal water variability between the wet and dry seasons of the year. This is mainly reflective of the use of spring and well water sources. Overall, only 1% of the piped water supplies had TDS levels over 1000 mg/L during the peak of the wet season. However, the rest of the piped water supplies had TDS levels less than 500 mg/l and did not exceed the LIBNOR Standard (Table 4.16a).

Moreover, hardness levels were moderate reflective of ground water sources, and the levels of non-carbonate hardness was relatively minimal (10 - 60 mg/L) reflective of minimal exposure to pollution. The chloride levels were all below the LIBNOR standards except for 1% of the piped water supplies along the costal line (Table 4.16a). The highest determined chloride level was 440 mg/L exceeding the WHO guideline of 250 mg/L. This would result in a salty taste of the water and would be rejected by consumers (WHO, 2011). The sulfate levels also did not exceed the LIBNOR standard of 250 mg/L (Table 4.16a). And, the nitrate levels did not also exceed the LIBNOR standard of 10mg/L as nitrate-nitrogen and are not as such correlated to any health impact (WHO, 2011).

The pH of ranged between 7.3 and 8.5 (Table 4.16a). Only one sample slightly exceeded the upper limit (8.51) resulting in a mean on 1% exceedance for pH (Table 4.16a). As for trace metals, the levels of copper, nickel, zinc and manganese were all below the health LIBNOR Standards /WHO Guideline levels (LIBNOR/ of 1 mg/L, 0.02 mg/L, and 5 mg/L, 0.4 mg/l, respectively. Still, the lead levels of rounds 1, 3 and 4, (June 2015, and

January & April 2016) exceeded the LIBNOR standard (0.01 mg/L) as presented in table 4.16a. And, although the levels of manganese did not exceed the health standard (WHO guideline of 0.4mg/L, it is impacting water acceptability based on the 0.05mg/L LIBNOR standard. This is will further degrade networks by coating the pipes leading to a black precipitate at high levels of 0.2mg/L (WHO, 2011).

Microbiologically, 13% of the piped water supplies were faecally contaminated as presented in table 4.16b. This could reflect on insufficient levels of free residual chlorine that should be maintained to protect the microbiological safety of the distribution network. And, this is further evident by the levels of free residual chorine that are less than 0.1 mg/l in 21 % of the supplies as presented in table 4.16b. The chlorination problem needs to be addressed in order to properly control disinfection and monitor the levels of free residual chlorine in distribution networks.

Table 4.16a: Mean Levels of Critical Physical and Chemical Water Quality Indicators for Qadaa El Matn Piped Water Supplies

| Sampling Round | pH | TDS | | $NO_3$-N | $SO_4^{2-}$ | $Cl^-$ | Pb | Cd |
|---|---|---|---|---|---|---|---|---|
| | | mg/L | | mg/L | mg/L | mg/L | mg/L | mg/L |
| | % <6.5 & > 8.5 | % > 500 mg/L | % > 1000 mg/L | % > 10 mg/L | % > 250 mg/L | % > 200 mg/L | > 0.01 mg/L | > 0.005 mg/L |
| Round 1 | 0% | 0% | 0% | 0% | 0% | 0% | 95% | 0% |
| Round 2 | 0% | 0% | 0% | 0% | 0% | 0% | 85% | 0% |
| Round 3 | 5% | 5% | 5% | 0% | 0% | 5% | 95% | 0% |
| Round 4 | 0% | 0% | 0% | 0% | 0% | 0% | 95% | 0% |
| Mean | 1% | 1% | 1% | 0% | 0% | 1% | 93% | 0% |
| EPA | 6.5-8.5 | 500 | | 10 | 250 | 250 | 0.015 | 0.005 |
| WHO | 6.5-8.5 | 1000 | | 50 | 250 | 250 | 0.01 | 0.003 |
| LIBNOR | 6.5-8.5 | 500 | | 45 | 250 | 200 | 0.01 | 0.005 |

4.16b: Mean Levels of Critical Microbiological Water Quality Indicators for Qadaa El Matn Piped Water Supplies

| Sampling Round | Free Residual Chlorine | | | F. Coliforms |
|---|---|---|---|---|
| | mg/L | | | / 100 ml |
| | % > 0.3 mg/L | % < 0.1 mg/L | % = 0 mg/L | % positive |
| Round 1 | 60% | 4% | 0% | 10% |
| Round 2 | 50% | 18% | 0% | 10% |
| Round 3 | 40% | 30% | 10% | 10% |
| Round 4 | 40% | 30% | 0% | 20% |
| Mean | 48% | 21% | 3% | 13% |
| EPA | | | | - |
| WHO | | | | - |
| LIBNOR | 0.3 | | | - |

Evaluating the quality based on the HWQI, AWQI, UNEP WQI and the proposed PWQI (Table 4.17-4.18 and Figure 4.11), the following can be noted:

- Based on the calculated PWQI, 65% of the piped water supplies are of good quality. Still, 15% are classified as fair and 20% as marginal in quality and often depart from the LIBNOR Standards (Table 4.17, Table 4.18).
- Based on the HWQI, 75% of the piped water supplies are of good quality, and only 5% of fair quality. Additionally, 15% are marginal in water quality and 5% are of poor quality which is mostly noncompliant with LIBNOR Standards (Tables 4.17-4.18). The variability in HWQI results in Qadaa Matn is due to different exceedances of parameters; mainly due to the relatively large contribution of faecal coliforms to the overall HWQI as indicated in section 4.2.1. Hence, in the supplies where any faecal coliforms were

present (13%), the HWQI automatically dropped the quality classification to either marginal or poor.

- Based on the AWQI, 90% of the piped water supplies are of excellent quality and 10% are good quality (Table 4.17-4.18). Most the AWQI water quality classification were excellent receiving a score of 100% since the levels for the acceptability parameters were in compliance with LIBNOR standards. The exceptions were for some of the supplies with levels of color and chlorides exceeding standard leading to a drop in the water quality classification to good.
- Based on the UNEP WQI, the quality of 5% of the piped water supplies are of excellent water quality, and 75% were classified as good, quality, while 20% as were classified as marginal (Table 4.17, Table 4.18).
- The PWQI is more reflective of the water quality than the AWQI which only reflects on the acceptability of the water due to the unaccounted for microbiological profile. Thus as before, the AWQI gave false positives boasting the water quality classification to excellent for all the supplies (figure 4.12).
- The HWQI is also non-reflective on the actual water quality since it automatically drops the quality classification to marginal or poor when faecal coliforms are present. As before, the HWQI mostly yielded the lowest scores among the 4 computed indices. This is due to the high contribution of the faecal coliform parameter to the HWQI that monitors limited water quality parameters. Moreover, the HWQI reflects only the health concern and does not reflect on water acceptability which is a major factor in determining water use by consumers (Figure 4.12).

- The UNEP WQI and the PWQI yield overall similar results in terms of water quality classification; still, the ranges seem to be more defined by the PWQI possibly as it includes parameters that reflect more on the types of water sources, sources of pollution and the management of water supplies (Figure 4.10). As, such, the UNEP WQI seems to boast minimally the water quality classification as it constitute 5 water quality parameters (arsenic, boron, chromium, fluorides, and mercury) that are below detection limits.

Table 4.17: Quality of Piped Water Supplies of Qadaa El Matn based on determined Indices

| | | HWQI | | AWQI | | UNEP WQI | | PWQI | |
|---|---|---|---|---|---|---|---|---|---|
| Qadaa MATN | M1 | 49.8 | Marginal | 100.0 | Excellent | 60.6 | Marginal | 60.4 | Marginal |
| | M2 | 89.4 | Good | 100.0 | Excellent | 95.9 | Excellent | 88.3 | Good |
| | M4 | 89.4 | Good | 98.3 | Excellent | 91.8 | Good | 88.2 | Good |
| | M5 | 88.0 | Good | 100.0 | Excellent | 94.7 | Good | 84.2 | Good |
| | M6 | 44.9 | Poor | 100.0 | Excellent | 55.3 | Marginal | 55.9 | Marginal |
| | M8 | 87.9 | Good | 90.1 | Good | 86.6 | Good | 78.3 | Fair |
| | M9 | 87.8 | Good | 97.6 | Excellent | 91.1 | Good | 88.0 | Good |
| | M10 | 87.9 | Good | 98.4 | Excellent | 91.3 | Good | 90.9 | Good |
| | M11 | 87.9 | Good | 92.7 | Good | 90.7 | Good | 85.2 | Good |
| | M12 | 65.1 | Fair | 100.0 | Excellent | 80.8 | Good | 78.0 | Fair |
| | M13 | 51.1 | Marginal | 98.3 | Excellent | 63.5 | Marginal | 63.6 | Marginal |
| | M14 | 87.8 | Good | 100.0 | Excellent | 94.6 | Good | 87.6 | Good |
| | M15 | 88.0 | Good | 100.0 | Excellent | 94.7 | Good | 88.8 | Good |
| | M16 | 46.7 | Marginal | 100.0 | Excellent | 57.8 | Marginal | 57.3 | Marginal |
| | M18 | 90.7 | Good | 98.4 | Excellent | 92.3 | Good | 88.9 | Good |
| | M19 | 87.9 | Good | 100.0 | Excellent | 94.7 | Good | 85.4 | Good |
| | M20 | 87.8 | Good | 98.4 | Excellent | 91.3 | Good | 84.3 | Good |
| | M21 | 87.7 | Good | 97.5 | Excellent | 91.1 | Good | 79.1 | Fair |
| | M22 | 87.6 | Good | 97.7 | Excellent | 91.1 | Good | 86.7 | Good |
| | M23 | 87.5 | Good | 98.3 | Excellent | 91.2 | Good | 87.8 | Good |

Table 4.18: Classification of the Quality of Qadaa El Matn Piped Water Supplies based on the determined Indices

| | | HWQI | AWQI | UNEP WQI | PWQI |
|---|---|---|---|---|---|
| Qadaa Matn | Excellent | 0% | 90% | 5% | 0% |
| | Good | 75% | 10% | 75% | 65% |
| | Fair | 5% | 0% | 0% | 15% |

| | | | | | |
|---|---|---|---|---|---|
| | Marginal | 15% | 0% | 20% | 20% |
| | Poor | 5% | 0% | 0% | 0% |

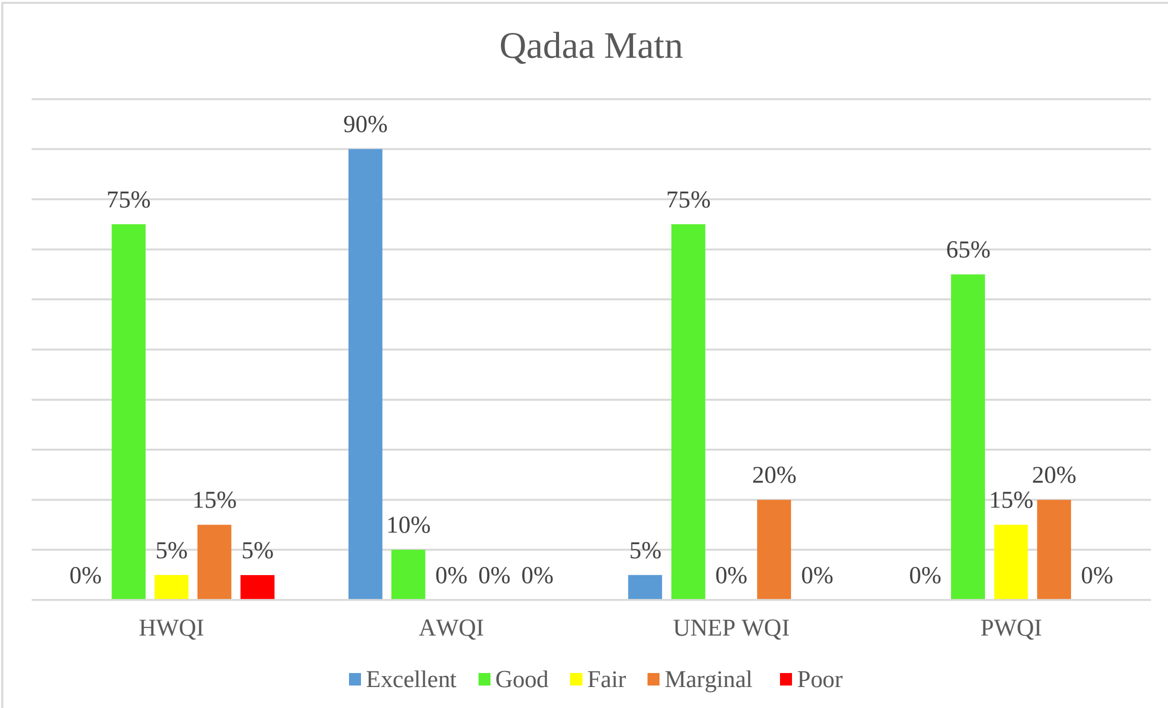


Figure 4.11: Bar Chart showing the Classification of the Quality of Qadaa El Matn Piped Water Supplies based on the determined indices

