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Risk-based Analysis of Urban Water Security: Application to Palestinian Cities

By

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Analyse basée sur les Risques de la Sécurité de L'eau Urbaine: Application aux Villes Palestiniennes

Par:

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La Soutenance s'est Déroulée le 23 Juillet 2020 Devant La Commission des Examinateurs Suivants:

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Abstract

This thesis concerns the critical issue of water security assessment at urban level with application on the Palestinian territory. It is based on the risk-based semi-quantitative approach. Indicators and methodology were established from the literature review and experts' opinions. Data were collected from the Palestinian Water Authority, Water Sector Regulatory Council, and Palestinian cities. The SWARA method was used for data analysis. Risks were expressed in scores and levels and translated to index. The research confirms that the risk-based approach, combined with the water security index, constitutes a powerful method for addressing the urban water risks. It provides a clear understanding of the urban water security and helps in making the right decisions.

The research revealed that the level of water security in the Palestinian territory is between alarming and poor. Water resources have the highest risk score, followed by the water governance and water services. It resulted in establishing a new system for proactive management of the urban water security risk in Palestine.

Keywords: Water Security, Urban, Risk, SWARA, Index, Palestinian territory.

Résumé

Cette thèse concerne l'évaluation de la sécurité de l'eau au niveau urbain avec application sur le territoire palestinien. Elle s'appuie sur une approche semi-quantitative du risque. Des indicateurs et une méthodologie ont été établis à partir de la littérature et de l'avis d'experts. Les données ont été collectées auprès de l'Autorité palestinienne de l'eau, du Conseil de réglementation du secteur de l'eau et des villes palestiniennes. La méthode SWARA a été utilisée pour l'analyse des données. Les risques ont été exprimés en scores et niveaux et traduits en index. Le travail de thèse rconfirme que l'approche basée sur le risque combinée à l'indice de sécurité de l'eau constitue une méthode puissante pour traiter les risques liés à l'eau en milieu urbain. Cette approche fournit une bonne compréhension de la sécurité de l'eau et aide à prendre les bonnes décisions.

La recherche a révélé que le niveau de sécurité de l'eau dans le territoire palestinien est entre alarmant et médiocre. Les ressources en eau ont le score de risque le plus élevé, suivies par la gouvernance de l'eau et les services de l'eau. Elle a abouti à la mise en place d'un nouveau système de gestion proactive du risque de sécurité de l'eau en milieu urbain en Palestine.

Mots clés: Sécurité de l'eau, Urbain, Risqué, SWARA, Indice, Territoire Palestinien.

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List of Abbreviations

Symbol	Meaning
ADI	Access to Data and Information
AFD	French Development Agency
AHP	Pair-wise comparisons Analytic Hierarchy Process
ANP	Analytic Network Process
ANERA	American Near East Refugee Aid
AP	Annual Precipitation
ARAS	Additive Ratio Assessment
ARIJ	Applied Research Institute- Jerusalem
CRR	Clear Roles and Responsibilities
CWS	Continuity of Water Supply
COPRAS	Complex Proportional Assessment
Delphi	The name refers to the Oracle of Delphi, a priestess at a temple of Apollo in ancient Greece known for her prophecies
ELECTRE	Elimination and Choice Expressing Reality
GES	Global Environmental Services
GIZ	German Corporation for International Cooperation GmbH
GWP	Global Water Partnership
IWA	International Water Association
JSCs	Joint Service Councils
JWC	Joint Water Committee
KFW	German development Bank
KPIs	key Performance Indicators
l/c/d	litter per capita per day
MADM	Multiple Attribute Decision Making
MCDM	Multi Criteria Decision Making

MCM	Million Cubic Meter
MOORA	Multi-objective Optimization by Ratio Analysis
OECD	The Organization for Economic Co-operation and Development
PHG	Palestinian Hydrology Group
PMD	Palestine Meteorological Department
PWA	Palestinian Water Authority
RTWW	Ratio of Treated Waste Water
SDEWES	The international center for sustainable development of energy, water and environment systems
SE	Stakeholder Engagement
SoS	The State of Sewers
SPs	Service Providers
SWARA	Step-wise Weight Assessment Ratio Analysis
TL	Treatment Level
TODIM	an acronym in Portuguese for Interactive Multi-criteria Decision Making
TOPSIS	The Order Preference by Similarity to Ideal Solution
UPWSP	Union of Palestinian Water Service Providers
USAID	United States Agency for International Development
UN	United Nations
UNU	United Nations University
WASPAS	Weighted Aggregated Sum-Product Assessment
WBWD	West Bank Water Department
WC	Water coverage
WDs	Water Departments
WHO	World Health Organization
WL	Water losses

WRA	Water Resources Availability
WSRC	Water Sector Regulatory Council
WSSA	Water Supply and Sewerage Authority
WWC	Waste Water Coverage

General Introduction

Problem Statement

This research concerns a vital subject for our society, which is related to the security of water supply in urban areas, with a focus on the critical water situation in Palestinian territory.