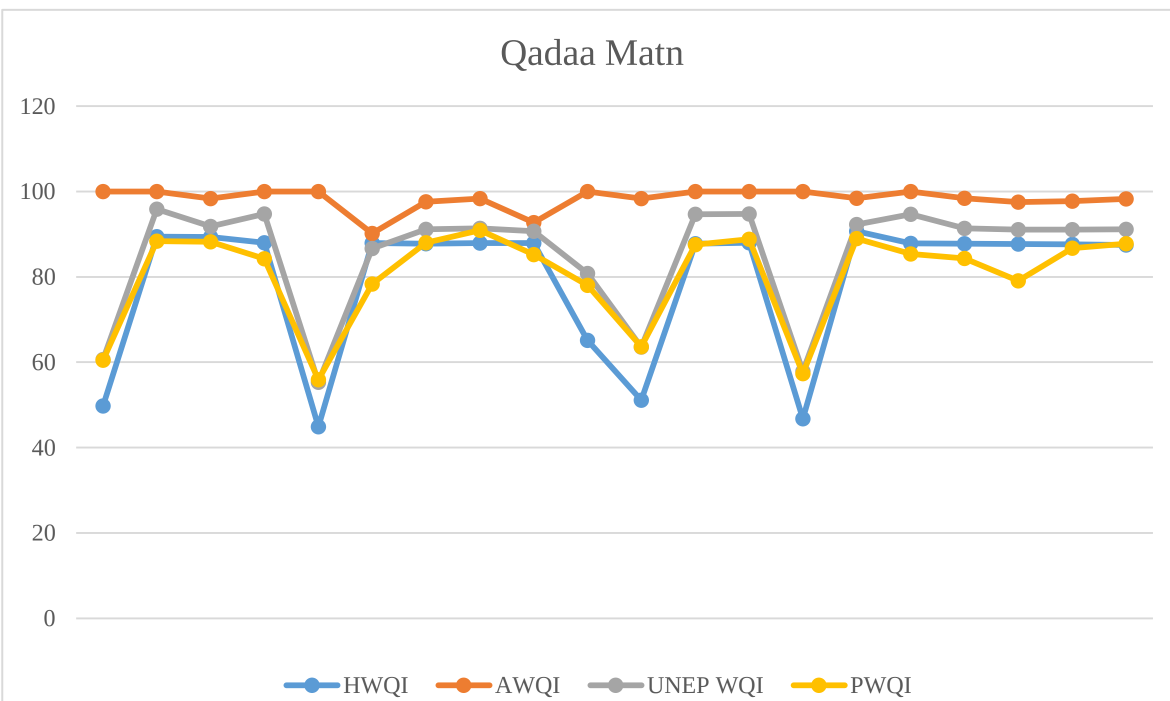


Figure 4.12: Sensitivity of Computed Water Quality Indices

### *4.2.7 Quality and Safety of Piped Water Supplies of Mount Lebanon*

The overall classification of the quality of the piped water supplies of Mount Lebanon for all 6 Qadaas, based on the PWQI and as presented in table 4.19, is as follows:

- Around 9% of the piped water supplies, across the 6 Qadaas, are of excellent quality in compliance with the LIBNOR standards virtually all the time.
- Around 49% of piped water supplies, across the 6 Qadaas, are of good quality in compliance with the LIBNOR standards mostly all the time.
- Around 21% of the piped water supplies, across the 6 Qadaas, are of fair quality where conditions sometimes depart from the LIBNOR standards.
- Around 17% of piped water supplies, across the 6 Qadaas, are of marginal quality where conditions often depart from the LIBNOR standards.
- Around 3% of piped water supplies, across the 6 Qadaas are of poor quality where conditions mostly depart from the LIBNOR standards.

Table 4.19: Classification of the Water Quality of Mount Lebanon Piped water Supplies based on the PWQI

| Distribution Areas | (%) | Designation | Index Value | Description |
|---|---|---|---|---|
| Aley | 0% | Excellent | 95-100 | All measurements are within objective s virtually all the time |
| El Chouf | 0% | | | |
| Baabda | 0% | | | |
| Jbeil | 37% | | | |
| Keserwan | 16% | | | |
| El Matn | 0% | | | |
| Average | 9% | | | |

| | | | | |
|---|---|---|---|---|
| Aley | 82% | Good | 80-94 | Conditions rarely depart from natural or desirable levels |
| El Chouf | 18% | | | |
| Baabda | 33% | | | |
| Jbeil | 37% | | | |
| Keserwan | 58% | | | |
| El Matn | 65% | | | |
| Average | 49% | | | |
| Aley | 0% | Fair | 65-79 | Conditions sometimes depart from natural or desirable levels |
| El Chouf | 55% | | | |
| Baabda | 20% | | | |
| Jbeil | 11% | | | |
| Keserwan | 26% | | | |
| El Matn | 15% | | | |
| Average | 21% | | | |
| Aley | 9% | Marginal | 45-64 | Conditions often depart from natural or desirable levels |
| El Chouf | 27% | | | |
| Baabda | 27% | | | |
| Jbeil | 16% | | | |
| Keserwan | 0% | | | |
| Matn | 20% | | | |
| Average | 17% | | | |
| Aley | 9% | Poor | 0-44 | Conditions usually depart from natural or desirable levels |
| El Chouf | 0% | | | |
| Baabda | 20% | | | |
| Jbeil | 0% | | | |
| Keserwan | 0% | | | |
| Matn | 0% | | | |
| Average | 5% | | | |

Overall, the management of the Mount Lebanon piped water supplies is challenged by various concerns that should be addressed to ensure the quality and safety of the water supply. Among these issues, the following is noted:

- Increased mineral content of coastal ground water sources; few distribution areas of Mount Lebanon (5.5%) (mostly along the costal line) get piped water supplies that have high TDS levels surpassing the LIBNOR standard of 500 mg/L throughout the year. In addition, 4.6% have TDS levels over 1000 mg/L. The problem of high salinity in potable water is due to the seawater infiltration into the coastal wells that enhanced by excessive pumping. This is a chronic problem that challenges most coastal ground water sources in Lebanon, and is yet to be tackled.
- Deterioration of distribution networks; the distribution network appears to be deteriorating. This is evident from the high levels of manganese, lead, and cadmium. When manganese is found at concentrations as low as 0.02 mg/L, it can coat the water distribution pipes which then lead to a black precipitate that might slough off in the water (WHO, 2011 manganese). Lead and cadmium are also indicator parameters that reflect on pipe deterioration and corrosion. Lead leaching is due to the corrosion of the brass fittings in water pipes while cadmium is due to the corrosion of the galvanized pipes themselves (Tavanpour et. al, 2016; WHO, 2011 Cadmium).

In addition, one of the problems that could cause scale formation in the distribution networks is the pressure drop and the fluctuating flows. This is caused by the intermittent water distribution. Scaling thus leads to the deterioration and degeneration of the distribution network (Tavanpour et. al, 2016). As such, the conditions of the network should be continuously monitored and accordingly, properly maintenance should be instated.

- Degraded microbiological safety of piped water supplies; faecal contamination is major problem in Mount Lebanon. Around 24.8% of the piped water supplies of Mount Lebanon were found to be feacally contaminated all year round (4 sampling rounds). This is a clearly a chronic problem mostly due to the deteriorated networks and the intermittent water distribution. Exposure of the distribution networks to faecal contamination is aggravated by deficient/insufficient chlorination. This is evident by the absence of free residual chlorine levels of 0.3 mg/l as recommended by LIBNOR Standards. Overall, 43.5% of the free residual chlorine levels of all the Mount Lebanon piped water supplies were less than 0.1mg/L all year round (4 sampling rounds). In addition, in 8.5% of piped water supplies no free residual chlorine levels were detected. So either disinfection by chlorine was not applied or the chlorine dose was not sufficient to meet the chlorine demand and maintain free residual levels. As such, chlorination should be properly controlled; chlorine demand test should be conducted on continuous basis to determine the required chlorine dose and the free residual chlorine levels should be monitored throughout the network and at all end points to ensure the microbiological safety of water supplies.
- Protection of water sources; another problematic concern in Mount Lebanon is the high levels of cadmium This could reflect on water pollution due to the leaching of fertilizers into water sources feeding networks (WHO, 2011 Cadmium). This concern is currently investigated by a parallel research project.

### 4.3 F1, F2 and F3 Validation and Sensitivity Analysis

The computation of the water quality indices, as presented in section 4.1 page 54, was based on [F1] the scope: the percentage, or how many parameters exceeded the guideline (LIBNOR standard) at each sampling point at each round; [F2] the frequency: the percentage of individual tests within each parameter that exceeded the guideline, showing how many times each parameter exceeded the guidelines (in all 4 rounds); and [F3] the amplitude: the extent (excursion) to which the failed test exceeds the guideline, showing by how much each parameter exceeded the guideline.

Hence, validation and sensitivity analysis was conducted to assess which of the 3 factors (F1, F2 or F3) is contributing the most to the overall index and each factor was plotted against each corresponding index in scatterplots. This was done for all the indices as presented in figure 4.12.

Next, multiple regression analysis by using forced entry method was conducted on SPSS for each index and its corresponding [F1], [F2] and [F3] (table 4.18). The regression analysis showed that for HWQI, UNEP WQI and PWQI, [F3] was the driving factor ($R^2$= 0.981, *p value* <0.001; $R^2$= 0.987, *p value* <0.001; $R^2$= 0.966, *p value* <0.001, respectively). In comparison, the AWQI was driven by [F2] ($R^2$= 0.944, *p value* <0.001). As such, these results advocate that (Table 4.20):

- The HWQI, UNEP WQI, and the PWQI are significantly influenced by [F3] the amplitude: the extent (excursion) to which the failed test exceeded the guideline, showing by how much each parameter exceeded the guideline; while being little inclined by how many, and how many times each parameter exceeded the guideline. This was confirmed by the scatterplots presented in figure 4.13.

- AWQI is significantly influenced by [F2]: the frequency of individual tests within each parameter, that exceeded the guideline showing how many times each parameter exceeded the guidelines (in all 4 rounds) with little influence of the number of exceeding parameters at each sampling point at each round. In addition, the extent (excursion) to which the failed tests exceeds the guideline, showing by how much each parameter exceeded the guideline, was not as influencing to the AWQI as was the [F2].
- The UNEP WQI is significantly influenced by [F3]. The index is comprised of both HWQI, and the AWQI. However, based on the regression analysis, the UNEP WQI is driven by [F3] similar to the HWQI, and contrary to the AWQI which is driven by [F2]. This signifies that the effect of the extent to which each parameter fails the guideline outweighs the number of times each parameter exceeded the guidelines. Hence, it can be concluded that the UNEP WQI is more impacted by the HWQI than the AWQI.
- The PWQI is significantly influenced by [F3]. Similar to the UNEP WQI this index is also comprised of the HWQI, the AWQI and additional water quality parameters. Furthermore, the PWQI is also highly influenced by the HWQI, over the AWQI. Thus it is expected that the PWQI and the UNEP WQI will yield similar results with slight variations based on the added parameters that are not monitored by the UNEP WQI.
- All the indices were the not impacted by [F1] the scope: percentage of how many parameters exceed the guideline at each sampling point, at each round. This implies that the number of parameters that fail is not as important as the other factors.

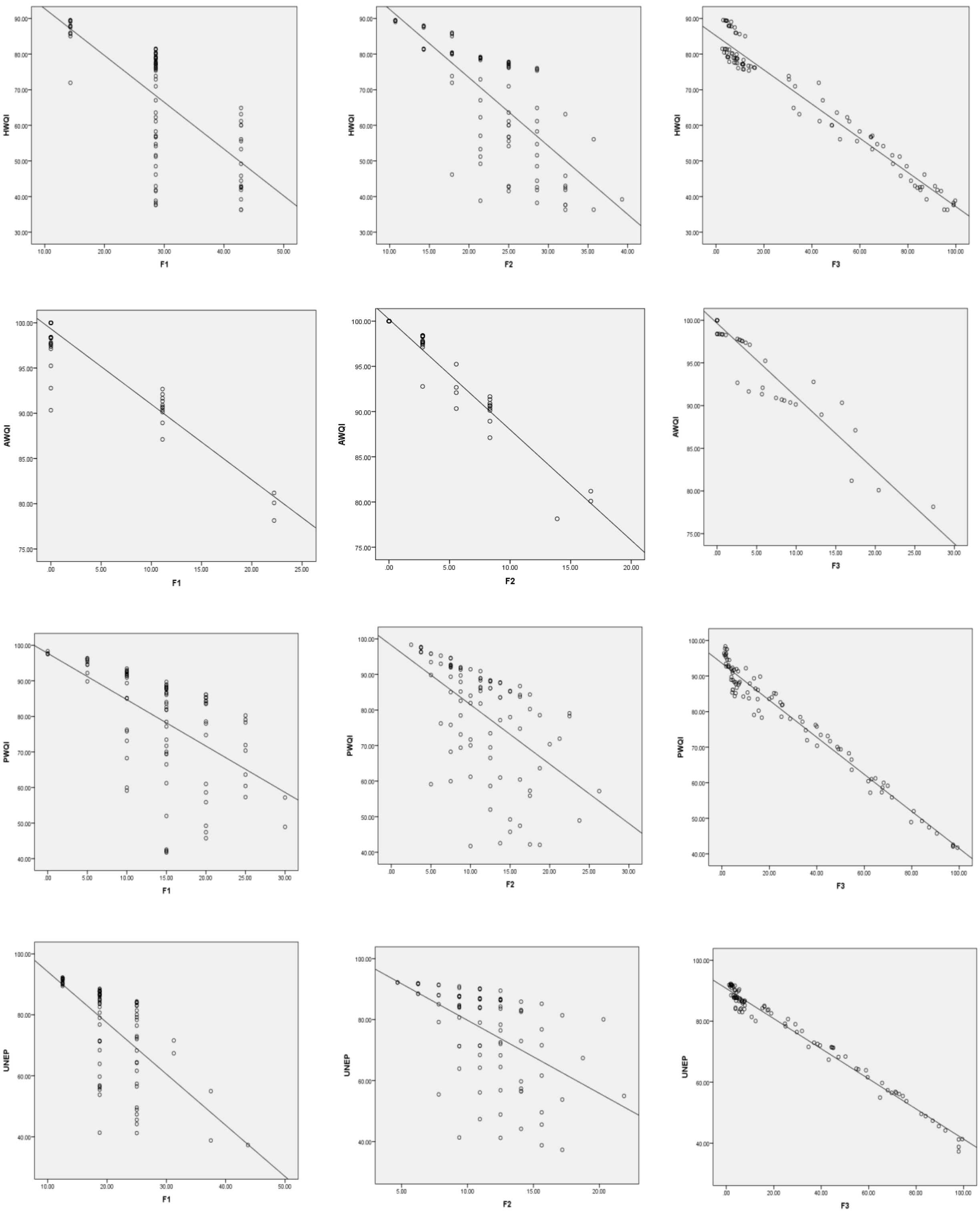

Figure 4.13: F1, F2 and F3 scatterplots against HWQI, AWQI, UNEP WQI, and PWQI

Table 4.20: Results of the Multiple Regression Analysis by Forced Entry Method

| | $F^1$ | | $F^2$ | | $F^3$ | |
|---|---|---|---|---|---|---|
| | $R^2$ | *p value* | $R^2$ | *p value* | $R^2$ | *p value* |
| HWQI | 0.454 | < 0.001 | 0.573 | < 0.001 | 0.981 | < 0.001 |
| AWQI | 0.888 | < 0.001 | 0.944 | < 0.001 | 0.918 | < 0.001 |
| UNEP WQI | 0.403 | < 0.001 | 0.294 | < 0.001 | 0.987 | < 0.001 |
| PWQI | 0.31 | < 0.001 | 0.298 | < 0.001 | 0.966 | < 0.001 |

The above information allows the affirmation of which parameters were driving the indices (HWQI, UNEP WQI and PWQI) by having the greatest excursion of the standard. In addition, this can also be applied to the AWQI to infer which parameters were driving the index by exceeding the standard the most times.