Water security management is very complicated because it combines environmental, technical, management, governance, and social issues. It is related to the water stress resulting from rapid demographic increase, climate change, lack of water infrastructures and contamination of water resources by the industrial, agriculture and domestic activities (OECD, 2013, ITU, 2014, OECD, 2016, Nazemi and Madani, 2017, Silva at el., 2018). Many countries around the world suffering from a wide range of water challenges, in particular shortage in water services, and its consequences on public health, economic activity, quality of life, and social stability. The stress on water resources could cause local and regional conflicts, with a dramatic impact on the population and peace; all of these challenges constitute a severe security issue.

Previous researches focused on water security issues through explaining the concept, studying its importance, and building evaluation frameworks. However, the number of papers about water security in urban areas still limited. Consequently, there is a need for research in this field. Aboelnga et al. (2019) highlighted the complexity of this issue because it combines the complexities of both water security and urban development. Scholars used the risk concept for the assessment of water security (Nazemi and Madani, 2017). This approach was used to identify uncertainties and to characterize the risk related to water (Garrick and W.Hall, 2014, OECD, 2013, and Hall and Borgmeo, 2013). They concluded that risk assessment provides a comprehensive approach for the water security understanding as well as for developing water security policies and strategies (Zio, 2018, Rovins et al., 2015, Garrick and W.Hall, 2014). As mentioned earlier, these works did not focus on the urban area. This research work presents a contribution to the water security in urban areas with an application to the Palestinian cities. National and international organizations classified the Palestinian territory as an area suffering from a high level of water insecurity, which is related to political, natural, and human-made conditions. Indeed, the water sector in the Palestinian territory faces severe and chronic challenges concerning low water resources, weak access to water supply services, and poor water governance. At the urban level, water security in the Palestinian territory is breaking down.

This research focused on assessing water security at the urban level, as well as proposed a novel index for urban water security. The study built an innovative framework combined with water security, risk management, indicators, and the SWARA method.

Research Objectives

This research aims to:

- Identify urban water security challenges and risks.
- Provide a coherent and robust framework for assessing urban water security from the risk perspective.
- Establish an innovative index for expressing urban water security in areas subjected to high water stress.
- Provide governments and policymakers with a new water management system based on proactive actions.

It contributes to answering the following questions:

- What are the key drivers of the risks of water security in urban areas?
- What is the current situation of urban water security in the Palestinian Territory?
- How could the concept of "risk" contribute to cope with the "water security" challenges?
- How could we build an effective management system for the urban water security in high water stress areas?

Research Significance

Water security in Palestinian territory is critical, because of the occupation, demographic growth, urbanization, climate change, aging infrastructures, lack of investment and poor governance. Since 20 years ago, Palestine by regional standards is suffering from the lowest access to water resources, low availability, which led to low water consumption, poor water services, together with the high cost (World Bank, 2009). The water crisis in Palestine has been severe for decades. McKee, (2012) has already noted the absence of critical actions in the field of water security in Palestine. This field also suffers from a lack of academic works, which are necessary for establishing valuable strategies in this complex field. This research aims at filling this serious gap through a contribution to the scientific knowledge in the field of water security in Palestine and establishing a proactive scientific-based approach for this issue.

Methodology

The risk-based approach is adopted in this work for the evaluation of the urban water security in high water stress regions, with application to the Palestinian territory. Water security data were collected for 10 Palestinian cities. They included data about water resources, water services, and water governance. For each risk indicator, severity and likelihood levels as well as the risk score were determined according to the literature and experts' opinions. The methodology consisted of seven stages: data collection, identification of risks drivers and indicators, weighting and ranking of risks drivers and indicators, risk assessment, estimation of urban water security index, risk evaluation, and risk management.

Layout of the Thesis

The thesis report is organized into four chapters. The first chapter presents state of the art about the water security challenges, risk assessment approaches and the importance of the multi-criteria decision making (MCDM) in indicators' ranking. The second chapter presents a comprehensive methodology for water security evaluation, including indicators identification, data collection, data pre-analysis, risk analysis, and water security assessment. The last two chapters present an analysis, assessment, evaluation and management of the water security in ten Palestinian cities, and some recommendations to improve this security.

Chapter One: Water security in urban areas - Literature Review

Chapter 1: Water Security in Urban Areas - Literature Review

1.1 Introduction

The water security issue concerns the continuous supply of good quality water for domestic use as well as for industrial and agriculture activities at a reasonable price. The rapid demographic increase together with the climate change, the lack of water infrastructures and the contamination of water resources by the industrial, agriculture and domestic activities resulted in a high stress on water resources. Many countries around the world, in particular in developing countries, suffer from shortage in water services, with dramatic consequences on public health, economic activity, quality of life and social stability. The stress on water resources could also cause major local and regional conflicts, with dramatic impact on the population and peace. Since, shortage in water services constitutes a serious security issue, national, regional and international authorities should establish and implement strategies to ensure required water services. These strategies should be based on deep risk assessment of the water security covering social, economic, environmental and international cooperation issues.

While water security constitutes a major concern in the world. In regions under conflicts, it constitutes a critical issue. Cities in these regions have to establish with the support of national and international institutions strategies to ensure water security. For this purpose, they have to consider water resources availability as well as infrastructures for water treatment and distribution as well as for the collection, treatment and re-use of sanitation water. This issue is highly challenging, because of its huge cost as well as of its major impact on the population.

This chapter presents the state of the art about water challenges as well as the water security at urban level, together with the risk concept and the Multiple-Criteria Decision-Making (MCDM) methods in the water security context.