### 4.4 Parameter Contributions and Correlation Analysis

To specify which quality parameters were the largest contributors to each computed index all the parameters that exceeded the LIBNOR standards, within each index, were plotted as presented in figures 4.14-4.17.

The indicated figures show the [F1] – the exceeded parameters and their separate (%) contribution to the total number of exceedances in each overall index. As such, these figures allow the parameters that are most likely to fail, to be identified. Hence:

- HWQI: it follows the same trend as the UNEP WQI with lead (52%) and faecal coliform (32%) as the major exceeding parameters (84%) as presented in figure 4.14.

- AWQI: color by itself contributes to 62% of total exceedances followed by turbidity (16%) and chlorides (16%) as presented in figure 4.15.
- UNEP WQI:  Lead, and faecal coliform account for around 63% of the total exceedances as presented in figure 4.16.
- PWQI: the major exceeding parameters are manganese (22%) and lead (22%), followed by total hardness (13%), free residual chlorine (12%), and faecal coliforms (10%) as presented in figure 4.17.

It is to be noted that the 2 quality parameters of free residual chlorine and total hardness are only computed as part of the PWQI (Figure 4.17).  Moreover, the quality parameters of nitrates, ammonia, sulfates, sodium, nickel, copper and zinc did not have any exceedances at any of the sampling points in any of the 4 rounds. Hence they were not included in the sensitivity analysis (Figures 4.14-4.17).

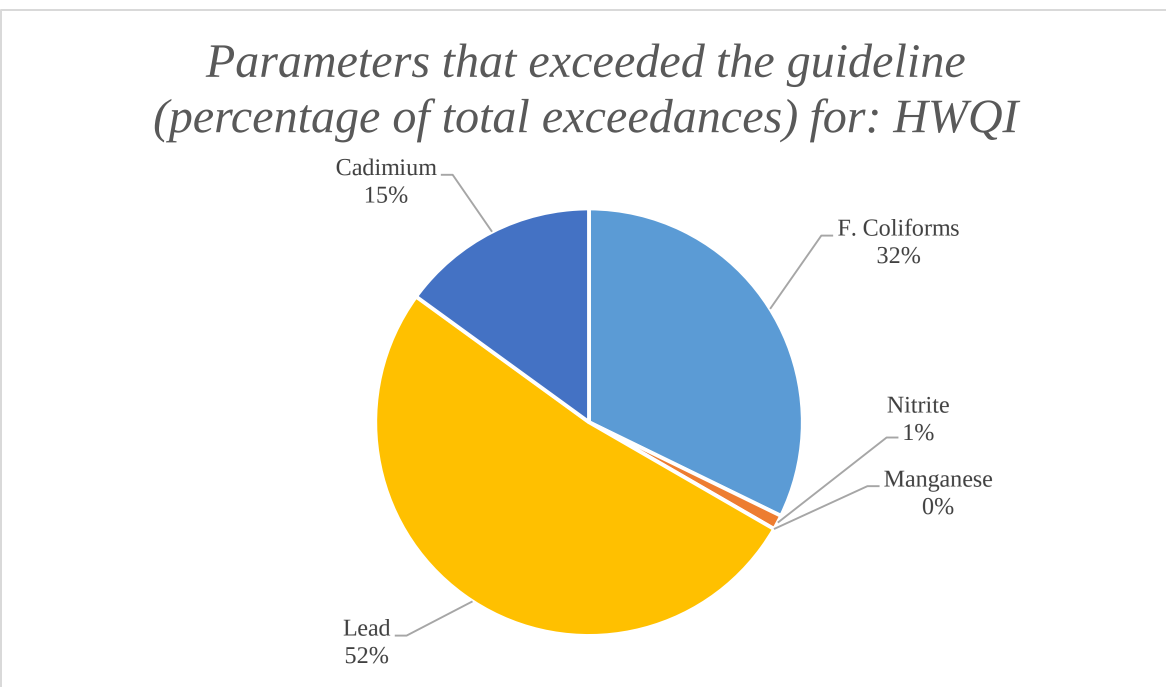


Figure 4.14: Contribution of Quality Parameters to the HWQI

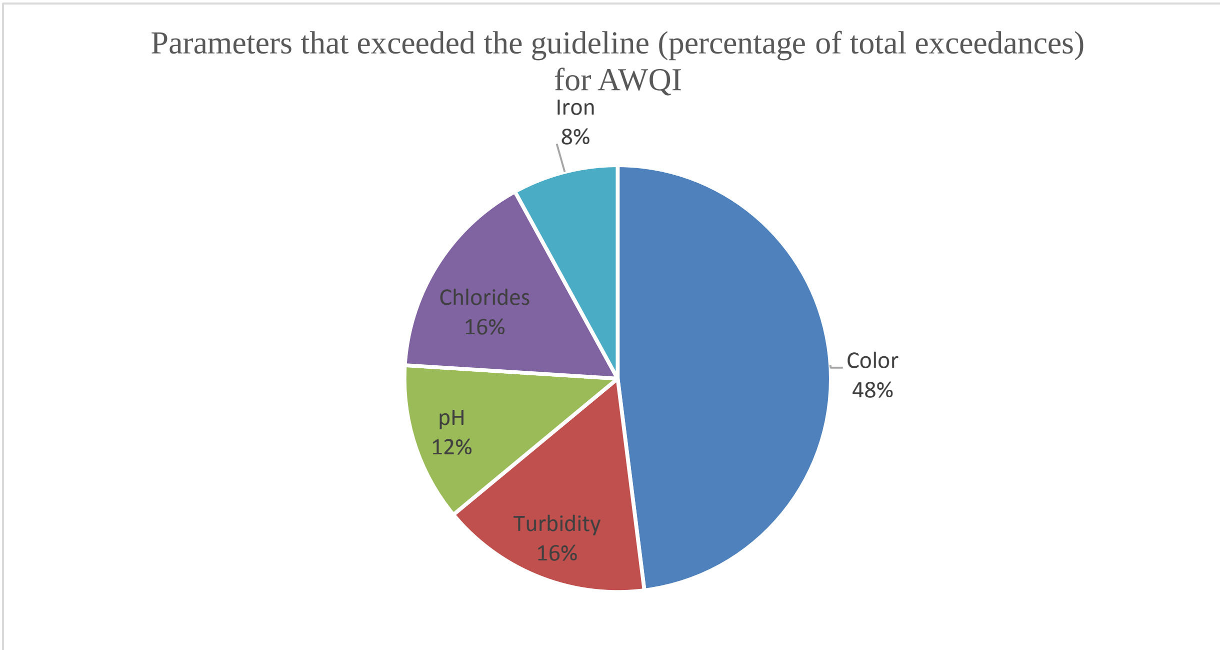


Figure 4.15: Contribution of Quality Parameters to AWQI

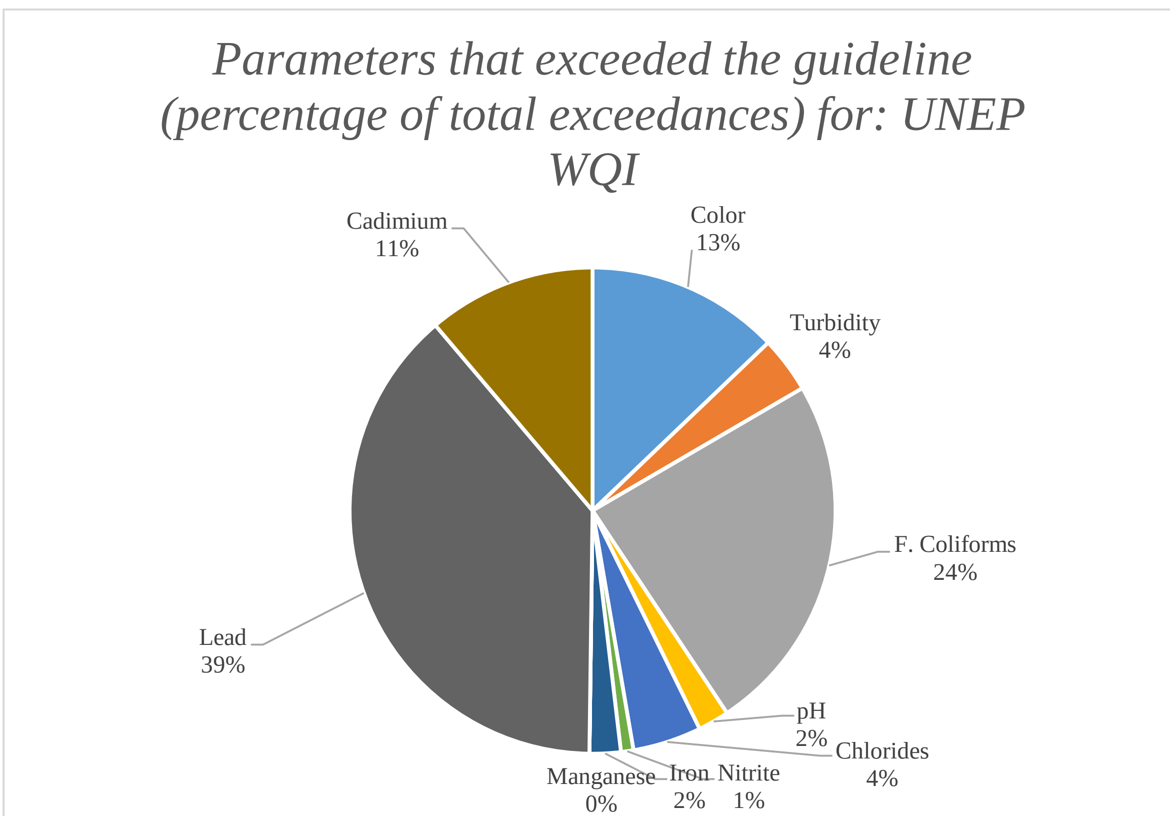


Figure 4.16: Contribution of Quality Parameters to UNEP WQI

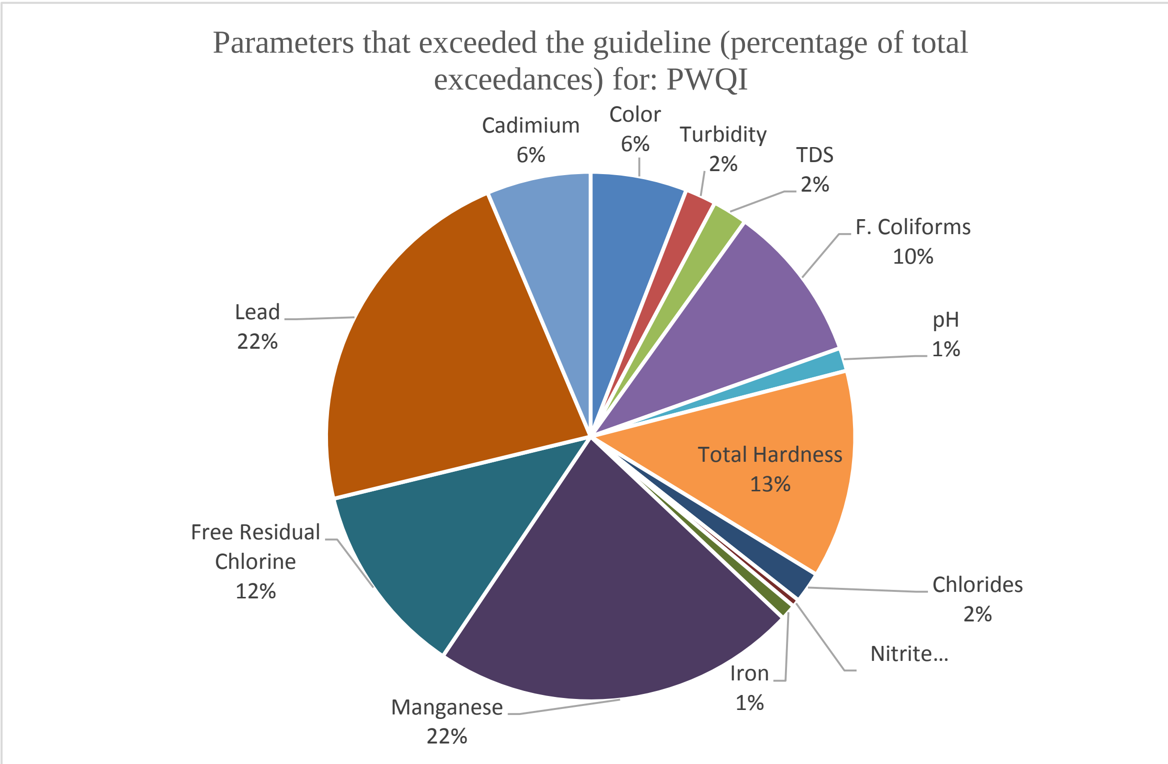


Figure 4.17: Contribution of Quality Parameters to PWQI

Moreover, in order to statistically evaluate the contribution of each of the parameters to each of the determined indices, correlation analysis was done for each parameter against its corresponding index. To permit comparison between all exceedances, a standardized value (Excursion Sum) was adopted and was calculated as follow (UNEP, 2012):

1) (Value/Guideline)-1 = Excursion

2) Σ (Excursions for all rounds)

The scatterplots for HWQI, AWQI, UNEP WQI and PWQI against their respective exceeding parameters are presented in figures 4.18 - 4.21 and the correlation matrix is presented in table 4.21.