1.2 Global Water Challenges

Despite the fact that water is essential to sustain human life and to develop communities, more than 90 % of the world population live in areas subjected to high water stress, the expected number of those people will reach five billion by 2050. In 2012, tow billions of the world population were living in stress water areas, more than 800 million people had no access to secure potable water. Actually, many countries are facing a real water crisis, most of them are developing countries (UNESCO, 2012, AWDO, 2013 and UNESCO, 2018).

The world faces a big challenge related to the increase in the population. World population will reach around 9.7 million in 2050 (Table 1.1). This increase will result in huge pressure on natural resources, infrastructure facilities and water consumption (Population Institute, 2015). This problem will have a great impact in developing countries where 70 % of the population live in unplanned urban areas (Al-Mulali & Ozturk, 2015). The global water demand is expected to increase by 55% between 2000 and 2050 (Kammeyer, 2017, Schwartz et al, 2018).

Table 1.1: World Population Growth and Urbanization

year	Population Current & Expected	Urban population	Urban Population %
2000	6.14	2.87	46.7 %
2010	6.96	3.60	51.7 %
2020	7.79	4.38	56.2 %
2030	8.55	5.17	60.4 %
2040	9.20	5.94	64.6 %
2050	9.74	6.68	68.6 %

Source: www.Worldometers.info

On the other hand, climate change results on huge challenges in water security. Under the global warming, cities suffer from the decrease in water availability, increase in water scarcity, over-extraction of water resources and intensification of floods and droughts events. Climate change has also a great impact on water quality, deterioration of urban water infrastructures and disrupting water services (OECD, 2013, ITU, 2014, Nazemi and Madani, 2017).

Cities suffer also from water infrastructure aging, which leads to infrastructures deterioration with catastrophic impact on both quality and efficiency of water service as well as on public health and economic activity (ITU, 2014, OECD, 2016, Silva at el., 2018).

Water governance and management constitute also a big challenge in water security. Water experts consider the "water crisis" as a "governance crisis". The absence of a clear and efficient water governance as well as poor management result in a degradation of the water services, water infrastructures and water resources, which are the backbone of the water security (ITU, 2014, OECD, 2016).

Conflicts have catastrophic impact on the degradation of water resources and the destruction of physical infrastructures as well as on the disturbance of the water governance and management (UNU, 2013).

Table 1.2 summarizes the water security challenges and their impact on the water services. All the countries are not be subjected to these challenges. But some countries, could be subjected now or in the coming years to these challenges with catastrophic impact on the population health, quality of life and security. Consequently, a rapid water security assessment is a "must" for these countries. The following sections will explore the state of the art in this field.

Table 1.2: Water Security Challenges and Their Impact

Challenge	Impact
World population growth and urbanization	Increase in the pressure on water demand, water services and infrastructures
Climate change	Intensification of climate-related hazard, deterioration of water resources and infrastructures, water stress
Infrastructures ageing	Degradation of water infrastructures, deterioration of the water system efficiency and quality
Governance and management	Lack of vision, strategy, monitoring, bad use of resources, lack of innovation
Conflicts	Destruction of water resources and infrastructures, population privation of their water resources, disturbance of the water governance and management

1.3 Water Security

1.3.1 What is Water Security?

Water security concerns water supply of current and future communities to meet their needs for domestic and economic activities at a fordable cost (Tarhule, 2017).

Discussion about water security started in the 1990s with a focus on water quantity. Then, it was extended to an inclusive approach, including management, science, governance and engineering, water security concept is dependent on geographical, political, social, economic and environmental conditions (Nazemi and Madani, 2017). In the last few years, researchers have been giving water security different definitions with various methods for analysis and assessment (Zhang et al., 2018).

At the World Water Forum in 2000, the UN described water security as “ensuring that ecosystems are protected and improved; that sustainable development and political stability are promoted, that every person has access to enough safe water at affordable cost to lead a healthy and productive life and the vulnerable are protected from the risks of water-related hazards” (UN, 2000).

The Global Water Partnership (GWP, 2014) established a comprehensive definition for the water security: “Every person has the ability to access to water with acceptable quality, quantity and cost. Safe water must be available for the population for healthy and productive life. Communities are protected from risks related to natural hazards such as floods, droughts, erosion and water-borne diseases. Water security is essential to protect the environment, enhance the social equity and to improve water management”.

The Organization for Economic Co-operation and Development (OECD) viewed water security as managing water risk at adequate level. Water security should be translated to minimum levels of water risks that sustain water services for basic population needs (OECD, 2013).

International agencies and water scientists gave high attention to water security. They proposed various definitions, which cover main issues such as water availability (quantity and quality), human basic needs (socially, economically and welfare), managing and protecting water related risks and sustainability (Hall and Borgomeo, 2013). Attention was also paid to other issues in water security such as geographic scale (regional, national, urban, household), economic and environmental impact as well as resiliency (Figure 1.1) (AWDO, 2013).