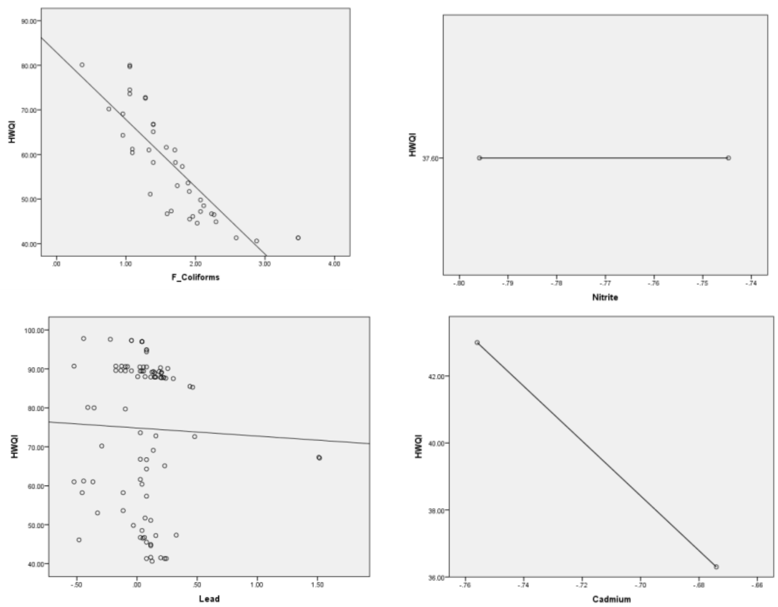


Figure 4.18: Scatterplots of excursion sums for each exceeded parameter against the HWQI.

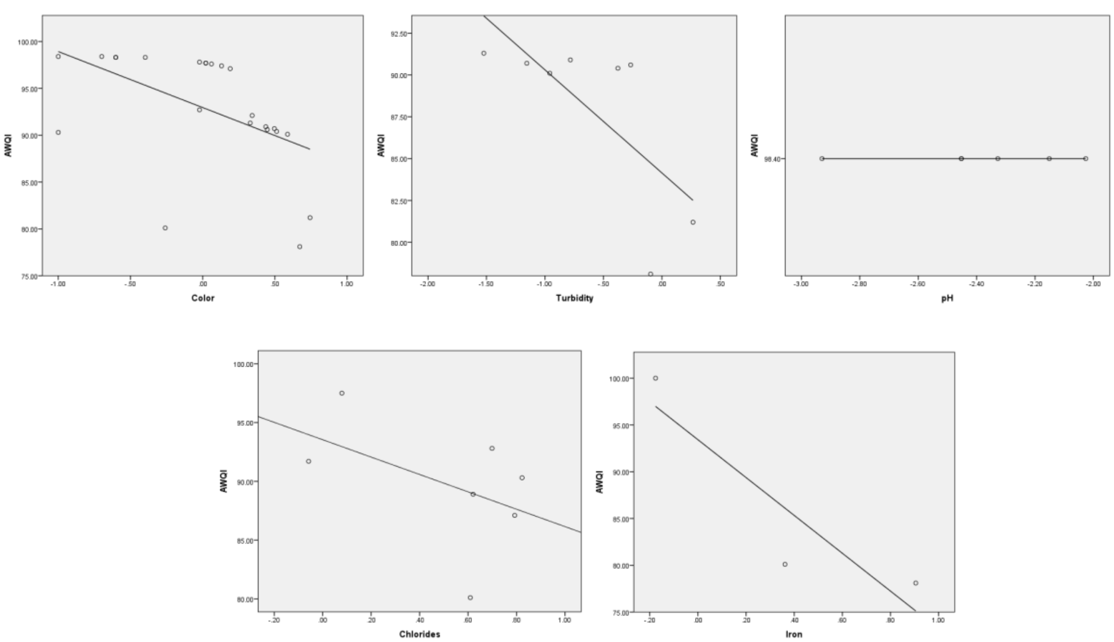


Figure 4.19: Scatterplots of excursion sums for each exceeded parameter against the AWQI.

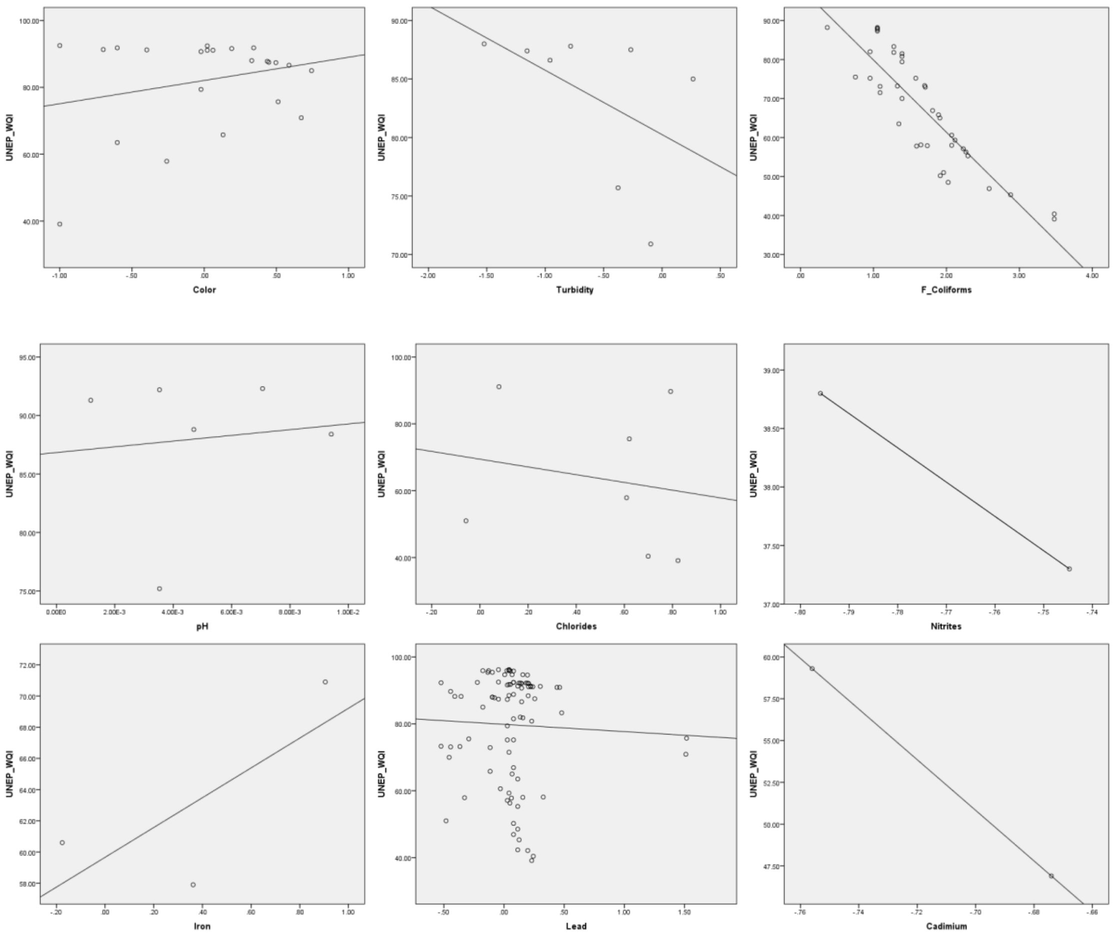


Figure 4.20: Scatterplots of excursion sums for each exceeded parameter against the UNEP WQI.

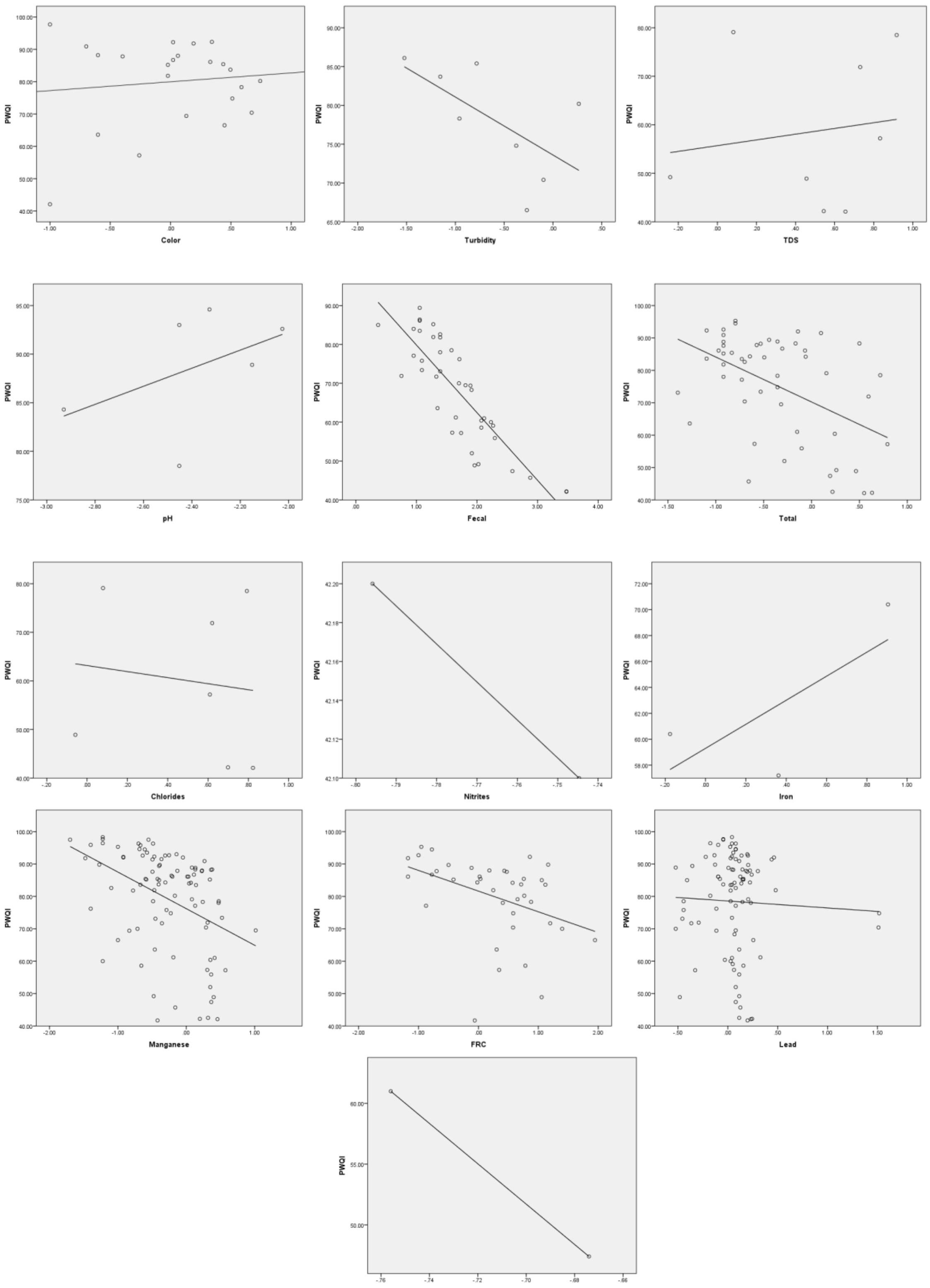


Figure 4.21: Scatterplots of excursion sums for each exceeded parameter against the PWQI.

Table 4.21: Simple Regression Matrix of Exceeding Water Quality Parameters as an Average for Each Round against the Corresponding Computed Index (HWQI, AWQI, UNEP WQI, and PWQI)

| Parameter | | HWQI | | AWQI | | UNEP WQI | | PWQI | |
|---|---|---|---|---|---|---|---|---|---|
| | n* | $R^2$ | *p value* | $R^2$ | *p value* | $R^2$ | *p value* | $R^2$ | *p value* |
| Color | 25 | | | 0.255 | 0.014 | 0.067 | 0.231 | 0.12 | 0.625 |
| Turbidity | 8 | | | 0.502 | 0.049 | 0.249 | 0.208 | 0.387 | 0.1 |
| TDS | 9 | | | | | | | 0.022 | 0.725 |
| F. Coliforms | 41 | 0.702 | < 0.001 | | | 0.761 | < 0.001 | 0.72 | < 0.001 |
| pH | 6 | | | - | - | 0.012 | 0.836 | 0.222 | 1.346 |
| Total Hardness | 54 | | | | | | | 0.233 | < 0.001 |
| Chlorides | 8 | | | 0.233 | 0.272 | 0.034 | 0.691 | 0.018 | 0.776 |
| Nitrite | 2 | - | - | | | 1 | - | 1 | - |
| Iron | 4 | | | 0.816 | 0.283 | 0.599 | 0.458 | 0.53 | 0.481 |
| Manganese | 0 | | | | | | | 0.166 | < 0.001 |
| Free Residual Chlorine | 50 | | | | | | | 0.161 | 0.011 |
| Lead | 95 | 0.001 | 0.753 | | | 0.002 | 0.654 | 0.002 | 0.707 |
| Cadmium | 27 | 1 | - | | | 1 | - | 1 | - |

n = the number of excursions
-: No cases found on SPSS

Analyzing the results presented in the scatterplots in figures 4.18 - 4.21 and table 4.21, the following can be concluded:

- For the HWQI and based on the correlation matrix table (Table 4.21), the largest contributors are lead ($R^2$ = 0.001 and *p value* = 0.753) and faecal coliform ($R^2$ = 0.702 and *p value* < 0.001) quality parameters. This shows that the largest contributor is faecal coliform even though it was not the most exceeding parameter as presented in figure 4.14.
- For the AWQI and based on the correlation matrix table (Table 4.21), the largest contributors are the color ($R^2$ = 0.255and *p value* = 0.014), chlorides ($R^2$ = 0.233 and *p value* = 0.272) turbidity ($R^2$ = 0.502 and *p value* = 0.049) and iron ($R^2$ = 0.816 and *p*

*value=0.283*) quality parameters. This shows that the largest contributor was iron even though it was not the most exceeding quality parameter as presented in figure 4.15.