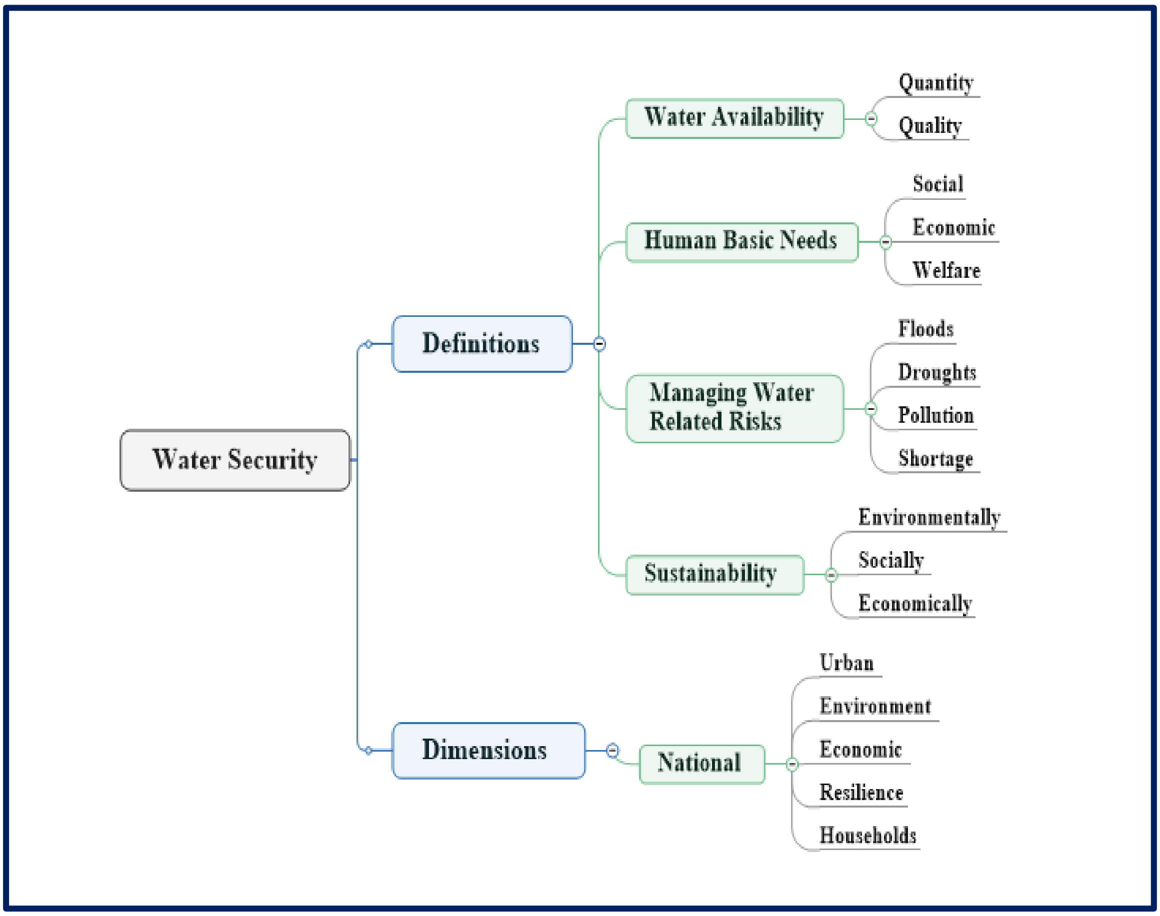

Figure 1.1: Water Security Definitions and Dimensions

1.3.2 Urban Water Security

The concept of urban water security focuses on the water security, as defined in the previous section, in urban area. This issue depends on the national water regulations and governance. In some countries, cities have the responsibility of the water supply as well as the management of the sewage. In other countries, this responsibility is exercised at the national level, or co-shared between the local and national levels. Then the urban water security should be conducted at the level of the water responsibility. In countries subjected to high water stress and insecurity, this question becomes very quickly a national issue.

The urban water security concerns the challenges treated at the level of a city with its specific socio-economic context as well as its environment, governance and infrastructures (Ginkel et al., 2018 and Hoekstraet al., 2018, Zeitoun, 2011, OECD, 2013).

Urban water security is highly complicated, because it combines multi-factors. In addition to the global water challenges (table 1.2), it deals with some local issues such as urbanization, low income families, poor infrastructures, taxes, lack of funding and illegal connections (Hoekstra et al., 2018 and Zhang et al., 2018).

In recent years, urban water security concept has gain an increasingly concern, however this subject yet requires more investigations (GWP, 2014). The water security has been evaluated based on qualitative approach more than quantitative one (van Beek and Lincklaen Arriens, 2014). The development of quantitative methods is more complex, but necessary for the establishment and evaluation of the water security strategy in urban area. The research in this area is still limited. According to water experts and scholars, quantitative approach of the water security in urban area is necessary to enhance our understanding of the water security term, decrease the fuzziness around the new concept and facilitate discussion between stakeholders. Moreover the quantitative approach could help in the assessment of implementation of the water security and in setting policy strategies and priorities in the decision making process (Lautze and Manthrithilake, 2012, Shrestha et al., 2018 and Varis et al. 2017).

Recently, scientists used index systems, indicators frameworks, cities ranking and water security scoring for evaluating the water security (Ginkel et al., 2018, Zhang et al., 2018, and Hoekstra et al., 2018). These indicators and indices are useful to figure out the significant challenges in water sector (Rouse, 2013) as well as to follow the process progress and performances indicators (GWP, 2014). In addition, indicators and indices give water experts capacities to make useful discussion with stakeholders and decision makers about important water issues using a well-defined concept and indicators (Hoekstra et al., 2018).