- For the UNEP WQI and based on the correlation matrix table (Table 4.21), the largest contributors are lead ($R^2$ = 0.002 and *p value* = 0.654), and faecal coliform ($R^2$ = 0.761 and *p value* < 0.001) as seen in figure 4.16. And, even though it was not the largest exceeding quality parameter, faecal coliform was the most contributing parameter and was highly significant based on the regression analysis as evident in figure 4.15.
- For the PWQI and based on the correlation matrix table (Table 4.21), the largest contributors are manganese at acceptability levels ($R^2$ = 0.166 and *p value* =0.011), lead ($R^2$ = 0.002 and *p value* = 0.691), free residual chlorine ($R^2$ = 0.161 and *p value* < 0.001) and total hardness ($R^2$ = 0.133 and *p value* < 0.001) even though they were not the major exceeding parameters as presented in figure 4.17. However, the most contributing and the most significant parameter was the faecal coliform ($R^2$ = 0.75 and *p value* < 0.001) as evident in figure 4.16.

The presence of faecal coliform demonstrated consistently to be the largest contributor to the HWQI, UNEP WQI, and PWQI. This is significant since as presented in the [F1] [F2] [F3] analysis (section 4.3), [F3] the excursion was the most contributing factor to the HWQI, UNEP WQI and the PWQI, and not [F1] the exceedance. Hence, the overall water quality indices are driven by the excursion of each parameter from the guideline and not the number of exceeded parameters.

Moreover, it is evident that the faecal coliform is a substantial player in the computation of the 3 indices (HWQI, UNEP WQI, and PWQI). As such, based on the

LIBNOR standard of 0 coliforms/ 100ml, any presence of faecal coliforms would result in an exceedance.

In addition, compared to the nil standard the presence of faecal coliform will also result in a large excursion from the result with respect to the standard. This also clarifies the heavy influence of [F3] on the indicated indices.

### 4.5 Sensitivity Analysis

Further, to examine the impact of the significant parameters presented in table 4.22, sensitivity analysis was conducted. This analysis was done by removing one parameter at a time from its respective index calculation; and then comparing the altered index with the original. By doing this any change in the index would be evident. And, the more the index changes the larger would be the sensitivity of the index to that specific quality parameter; this would show how each parameter affects each of the 4 indices (HWQI, AWQI, UNEP WQI, and PWQI.

After calculating each index by removing the contributing parameters, one by one (Simple Regression by using backwards method) e.g. for the PWQI 20 Simple Regressions, by using backwards method were done to quantify the contribution of every parameter to the original index.

Firstly, the 4 indices (HWQI, AWQI, UNEP WQI, and PWQI) were compared based on the resulting classification of the water quality from poor-to-excellent (Figure 4.22). The analysis included all 95 sampling sites in Mount Lebanon across the six Qadaas.

Hence, as presented in figure 4.22 and based on the HWQI, the majority of the piped water supplies in Mount Lebanon had a good (44%) quality standing. On the other hand, based on the AWQI, 83% of the piped water supplies are of excellent quality standing. Meanwhile, 49% of the piped water supplies classification based on both the UNEP WQI PWQI are classified as good water quality.

The difference between the % classifications for the 2 indices (UNEP WQI and PWQI) is that PWQI better defines the quality over the range of excellent to poor. Whereas the UNEP WQI upgrades minimally the water quality classification as it constitute 5 water quality parameters (arsenic, boron, chromium, fluorides, and mercury) that are below detection limits

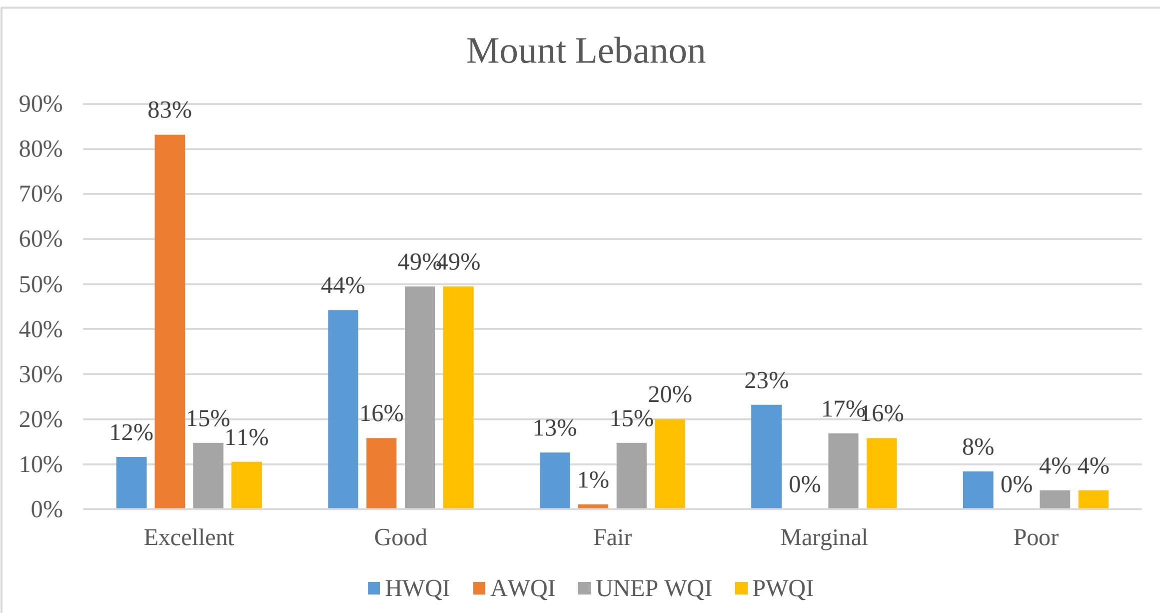

Figure 4.22: Classification of the Piped Water supplies based on the Various Water Quality Indices

Next, to observe the influencing parameters summarized in table 4.22 and in reference to section 4.3, (F1 F2 and F3 and sensitivity analysis) , additional sensitivity analysis was conducted by removing each parameter from the corresponding index, and then plotting it against its original index as presented in figures 4.23 - 4.29).

Table 4.22: Exceeding Parameters of the Indices included in the Sensitivity Analysis

| **HWQI** | **AWQI** | **UNEP WQI** | **PWQI** |
|---|---|---|---|
| Faecal Coliforms | Color | Color | Color |
| Nitrite | Turbidity | Turbidity | Turbidity |
| Lead | pH | Faecal Coliforms | TDS |
| Cadmium | Chlorides | pH | Faecal Coliforms |
| | Iron | Chlorides | pH |
| | | Nitrite | Total Hardness |
| | | Iron | Chlorides |
| | | Lead | Nitrite |
| | | Cadmium | Iron |
| | | | Manganese |
| | | | Free Residual Chlorine |
| | | | Lead |
| | | | Cadmium |

The results of the analysis should the following:

1.Conducting the sensitivity analysis for the HWQI (Figure 4.24) by separately removing the water quality parameters: faecal coliforms, nitrite, lead and cadmium, the results showed that:

- The removal of faecal coliform, and lead enhanced the % classification of good water quality category from 44% (original HWQI) to 75%, the % classification of excellent water quality category from 12% (original HWQI) to 56%, respectively (Figure 4.23).

- In addition, the removal of cadmium enhanced the % classification of excellent water quality category from 12% (original HWQI) to 15% (Figure 4.23).

- The removal of nitrite on the other hand played a negative role affecting the water quality classification by the index. It decreased the % of good quality classification from 44% (original HWQI) to 42%, dropping the difference to the fair and marginal water quality classification. This in term increased the fair water quality classification and the marginal from 23% to 24% and increased the poor water quality classification from 17% to 18% (Figure 4.23).

Moreover, as was evident from the backwards regression analysis presented in table 4.23, all the quality parameters were shown to be significantly correlated to the index regardless of which parameter was removed. In addition, it can be noted that the parameters showing the least strong correlation were the highest contributors that drove the index. This is clear for faecal coliform ($R^2$ = 0.46, p value = 0.037), followed by lead (R2 = 0.941, p value < 0.001), and cadmium (R2 = 0.930, p value < 0.001) (Table 4.23). Hence, faecal coliforms, cadmium and lead, are the major contributors to the HWQI (88%, 7%, 5%, respectively) as presented in figure 4.24.

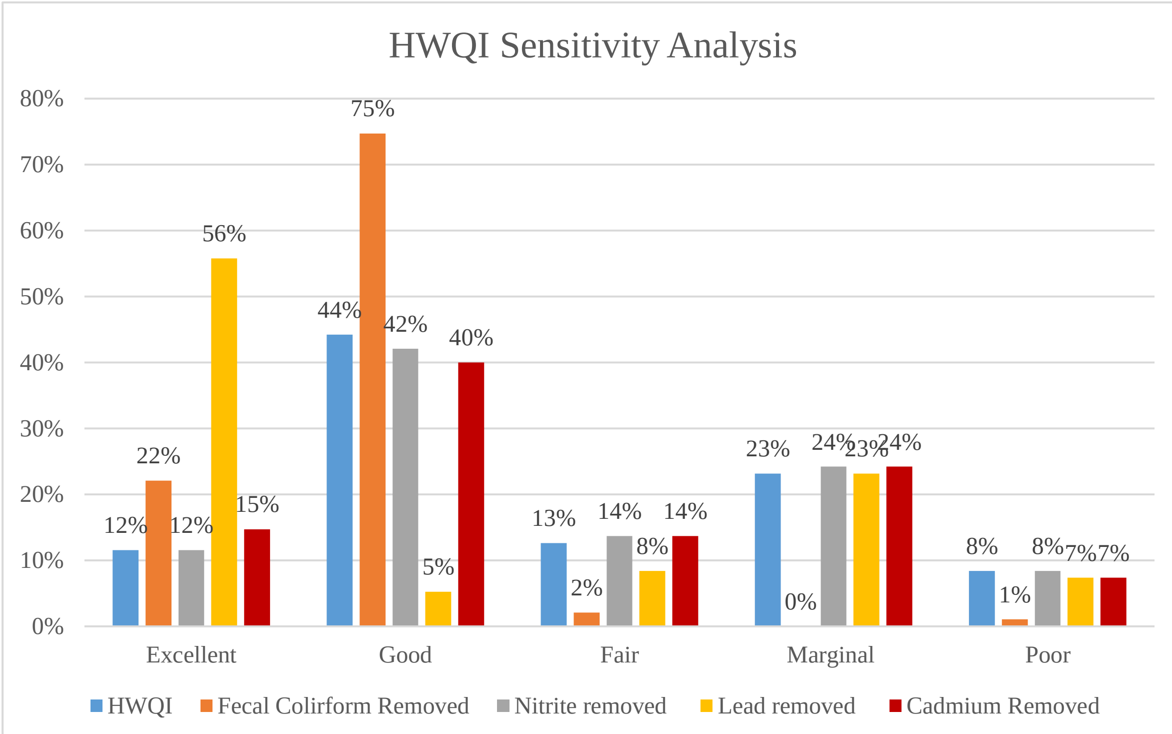


Figure 4.23: Classification of Water Quality by HWQI

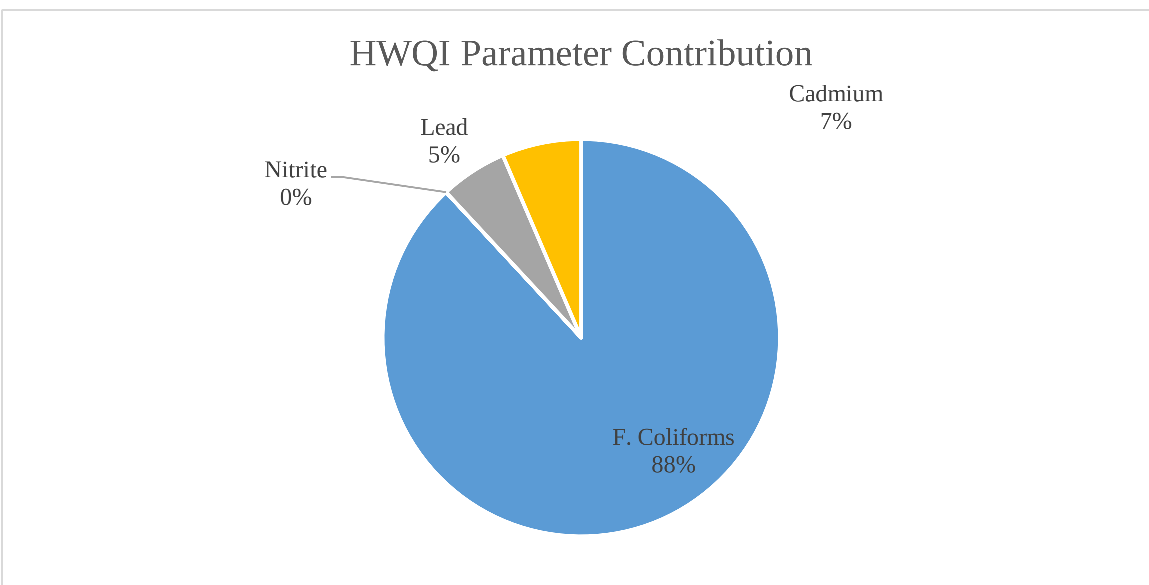


Figure 4.24: Contributions of each Exceeding Water Quality Parameter to the HWQI

2. Conducting the sensitivity analysis for the AWQI (Figure 2.25) by separately removing the water quality parameters: color, turbidity, pH, chlorides and iron, the results showed that:

- The backwards regression analysis showed that all the water quality parameters were significantly correlated to the index regardless of which parameter was removed.
- The removal of color from the AQWI index increased the percentage of excellent water quality classification from 83% to 92% (Table 4.23).
- The major contributor, color, with the least $R^2$ showed the strongest relationship is ($R^2 = 0.852$, p value $< 0.001$) (Table 4.23).

Hence, color is the major contributor (58%) followed by iron (28%) (Figure 4.25).

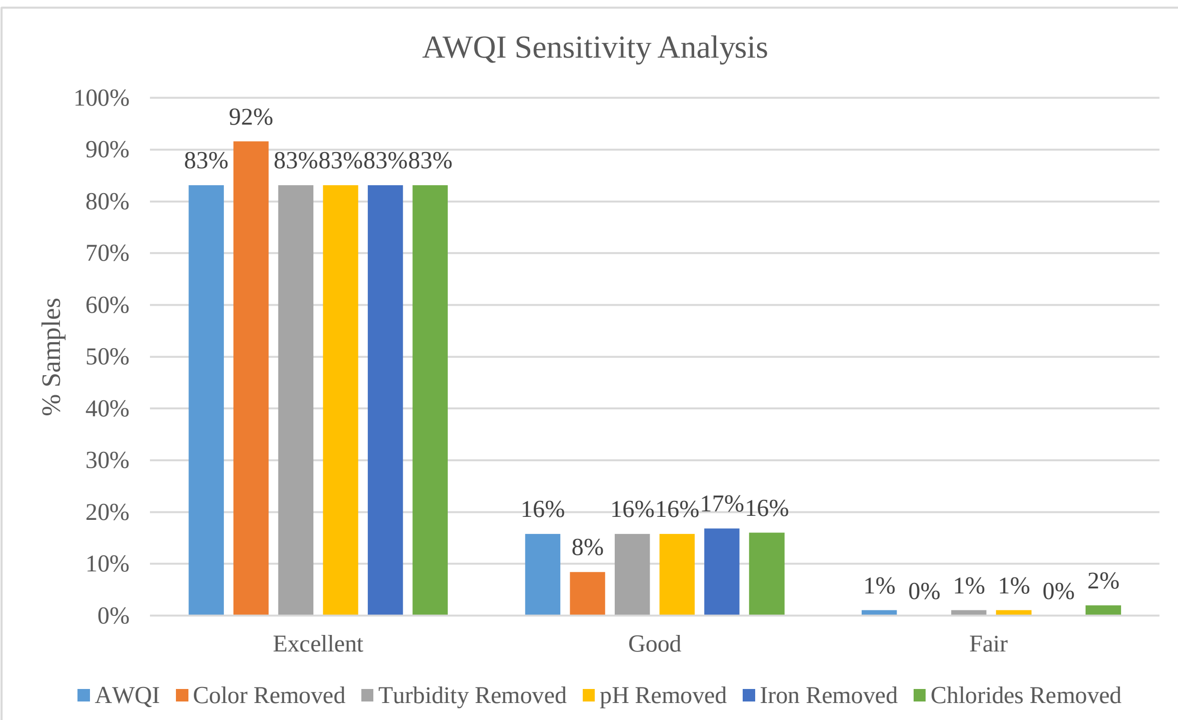


Figure 4.25: Classification of Water Quality by AWQI

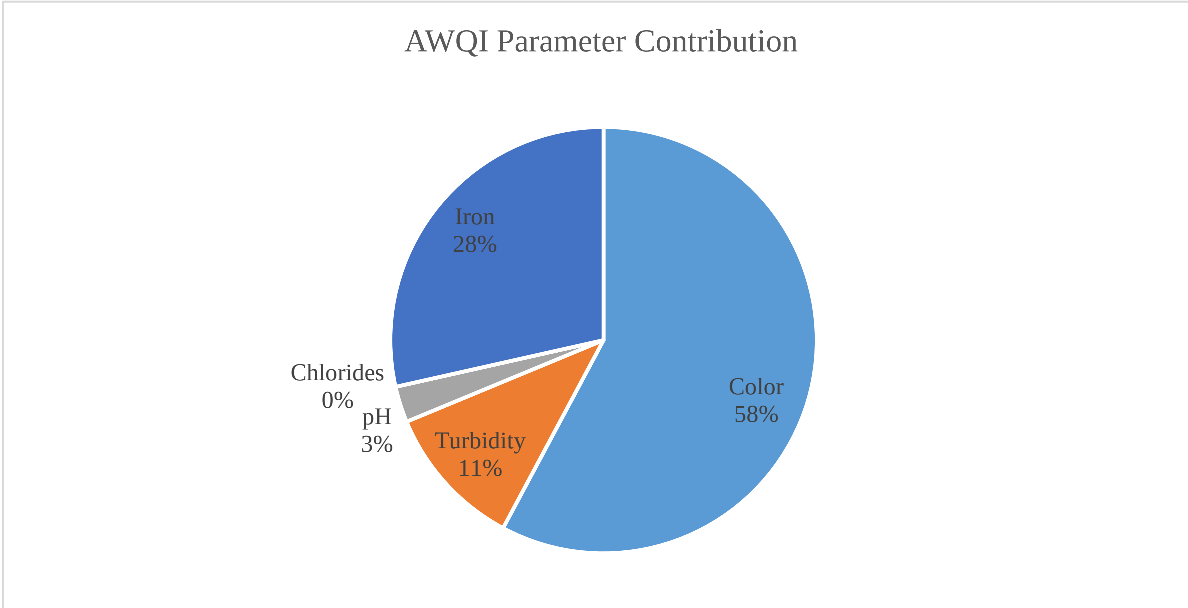


Figure 4.26: Contribution of each Exceeding Water Quality Parameter to the AWQI

3. Conducting the sensitivity analysis for the UNEP WQI (Figure 4.27) by separately removing the water quality parameters: color, turbidity, pH, chlorides and iron, the faecal coliforms, nitrite, lead and cadmium, the results showed that:

- Faecal coliforms and lead and cadmium were the major contributors
- The removal of faecal coliforms increased the percentage of excellent water quality from 15% to 31%, and good water quality classification form 49%, to 65% (Figure 4.27).
- The removal of lead from the index, increased the percentage of excellent water quality classification form 15%, to 43% (Figure 4.27).
- The removal of cadmium increased the percentage of excellent water quality from 15% to 23% (Figure 4.27).

- Hence removing these 3 parameters individually improved the index water quality classification of the water supplies of the samples (Figure 4.27).
- All the exceeding water quality parameters were significantly correlated to the equation, regardless of which parameter was removed (Table 4.23).
- The major contributor, with the least R2 showed the strongest relationship is faecal coliforms ($R^2$ = 0.112, p value < 0.001), followed by cadmium (R2 = 0.885, p value < 0.001), then lead (R2 = 0.988, p value < 0.001) (Table 4.23).
- Hence, faecal coliforms, cadmium and lead, are the major contributors to the UNEP WQI (86% 11%, 1%, respectively) (Figure 4.28).

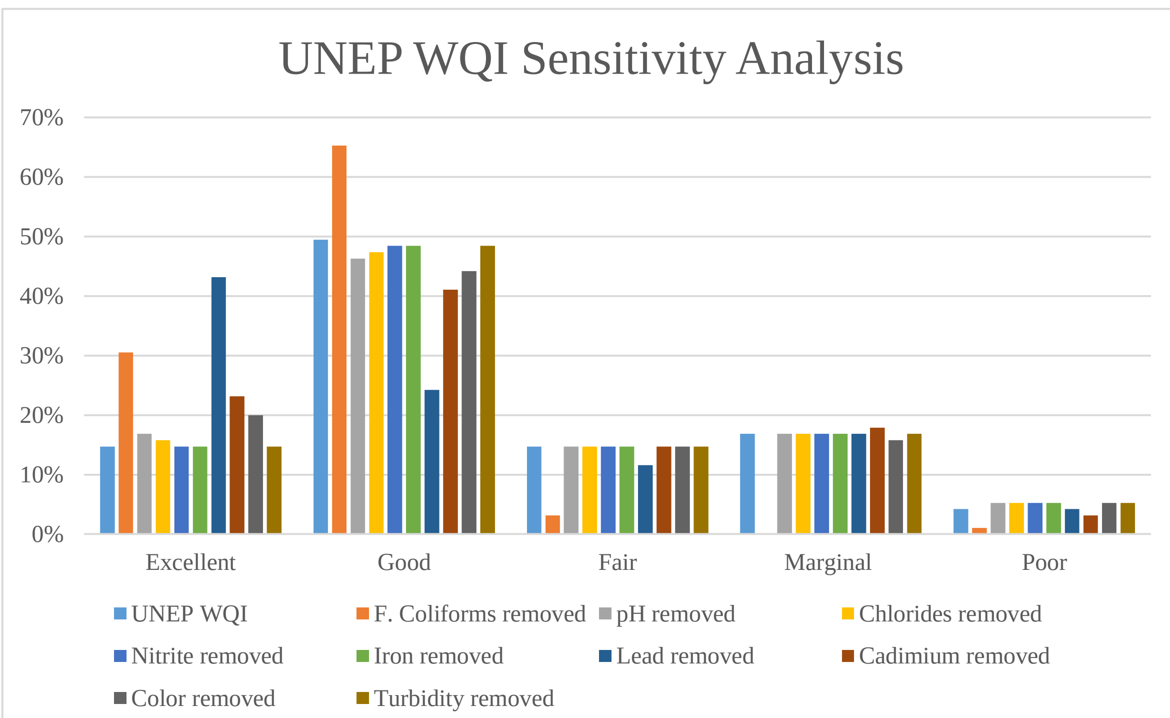


Figure 4.27: Classification of Water Quality by UNEP WQI

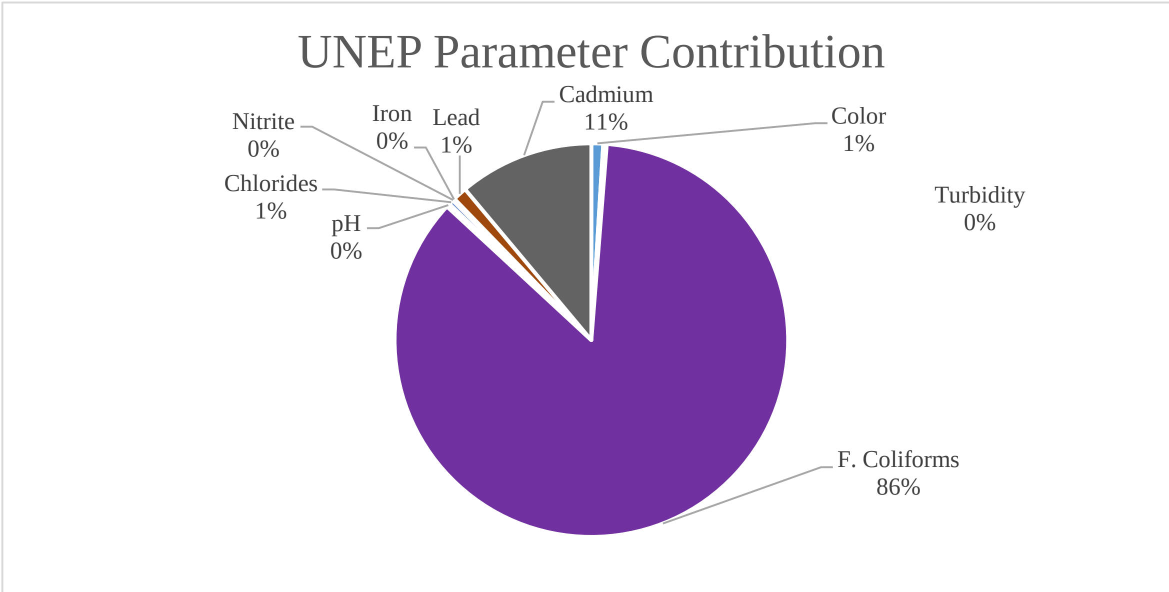


Figure 4.28: Contribution of each Exceeding Water Quality Parameter to the UNEP WQI

4. After conducting the analysis for PWQI (Figure 4.29) by separately removing one parameter of the index; faecal coliforms, manganese and lead were the contributing parameters.

- The removal of faecal coliforms, manganese and lead from the index, increased the percentage of excellent samples, form 11%, to 18%, 19% and 21% respectively. Hence removing these 3 parameters individually improved the index of the samples (Figure 4.29).

- All the exceeding water quality parameters were significantly correlated to the index regardless of which parameter was removed.

- The major contributor showing the least strong correlation leading to the strongest relationship is faecal coliforms ($R^2$ = 0.214, p value < 0.001), followed by cadmium

(R2 = 0.899, p value < 0.001), and free residual chlorine (R2 = 0.959, p value < 0.001) (Table 4.23).

Hence, faecal coliforms, cadmium and free residual chlorine are contributing significantly to the PWQI (81%, 11%, and 4%, respectively (Figure 4.30).