Table 1.3 summarizes a list of indicators and indices developed during the last ten years in various water security dimensions.

Table 1.3: Urban Water Security Indices

Framework	**Publishing Year**
City Blueprint	2012
Green City Index	2012
Sustainability Index for Integrated Urban Water Management	2013
City Resilience Index	2014
Sustainability Water City Index	2016
SDEWES Index	2017
Urban Water Security Indices and Indicators	2018
Urban Water Security Dashboard Index	2018
DECS Indicators	2019

Table 1.4 shows the indicators used in the City Blueprint which was proposed by Van Leeuwen et al. (2012) to assess the sustainability of urban water management. 24 indicators distributed in 8 groups were used. The index was the arithmetic mean of these indicators. City Blueprint framework provides a comprehensive system for understanding and evaluating challenges facing urban water management; it provides an opportunities for cities to learn from each other (Van Leeuwen et al., 2012). Koop and Leeuwen (2015) made a revision of the City Blueprint Index by removing 6 indicators and adding 7 indicators (Table 1.5). Then they applied the methodology on 45 municipalities in 27 countries (Koop and Leeuwen, 2015). This approach focused on the assessment of the urban water management more than on urban water security (Hoekstra et al., 2018).

***Table 1.4: City Blueprint Indicators** (Van Leeuwen et al. 2012)*

Framework	Indicators Group	Indicators
City Blueprint	Water Security	1. Total water footprint 1. Water scarcity 2. Water self-sufficiency
	Water Quality	3. Surface water quality 4. Ground water quality
	Drinking Water	5. Sufficient to drink 6. Water system leakage 7. Water efficiency 8. Consumption 9. Quality
	Sanitation	10. Safe sanitation 11. Sewage sludge quality 12. Energy efficiency 13. Energy recovery 14. Nutrient recovery
	Infrastructure	15. Maintenance 16. Separation of waste water and storm water
	Climate robustness	17. Local authority commitments 18. Safety 19. Climate robust building
	Biodiversity	20. Biodiversity 21. Attractiveness
	Governance	22. Management and action plan 23. Public participation

Table 1.5: Modified City Blueprint Indicators (Koop and Leeuwen 2015)

Framework	**Indicators Group**	**Indicators**
Modified City Blueprint	Water Quality	1. Secondary WWT 2. Tertiary WWT 3. Groundwater quality
	Solid Waste Treatment	4. Solid waste collection 5. Solid waste recycled 6. Solid waste energy recovery
	Basic Water Services	7. Access to drinking water 8. Access to sanitation 9. Drinking water quality 10. Nutrient recovery 11. Energy recovery
	Wastewater Treatment	12. Sewage sludge recycling 13. WWT energy efficiency
	Infrastructure	14. Storm water separation 15. Average age sewer 16. Water system leakage 17. Operation cost recovery 18. Green space
	Climate robustness	19. Climate adaptation 20. Drinking water consumption 21. Climate robust buildings
	Governance	22. Management and action plans 23. Public participation 24. Water efficiency measures 25. Attractiveness

The Green City Index was proposed by Siemens (2012) to deal with urban environmental sustainability. It includes 30 indicators distributed in eight groups or sometimes nine according to the region conditions, data availability and specific challenges (Table 1.6). It includes quantitative and qualitative indicators in order to cover the following issues; water and sanitation, waste management, Environmental governance, energy and buildings, CO_2 emissions, air quality and transport (Siemens, 2012).

Table 1.6: Green City Indicators (Siemens, 2012)

Framework	Indicators Group	Indicators
Green City	Water and Sanitation	1. Water consumption 2. System leakages 3. Wastewater system treatment 4. Water efficiency and treatment policies
	Waste Management	5. Municipal waste production 6. Waste recycling 7. Waste reduction policies 8. Green land use policies
	Environmental Governance	9. Green action plan 10. Green management 11. Public participation in green policy
	Energy and Buildings	12. Energy consumption 13. Energy intensity 14. Renewable energy consumption 15. Clean and efficient energy policies 16. Energy consumption of residential buildings 17. Energy-efficient buildings standards 18. Energy-efficient buildings initiatives
	CO_2 Emissions	19. CO_2 intensity 20. CO_2 emissions 21. CO_2 reduction strategy
	Air Quality	22. Nitrogen dioxide 23. Sulphur dioxide 24. Ozone 25. Particulate matter 26. Clean air policies
	Transport	27. Use of non-car transport 28. Size of non-car transport network 29. Green transport promotion

		30. Congestion reduction policies

Table 1.7 shows the indicators used in the Sustainability Index for Integrated Urban Water Management (Carden and Armitage, 2013). It was developed to understand water sustainability at urban level using 16 indicators distributed in four groups.

Table 1.7: Sustainability Index for Integrated Urban Water Management Indicators (Carden and Armitage, 2013)

Framework	**Indicators Group**	**Indicators**
Sustainability Index for Integrated Urban Water Management	Social	1. Level of service 2. Health 3. Vulnerability of disaster 4. Educational and Awareness
	Economic	5. Capacity to pay or access service 6. Cost recovery 7. Asset management
	Environment	8. Resources sustainability/ feasibility quantity 9. Sustainability of water resources 10. Climate change response 11. Resources sector per sector 12. Waste water management 13. Storm water management
	Institutional	14. Governance model 15. Progress with meeting targets 16. Institutional capacity/ policy.

Table 1.8 shows indicators used in the City Resilience Index (Arup, 2015) to measure cities adaptation capacity. It includes 52 indicators distributed in 12 groups.

Table 1.8: City Resilience Indicators (Arup, 2015)

Framework	Indicators Group	Indicators
City Resilience Index	Minimal human vulnerability	1. Safe and affordable housing 2. Adequate affordable energy supply 3. Inclusive access to safe drinking water 4. Effective sanitation 5. Sufficient affordable food supply
	Diverse livelihoods and employment	6. Inclusive labor policies 7. Relevant skills and training 8. Dynamic local business development and innovation 9. Supportive financing mechanisms 10. Diverse protection of livelihoods following a shock
	Effective safeguards to human health and life	11. Robust public health systems 12. Adequate access to quality healthcare 13. Emergency medical care 14. Effective emergency response services
	Collective identity and community support	15. Local community support 16. Cohesive communities 17. Strong city-wide identity and culture 18. Actively engaged citizens
	Comprehensive security and rule of law	19. Effective systems to deter crime 20. Proactive corruption prevention 21. Competent policing 22. Accessible criminal and civil justice
	Sustainable economy	23. Well-managed public finances 24. Comprehensive business continuity planning 25. Diverse economic base 26. Attractive business environment 27. Strong integration with regional and global economies
	Reduced exposure and fragility	28. Comprehensive hazard and exposure mapping

		29. Appropriate codes, standards and enforcement 30. Effectively managed protective ecosystems 31. Robust protective infrastructure
	Effective provision of critical services	32. Effective stewardship of ecosystems 33. Flexible infrastructure services 34. Retained spare capacity 35. Diligent maintenance and continuity 36. Adequate continuity for critical assets and services
	Reliable mobility and communications	37. Diverse and affordable transport networks 38. Effective transport operation & maintenance 39. Reliable communications technology 40. Secure technology networks
	Effective leadership and management	41. Appropriate government decision-making 42. Effective co-ordination with other government bodies 43. Proactive multi-stakeholder collaboration 44. Comprehensive hazard monitoring and risk assessment 45. Comprehensive government emergency management
	Empowered stakeholders	46. Adequate education for all 47. Widespread community awareness and preparedness 48. Effective mechanisms for communities to engage with government
	Integrated development planning	49. Comprehensive city monitoring and data management 50. Consultative planning process 51. Appropriate land use and zoning 52. Robust planning approval process

Table 1.9 summarizes the list of indicators used in the Sustainability Water City Index (ARCADIS, 2016). The framework is based on 19 indicators distributed in three groups: resiliency, efficiency and quality, was distributed over those groups. This index

requires huge amount of data from municipalities and water utilities in order to predict the future urban sustainability.

Table 1.9: Sustainability Water City Indicators (ARCADIS, 2016)

Framework	Indicators Group	Indicators
Sustainability Water City Index	Resiliency	1. Water stress 2. Green space 3. Water-related disaster risk 4. Flood risk 5. Water balance 6. Water reserves
	Efficiency	7. Leakage 8. Water charges \9. Service continuity 10. Wastewater reuse 11. Metered water 12. Drinking water 13. Sanitation
	Quality	14. Drinking water 15. Sanitation 16. Treated wastewater 17. Water-related disease 18. Water pollution 19. Threatened freshwater species

The international center for sustainable development of energy, water and environment systems proposed the SDEWES index to measure the city performance according to energy, water and environment using 35 indicators distributed in 7 groups (Table 1.10). In addition to these indicators, 25 sub-indicators were also used (SDEWES, 2017).

Table 1.10: The SDEWES Indicators (SDEWES, 2017)

Framework	Indicators Group	Indicators
The SDEWES index	Energy usage and Climate	1.Energy usage of buildings 2. Energy usage of transport 4. Energy usage per capita 5. Total degree days 6. Final to primary energy ratio
	Penetration of Energy and CO2 Saving Measures	7. Action Plan for energy and CO2 emissions 8. Energy system characteristic 9. Energy saving in buildings 10. Density of Public transport network 11. Efficient public lighting armatures
	Renewable Energy Potential and Utilization	12. Solar energy potential 13. Wind Energy potential 14. Geothermal energy potential 15. Renewable energy in electricity production 16. Green energy share in transport
	Water Usage and Environmental Quality	17. Water consumption per capita 18. Water quality index 19. Annual mean PM_{10} concentration 20. Ecological footprint per capita 21. Bio capacity per capita.
	CO_2 Emissions and Industrial Profile	22. CO_2 emissions of buildings 23. CO_2 emissions of transport 24. Average CO_2 intensity 25. Number of CO_2 intense industries 26. Airport ACA levels and measures
	Urban Planning and Social Welfare	27. Waste and wastewater management 28. Compact urban form and green space\ 29. Gross domestic product per capita 30. Inequality adjusted well being 31. Territory education rate
	R&D(Research and Development), Innovation and Sustainability Policy	32. R&D and Innovation Policy orientation 33. National patents in clean technology 34. Local public/private universities 35 Knowledge production (National h index)

Jensen and Wu (2018) proposed the Urban Water Security Indices and Indicators based on four major groups using 12 indicators (Table 1.11) in addition to 15 sub indicators. The framework was applied on Singapore and Hong Kong using data collected for 15 years. In the same context, Ginkel et al. (2018) proposed new Urban Water Security Dashboard Index based on the pressure-state-impact- response. The framework uses 56 indicators (Table 1.12) to evaluate different types of insecurities. However many indicators used in this system has been overlap.