Moreover, manganese (1%) is barely contributing to the equation as the rest of the quality parameters even though it shows increase the in index water quality classification. A reason for that might be the large number of exceedances the parameter had on the index (Figure 4.30)

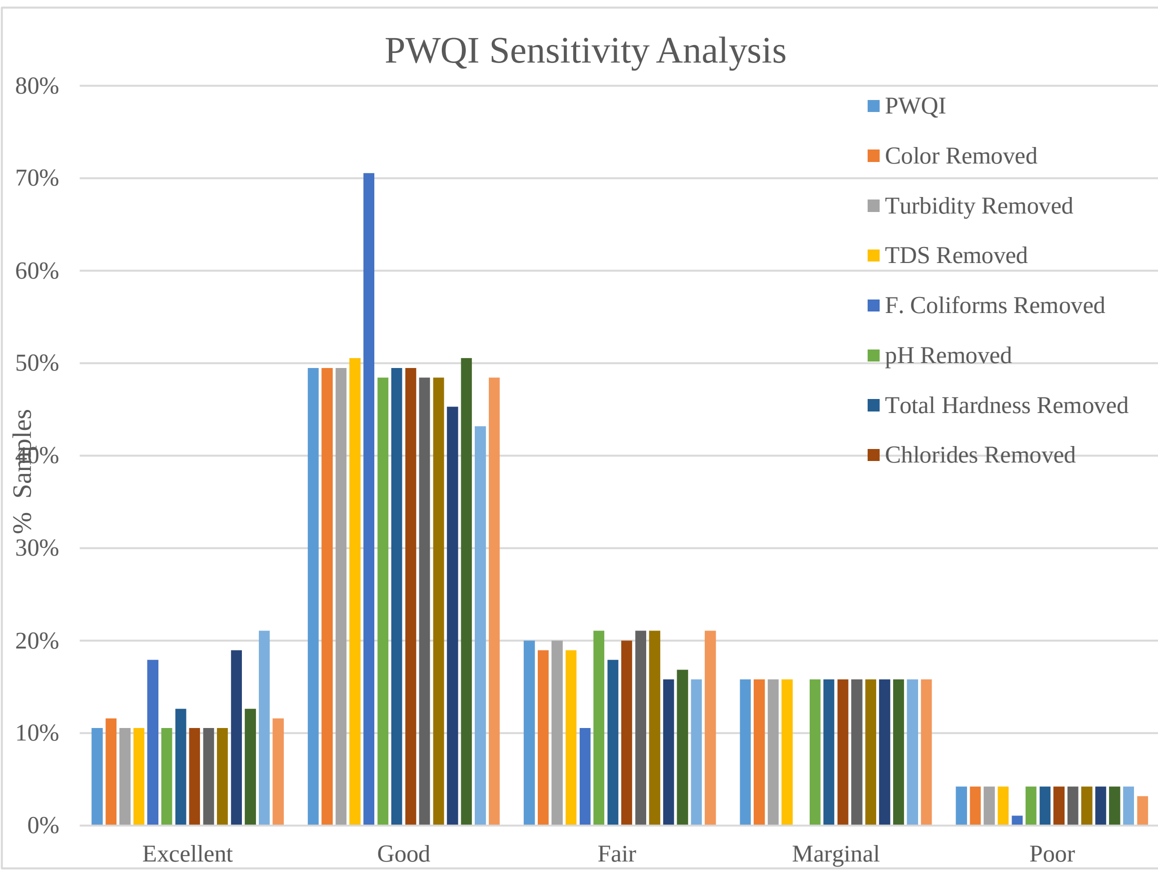


Figure 4.29: Classification of Water Quality by PWQI.

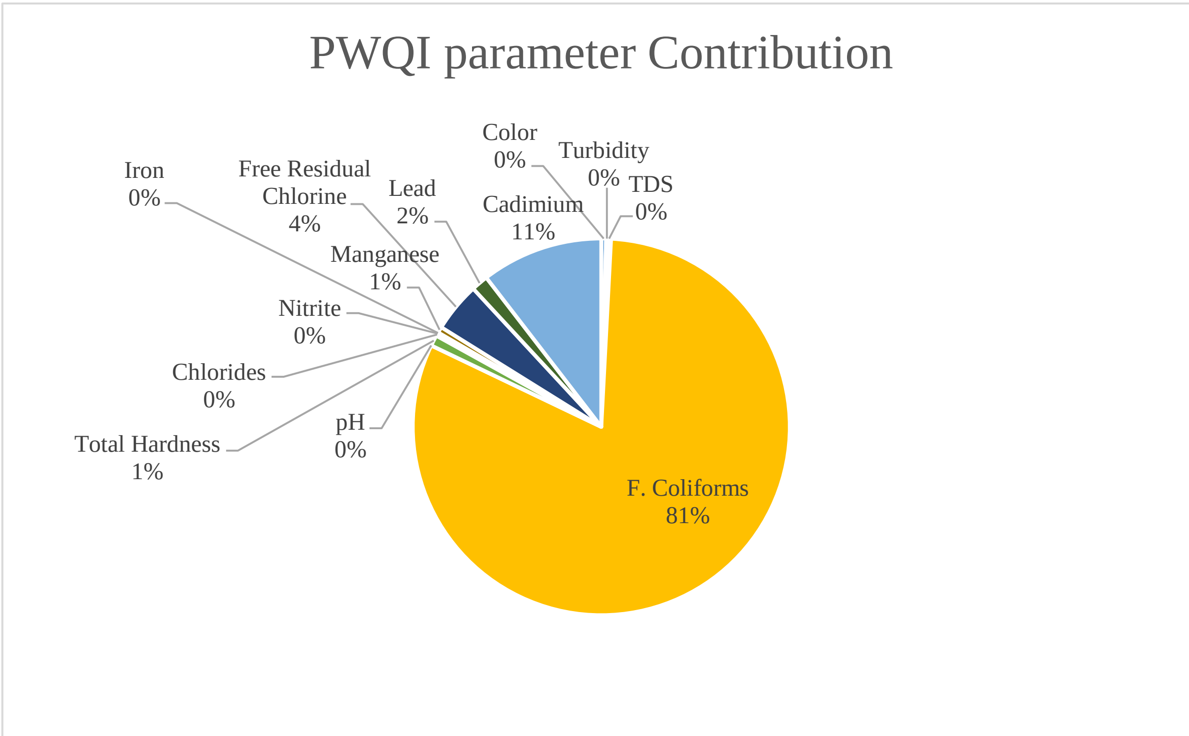


Figure 4.30: Contributions of Each exceeding Water Quality Parameter to the PWQI

Table 4.23: Correlation Matrix Sensitivity Analysis

| Parameter | HWQI | | AWQI | | UNEP WQI | | PWQI | |
|---|---|---|---|---|---|---|---|---|
| | $R^2$ | *p value* | $R^2$ | *p value* | $R^2$ | *p value* | $R^2$ | *p value* |
| Color | | | 0.852 | < 0.001 | 0.990 | < 0.001 | 0.996 | < 0.001 |
| Turbidity | | | 0.972 | < 0.001 | 0.997 | < 0.001 | 0.999 | < 0.001 |
| TDS | | | | | | | 0.997 | < 0.001 |
| F. Coliforms | 0.046 | 0.037 | | | 0.112 | 0.001 | 0.214 | < 0.001 |
| pH | | | 0.993 | < 0.001 | 0.997 | < 0.001 | 1 | < 0.001 |
| Chlorides | | | 1 | < 0.001 | 0.996 | < 0.001 | 0.998 | < 0.001 |
| Nitrite | 1 | < 0.001 | | | 0.999 | < 0.001 | 1 | < 0.001 |
| Iron | | | 0.927 | < 0.001 | 0.999 | < 0.001 | 0.999 | < 0.001 |
| Manganese | | | | | | | 0.995 | < 0.001 |
| Free Residual Chlorine | | | | | | | 0.959 | < 0.001 |
| Lead | 0.941 | < 0.001 | | | 0.988 | < 0.001 | 0.986 | < 0.001 |
| Cadmium | 0.930 | < 0.001 | | | 0.885 | < 0.001 | 0.899 | < 0.001 |

To conclude the correlation matrix for HWQI, AWQI, UNEP WQI and PWQI parameter sensitivity analysis (Table 4.23) revealed that no matter which parameter is removed all indices were significantly correlated. Despite that, for the HWQI, UNEP WQI, and PWQI; one parameter, the faecal coliforms, was always the main contributor. Meanwhile, for the AWQI, color was the main contributor.

When comparing the AWQI parameter sensitivity analysis to the F1, F2, F3 analysis (section 4.3), we notice that the AWQI is significantly influenced by F2, the frequency of the number of times each parameter exceeded the guideline. In the AWQI parameters, color was the parameter to exceed the guidelines the most (24 times for all piped water supplies). The other parameters that exceeded include: turbidity 9 times, pH 6 and iron 4 times each. Hence it is expected for color to have the largest contribution on the AWQI.

Meanwhile, when comparing the HWQI, AWQI, UNEP WQI, and PWQI parameter sensitivity analysis to the previous F1, F2, F3 analysis, PWQI are significantly influenced by (the amplitude: The extent (excursion) to which the failed test exceeds the guideline, showing by how much each parameter exceeded the guideline; while being little inclined by how many, and how many times each parameter exceeded the guidelines. Due to the stringent standard that LIBNOR has for faecal coliforms in drinking water (0 coliforms/100 ml), hence any exceeding would greatly contribute to the overall index, especially since exceeding would be 1 coliform/ 100ml, or greater. All the other parameters exceed by decimal digits, thereby not having great excursion. However, unlike the UNEP (2012) report, we are not able to remove faecal coliforms from the equation, since it is a major parameter in drinking water affecting human health.

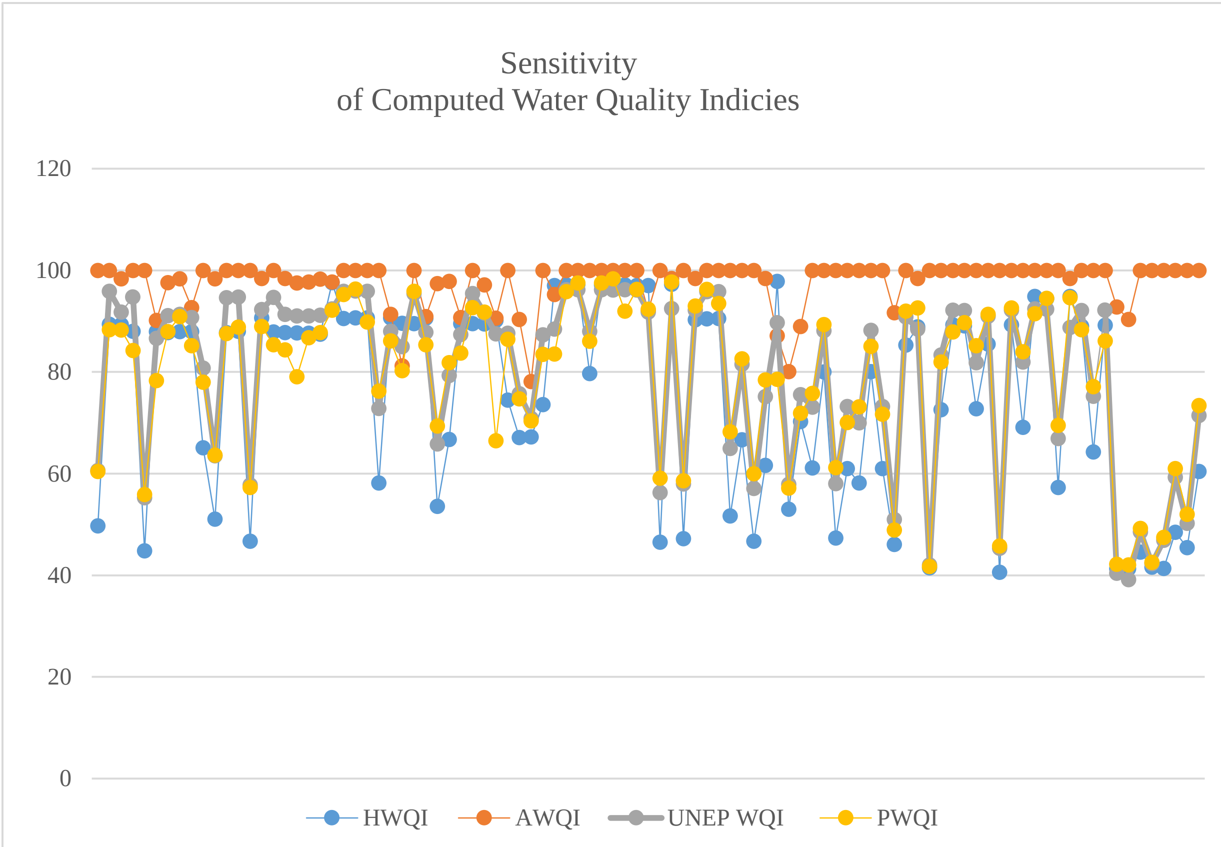


Figure 4.31: Sensitivity of HWQI, AWQI, UNEP WQI, and PWQI for all Mount Lebanon sampling points (n=95)

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Chapter Overview

This chapter discusses the main findings in the study, with respect to Mount Lebanon, and the 4 indices (AWQI, HWQI, UNEP WQI, and PWQI) their conclusions, and the recommendations.

## 5.2 Conclusion

Enhancing the quality of the water supply is challenged by various factors relating to water quality monitoring, water treatment, and water management from sources, to distribution network to end-users taps. In Lebanon, potable water quality monitoring is highly deficient mostly due to the lack of resources (technical and financial) needed for implementing and sustaining such programs. As such, the quality of the water supply is not properly determined and accordingly, no interventions are planned to upgrade quality.

Per se, the use of water quality indices as screening tools has become increasingly more popular as simple, concise and valid tools that summarize complex scientific data into a simpler form, for proper risk assessment, management and communication. The water quality index (WQI) expresses water quality by integrating measurements of selected water quality parameters into a single number between 1 and 100; 1 being the poorest and 100 being the "best". And accordingly, +classifies water quality as poor (conditions usually depart from standards); marginal (conditions often depart from standards); fair (conditions sometimes depart from standards); good (conditions rarely depart from standards) or excellent (quality in compliance with standards) (UNEP GEMS/Water Programme, 2007).

Hence, the piped water supplies of Mount Lebanon six Qadaas (Alley, El Chouf, Baabda, Jbeil, Keserwan and El Matn) were evaluated based on 4 different types of water indices (1) the AWQI: monitors the 9 water quality parameters of color, turbidity, ammonia, chlorides, iron, pH, sodium, sulfate, and zinc; (2) the HWQI: monitors the 7 water quality parameters of cadmium, copper, lead, manganese, nitrate, nitrite, and faecal coliform; (3) the UNEP WQI: monitors 21 water quality indices of color, turbidity, pH, ammonia, chlorides, iron, sodium, sulfate, nitrate, nitrite, zinc, cadmium, copper, lead, manganese, faecal coliform, arsenic, chromium, mercury, fluoride and boron; (4) proposed PWQI: monitors 20 water quality indices of color, turbidity, TDS, pH, total hardness, chlorides, ammonia, nitrate, nitrite, sodium, sulfate, iron, manganese, nickel, zinc, cadmium, copper, lead, free residual chlorine, and faecal coliform. Results of the analysis showed that:

- The proposed PWQI is more reflective of the potable water quality than the AWQI which only reflects on the acceptability of the supplies by consumers. AWQI gave false positives when the levels of the all acceptability parameters (color, turbidity, ammonia, chlorides, iron, pH, sodium, sulfate, and zinc) were within LIBNOR standards. This is mainly because it does not take into account the microbiological profile. Thus, the AWQI gave false positives by inflating the water quality classification for Qaadaa Alley to excellent (100 %) although 16% of supplies were faecally contaminated); for Qadaa El Chouf to excellent (64%) and good (36%) although 55% of supplies are faecally contaminated; for Qadaa Baabda to excellent (87%) and good (13%) although 30% of supplies were faecaly contaminated; Qadaa Jbeil to excellent (95%) and good (5%) although 65% of supplies were faecally contaminated; Qadaa Keserwan to excellent (63%) and good (32%) although 13% of supplies are faecally; and Qadaa El Matn to excellent (90%) and good (10%) although 13% of supplies are faecally contaminated (Tables 4.1b, 4.3, 4.4b, 4.6, 4.7b, 4.9, 4.10b, 4.12, 4.13b, 4.15, 4.16b & 4.18 and Figures 4.1- 4.12). As such, the use of the AWQI masks the inferiority of the piped water supplies making it difficult to identify problematic areas.