Table 1.11: The SDEWES Indicators (Jensen and Wu 2018)

Framework	Indicators Group	Indicators
Urban Water Security Index	Resources	1.Availability 2. Diversity 3. Quality
	Access	4. Capacity 5. Service 6. Sustainability 7. Affordability
	Risk	8. Flood risk 9. public health
	Governance	10. Strategic planning 11. Disaster management 12. Regulation

Table 1.12: Urban Water Security Dashboard Indicators (Ginkel et al. 2018)

Framework	Indicators Group	Indicators
Urban Water Security Dashboard Index	Environmental pressures	1. Water scarcity 2. Annual precipitation and variability 3. Freshwater scarcity around city 4. Flooding 5. Rainfall intensity and variability 6. Storm surge hazard 7. Tsunami hazard 8. Expected SLR by 2100 9. Area below MSL 1 m and subsidence
	Socioeconomic pressures	10. City population

		11. Population growth 12. GDP 13. Slums 14. Domestic water use 15. Water-intensive industries 16. Water footprint of consumption 17. Condition upstream watershed
	Water quantity	18. Supply continuity of reservoirs and lakes 19. Dependency on overexploited aquifers 20. Local groundwater drawdown
	Water supply infrastructure	21. Coverage and leakage of water supply system 22. Continuity and quality of water supply
	Flood protection infrastructure	23. Coastal flood protection infrastructure 24. River flood protection infrastructure 25. Storm water drainage infrastructure
	Sanitation infrastructure	26. Coverage and leakage of sewer system 27. Adequacy of wastewater treatment
	Water quality	28. Surface water quality 29. Polluted sediments 30. Garbage in surface water 31. Groundwater quality 32. Salt water intrusion in groundwater
	Water supply dependencies	33. Conflicts over water supply 34. Sustainability of urban water footprint
	Water supply	35. People with adequate water supply
	Flood protection	36. Coastal flooding 37. River flooding 38. Storm water flooding
	Sanitation	39. People with adequate sanitation 40. Water-associated diseases
	Ecology	41. Ecological quality of urban water
	Aesthetic	42. Water image of city
	Institutional framework	43. Clarity of roles and responsibilities 44. Horizontal coordination 45. Vertical coordination 46. Corruption

		47. Accountability
	Planning	48. Access to data and information 49. Financial resources 50. Effectiveness of disaster management 51. Strategic planning 52. Degree of public participation
	Operational management	53. Effectiveness of water supply management 54. Effectiveness of sanitation management 55. Effectiveness of flood protection management 56. Effectiveness of environmental and ecological management

Recently, Aboelnga et al. (2019) proposed the (DECS) indicators. The framework uses 32 indicators distributed over four major groups, each group has many dimensions, and several variables. They proposed a special definition of urban water security according to the proposed framework, as well they suggest a thresholds system for each group and finally they proposed a grades system for urban water security. The framework requires a huge amount of accurate data, as well it has some redundancy and overlapping in the chosen indicators, in addition to that the implementation of the methodology over some cities was absence. The framework remained theoretically without application and without knowing its results in any region.

Table 1.13: DECS Indicators (Aboelnga et al. 2019)

Framework	Indicators Group	Indicators
DECS Indicators	Drinking Water and Human Well-being	1. Availability
		2. Diversity
		3. Consumption
		4. Reliability
		5. Wastewater treatment plant
		6. Drinking water quality
		7. Proportion of population using safely managed drinking water services
		8. Proportion of population using safely managed sanitation services

		9. Average supply time compliance with minimum service standard
		10. The percent of annual volumes abstracted from transboundary/imported water bodies to total annual available water resources
	Ecosystem	11. State of pollution
		12. Bodies of water with good ambient water quality
		13. Change the extent of water-related ecosystems over time
		14. Green roofing
		15. Green surfaces
		16. Effectiveness of storm network and wastewater network
	Climate change and water related hazards	17. Greenhouse gas emissions emitted from the system
		18. Public health
		19. Frequency of floods
		20. No. of droughts
		21. Flood-prone areas
		22. Average annual precipitation
		23. Average annual temperature
	Socio-economic	24. Water energy consumption
		25. Wastewater energy consumption
		26.Water tariffs
		27.Sanitation tariffs
		28. affordability
		29. Percentage of national budget directed to WWS
		30. Operation and maintenance cost recovery
		31. No. of illegal uses
		32. No. of total complaints

As has been noted in the above sections, new trends in water management focus on security, sustainability and resiliency. Understanding and assessing these issues require indicators concerning water resources quality and quantity, water demand, water supply, water services, infrastructure and governance (Garrick and W.Hall, 2014, Hoekstra et al., 2018). Although a high number of water security indicators were proposed, few focused on urban water security. The latter requires a large amount of data. In addition, it includes complex processes for data analysis and decision making. Finally, water security indices were used in cities benchmarking, which is very important to make comparisons of water security strategies and to learn from cities experiences.