- The HWQI is also non-reflective on the quality of the piped water supplies, since it automatically drops the index to a fair or poor quality when faecal coliforms are present. (Tables 4.1b, 4.3, 4.4b, 4.6, 4.7b, 4.9, 4.10b, 4.12, 4.13b, 4.15, 4.16b & 4.18 and Figures 4.1- 4.12). As such, the HWQI yielded the lowest scores among the 4 computed indices, downgrading the quality of the Mount Lebanon water quality supplies. This is mainly due to the high contribution of the microbiological quality parameter to the index due to the limited number of parameters (7) that are monitored (faecal coliforms, nitrates, nitrites, manganese, lead, cadmium, and copper). However, in cases where no faecal coliforms were present, the HWQI quality classification was similar to that of the PWQI. Moreover, the HWQI does not take into consideration the water quality parameters that impact water acceptability (color, turbidity, ammonia, chlorides, iron, pH, sodium, sulfate, and zinc). This is additionally a major limitation as acceptability of water supplies determines water use by end-users. Rejection of piped water supplies as such, would increase dependence on complementary water sources of undetermined quality or safety.

- The UNEP WQI and the PWQI yield overall similar results in terms of water quality classification; still, the ranges seem to be more defined by the PWQI possibly as it additionally includes parameters that reflect more on the types of water sources, sources of pollution and the management of water supplies (TDS, total hardness, and free residual chlorine) (Figure 4.2). Moreover, the quality of the piped water supplies were downgraded by the UNEP WQI once faecal contamination was present and enhanced in its absence as it in includes parameters (fluoride, boron, chromium, mercury and arsenic) that are below detection limits, and as such do not constitute an exceedance to standards as they do not reflect on major characteristics of water supplies in Mount Lebanon as indicated before. This boosted the contribution of faecal coliforms to the index and consequently led to the drop in the water quality classification.

Moreover, the [F1], [F2] and [F3] validation and sensitivity analysis was conducted to assess which factor is contributing the most to the overall index: the scope ( the percentage, or how many parameters exceeded the guideline at each sampling point at each round); the frequency (the percentage of individual tests within each parameter that exceeded the guideline, showing how many times each parameter exceeded the guidelines) or the amplitude (the extent to which the failed test exceeds the guideline, showing by how much each parameter exceeded the guideline). The regression analysis showed that for HWQI, UNEP WQI and PWQI, [F3] was the driving factor ($R^2$= 0.958, *p value* <0.001; $R^2$= 0.981, *p value* <0.001; $R^2$= 0.966, *p value* <0.001, respectively). In comparison, the AWQI was driven by [F2] ($R^2$= 0.944, *p value* <0.001). And, all the indices were the least impacted by [F1] the scope or percentage of how many parameters exceed the guideline at each sampling point, at each round. This implies that the number of parameters that fail is not as important as the other factors, as shown in the scatter plots (Figure 4.13), and in table 4.22. Further, both the UNEP WQI and PWQI were significantly influenced by [F3]. And, although the indices are both comprised of acceptability and health parameters, based on the regression analysis they were driven by [F3] similar to the HWQI and contrary to the AWQI which is driven by [F2]. This signifies that the effect of the extent to which each parameter fails the guideline outweighs the number of times each parameter exceeded the guidelines. Hence, it can be concluded that the UNEP WQI and PWQI are more impacted by the HWQI than the AWQI (table 4.20 and figure 4.13). And, all the indices were the least impacted by [F1] the scope or the percentage of how many parameters exceed the guideline at each sampling point, at each round. This implies that the number of parameters that fail is not as important as the other factors.

Additionally, the parameter contributions and correlation analysis was conducted to specify which of the parameters were the largest contributors to each computed indices (Figures 4.14-16). Results showed that the quality parameters faecal coliforms, cadmium and lead, are the major contributors to the HWQI (88%, 7%, 5%, respectively); color and chlorides were the major contributors to the AWQI (73%); faecal coliforms, cadmium and lead, are the major contributors to the UNEP WQI (86% 11%, 1%, respectively); and manganese (22%), lead (22%), total hardness (13%), free residual chlorine (12%), and faecal coliform (10%) were the major contributors to the proposed PWQI. This further confirms the importance of the addition to the computation of the index quality parameters that reflect on type of water source (ground water spring and wells) and management specified (treatment by chlorination), as the hardness and free residual chlorine.

Additionally, to permit comparison between all exceeding contributing water quality parameters, the simple regression matrix (Table 4.21) and the scatterplots (figure 4.18) showed that for the HWQI the largest contributor is faecal coliform ($R^2 = 0.702$ and *p value* < 0.001) even though it was not the most exceeding parameter as presented in figure 4.14. For the AWQI and based on the correlation matrix table (Table 4.21) and the scatterplots (figure 4.19), the largest contributor was iron ($R^2 = 0.816$ and *p value=0.283*) even though it was not the most exceeding quality parameter as presented in figure 4.15. For the UNEP WQI and based on the correlation matrix table (Table 4.21), and the scatterplots (figure 4.20), the largest contributors is faecal coliform ($R^2 = 0.761$ and *p value* < 0.001) was the most contributing parameter and was highly significant based on the regression analysis as evident in figure 4.16. Similarly for the PWQI and based on the correlation matrix table (Table 4.21), and the scatterplots (figure 4.21); the most contributing and the most significant parameter was the faecal coliform ($R^2 = 0.75$ and *p value* < 0.001) as evident in figure 4.16. The rest of the main contributors were found to be manganese, at acceptability levels ($R^2 = 0.166$ and *p value* =0.011), lead ($R^2 = 0.002$ and *p value* = 0.691), free residual chlorine ($R^2 = 0.161$ and *p value* < 0.001) and total hardness ($R^2 = 0.133$ and *p value* < 0.001), even though they were not the major exceeding parameters as presented in figure 4.17.

And, the presence faecal coliform demonstrated consistently to be the largest contributor to the HWQI, UNEP WQI, and PWQI. This is significant since as presented in the [F1] [F2] [F3] analysis (section 4.3), [F3] the excursion was the most contributing factor to the HWQI, UNEP WQI and the PWQI and not [F1] the exceedance. Hence, the overall water quality indices are driven by the excursion of each parameter from the guideline and not the number of exceeded parameters. This further emphasizes that the inclusion of water quality parameters that lead to deviation from standards as indicated for the PWQI, impact the more the quality classification.

Additionally, faecal coliform was the major contributor to the 3 indices (HWQI, UNEP WQI, and PWQI) as any deviation from the standard (0 coliforms/100 ml) will constitute a higher exceedance compared to other parameters.

Meanwhile, for the AWQI, as presented in according to section 4.3, as since [F2] is the main factor affecting the index, thus color was the main contributor since it exceeded the most exceeded the most (24 times).

Hence, and based on the proposed PWQI, the overall classification of the piped water supplies of Mount Lebanon, throughout the 6 Qadaas, is as follows (Table 4.19):

- Around 9% are of excellent quality in compliance with the LIBNOR standards virtually all the time.
- Around 49% are of good quality in compliance with the LIBNOR standards mostly all the time.
- Around 21% are of fair quality that is sometimes non-compliant with the LIBNOR standards.
- Around 17% are of marginal quality that is often non-compliant with the LIBNOR standards.
- Around 3% of poor quality that is non-compliant with the LIBNOR standards.

As such, the major quality concerns relating to the piped water supplies are the following:

- High mineral content of coastal ground water sources; few distribution areas of Mount Lebanon (5.5%) get their water from coastal aquifers show high TDS levels exceeding the LIBNOR standard of 500 mg/L, and throughout the year. In addition, 4.6% have TDS levels over 1000 mg/L. And, even though high levels of TDS do not have direct health impacts, levels above 1000 mg/L could be associated with irritation of the gastrointestinal tract. Additionally, such levels are concomitant with unpleasant taste and lead to excessive scaling in water pipes, heaters, boilers and household appliances (WHO, 2011).

- Increase in chloride levels is further associated with sea water infiltration. And, high levels of chlorides exceeding the WHO guideline of 250 mg/L are associated with a salty taste that is rejected by consumers (WHO, 2011).
- Moderate increase in water hardness associated with the geological formation and boasted by sources of pollution. The increase in non-carbonate hardness levels further confirms exposure to the various sources of pollution (e.g. deficient sewage and municipal solid waste management and sea water infiltration. High levels of hardness are mostly associated with corrosion and scaling. (4) Increased levels of lead and cadmium.
- High levels of lead, cadmium and manganese reflecting on deterioration of piped water distribution networks. Lead leaching is due to the corrosion of the brass fittings in water pipes while cadmium is due to the corrosion of the galvanized pipes (Tavanpour et. al, 2016; WHO, 2011 Cadmium); is increased by acidic pH, water softness, and the standing time of the water in the networks (WHO, 2011). Accordingly, it would be enhanced by precipitation (rainy season) as indicated in rounds 3 and 4. As for

manganese, exposure to networks and water sources from agricultural runoff, could lead to high levels leading to black precipitate (WHO,2011)

Exposure to high levels of lead is associated with several health risks in children under the age of 6 and pregnant women and their fetus. It affects the central nervous system resulting in neurological and behavioral effects, and is associated with acute lead intoxication (headaches, muscle tremor, abdominal cramps, kidney damage, hallucinations, and loss of memory) (WHO, 2011). Additionally, prolonged exposure to cadmium targets the kidneys and leads to cadmium toxicity (WHO, 2011).

Exposure to high levels of manganese from non-point sources of pollution can have some neurological effects when ingested, and can cause black sediments in water. Manganese concentrations can be reduced by simple chlorination, followed by filtration (WHO, 2011; EPA, 2016).

- Faecal contamination of water piped water supplies; around 24.8% of supplies were found to be feacally contaminated all year round (4 sampling rounds). This is a chronic problem aggravated by the deterioration of networks and the intermittent water distribution. Moreover, it is reflected by deficient/insufficient chlorination. This is evident by the absence of free residual chlorine levels of 0.3 mg/l as recommended by LIBNOR. Overall, 43.5% of the free residual chlorine levels of all the Mount Lebanon piped water supplies were less than 0.1mg/L all year round (4 sampling rounds). In addition, in 8.5% of piped water supplies no free residual chlorine levels were detected. So either disinfection by chlorine was not applied or the chlorine dose was not sufficient to meet the chlorine demand and maintain the recommended free residual levels (0.3 mg/L). As such, disinfection process should be properly controlled and the free residual chlorine levels should be monitored throughout the network, and at all end points. On the other hand, in cases of increased chlorine dose (22.6%) possible formation of hazardous disinfection byproducts is critical (WHO, 2011).

### 5.3 Recommendations

a. The use of the Potable Water Quality Index (PWQI) should be adopted to enhance monitoring of the piped water supplies in the four Regional Water Establishments of Lebanon (Beirut and Mount Lebanon, North Lebanon, South Lebanon and the Bekaa). This index is critical to overcome technical and financial resource deficiencies.

    i. The adoption of the PWQI would enhance (a) determining water quality and safety based on the extent of deviation from drinking water standards set by LIBNOR Standards (b) identifying hot spots to be addressed, (c) setting priorities for interventions, and (d) enhancing risk communications to policy makers and end-users on water quality and safety.

    ii. The use of the PWQI would summarize complex scientific data into a simple form to promote risk assessment, management, and risk communication. This would further build trust, increases awareness on water quality and its importance, and reduce dependence on unsafe complementary water sources by end-users.

b. The use of the PWQI should be coupled with the development of water safety plans and the need to screen the quality of water sources feeding networks, minimally twice per year (peak of dry and wet seasons). Consequently, the water quality parameters included in the calculation of the PWQI should be revisited based on such complementary activities, and modified accordingly.

i. The PWQI should be country specific, and sensitive to the type of water source (surface and ground), exposure to major sources of pollution (e.g sewage effluents, solid waste leachate, seawater infiltration, agricultural runoff: fertilizers and pesticides, and industrial waste) and type of treatment processes applied (disinfection by chlorination). As such, it is reflective of the types of hazards challenging water supplies within the local context.

Further, addressing water quality challenges of Mount Lebanon piped water supplies the following is recommended:

c. Regulate the use of coastal wells to reduce on increased salinity enhanced by seawater infiltration. This is a chronic problem that challenges most coastal ground water sources, in Lebanon and should be tackled as part of the Integrated Management of Water Resources (IWRM).

d. Upgrade and continuously maintain water distribution networks to avoid water wastage, leaching of contaminants; scale formation due to pressure drop and the fluctuating flows; and exposure to faecal contamination. Moreover, intermittent water flow is still a chronic challenge which should be addressed in a timely manner by proper Water Resources Assessment (WRA) which is an integral component of IWRM.

e. Address issues of deficient/insufficient water disinfection immediately. Chlorination should be properly controlled: the chlorine demand test should be conducted on continuous basis to determine the required chlorine dose and ensure free residual chlorine levels of 0.3mg/L throughout the network, and at all end points. This is critical to ensure the microbiological safety of water supplies.

f. Re-dose chlorine at specific locations, beyond the treatment plant, to reduce on high free residual levels that are rejected by consumers and additionally reduce on the possible formation of hazardous disinfection byproducts. Screening for disinfection by-products should be done on yearly basis to reduce the potential risks associated with such hazards.

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