1.4 Risk Assessment

1.4.1 Risk Assessment Concept

Risk assessment refers to scientific and independent process that determines the risk nature and extent, and provides clear identification, estimation and ranking of risks. It is essential for establishing policies and strategies (Rovins et al., 2015). Risk assessment is a component of the risk management process and decision making (Landell and Bokman, 2016). It provides a comprehensive understanding of phenomenon through three main steps (Zio, 2018, Shapiro and Koissi, 2015):

- Identification of hazards.
- Analysis of hazards' drivers and impacts.
- Qualitative and quantitative evaluation of the risk including uncertainties prospective.

These steps are defined by the International Standards Organization (ISO) as risk identification, analysis and evaluation (Rovins et al., 2015). Since risk is related to uncertainties, it is laborious to establish models for its analysis (Zio, 2018). However, it can be assessed using qualitative, semi-quantitative and quantitative approaches (Purdy, 2015).

Recently Tidwell et al. (2018) used the qualitative risk assessment of critical infrastructures. Through analysis of water utilities in USA, they found that qualitative assessment did not give a clear idea about risk differences within the same category and couldn't give water managers adequate tools for comparing risks between utilities. However, the approach was valuable for utilities facing high risks. They concluded that the risk assessment approach as a powerful tool that guides water managers to the system's weakness point.

Hall and Borgmeo (2013) used a risk-based approach to discuss the water security. They argued that the use of the risk concept for identifying and measuring water security is complex even with enough data, because risk is not a measurable quantity. They developed indicators for understanding water security from the risk view using a complete set of risk factors. They focused on the climate change as a main risk driver of the water security and proposed thirteen indicators (Table 1.14) for water supply, demand and availability. Neglecting the effect of water services, governance and management constitutes a major limitation of this approach, because these factors could significant impact on water security.

Table 1.14: Indicators of Risk to Water Security (Hall and Borgmeo, 2013)

Indicators Of	**Indicators**
Supply	1. Security of supply index
Overall Demand	2. Freshwater abstraction (non-tidal) by sector
Household Demand	3. Average *per capita* consumption—all households
Household Demand	4. Average *per capita* consumption—metered households
Household Demand	5. Average *per capita* consumption—unmetered households
Agricultural Demand	6. Average volume of water applied for irrigation per hectare by crop type
Reducing Demand	7. % Properties with water meters
Increasing Supply	8. Total leakage
Water Availability (public water supply)	9. % Of reservoir capacity filled
Water Availability (economic)	10. Catchments where water is available for abstraction
Water Availability (environmental)	11. Compliance with Environmental Flow Indicators
Water Availability (social)	12. Number of drought orders
Water Availability (social)	13. Number of water companies issuing hosepipe bans

1.4.2 Risk Assessment of Water Security

Recently, the water security was explored using the risk concept (Garrick and Hall, 2014). The latter provides powerful tools to identify water risks uncertainties and to characterize quantitatively and qualitatively water risk (OECD, 2013). It comes in line with water authorities' interest to focus on water related risks more than on the optimization of the water resources management (Hall and Borgmeo, 2013).

In 2012, Mason and Calow discussed the importance of risk with respect to water. They proposed a set of indicators distributed in five groups (Table 1.15): Resources stress, Variability and risk, Basic human needs and productivity, Environmental needs and Governance (Mason and Calow, 2012).

Table 1.15: Mason and Calow (2012) Water Security Indicators

Group of Indicators	**Indicator Name**
Resource Stress	1. Renewable water resources per capita 2. Social resource water stress 3. Relative water stress 4. Dynamic water resources per capita 5. Non sustainable water use
Variability and risk	1. Water storage capacity 2. Flood mortality risk 3. Rainfall variability 4. Climate vulnerability
Basic human needs and productivity	1. Access to drinking water 2. Access to sanitation 3. Irrigated agricultural water productivity 4. Industrial water productivity 5. Aquaculture production 6. Virtual water footprint
Environmental needs	1. Freshwater species 2. Water re-use index 3. Environmental adjusted water stress 4. Water quality 5. River fragmentation and flow regulation 6. Treated wastewater
Governance	1. IWRM planning 2. International water governance 3. Water monitoring effort 4. Protection of aquatic environments 5. Water accounting

In the same context, Grey et al. (2013) identified the water security as the "Society acceptable water related risks". The Institute for Water, Environment & Health of the United Nations University used the concept of water related risks in their water security definition (UNU, 2013). Lautze and Manthrithilake (2012) developed a water security framework using risk management as one of the water security components (Table 1.16).

Table 1.16: Lautze and Manthrithilake (2012) Water Security Indicator Framework

Indicators	Indicator Identification
Basic Household Needs	Ratio of people can access to good water resources
Agricultural Production	Level of availability of water for agricultural production
Environmental Flow	Ratio of renewable water resources
Risk Management	Level of country rainfall buffer
Independence	Level of country water and food supply.

The use of risk concept to explain and measure water security constitutes a new trend. It could provide clear demonstration and robust diagnoses for the status and level of the water security and its relation with water insecurity drivers (Garrick et al. 2014). In the same context, Hall and Borgomeo (2012) argued that risk management motivates water scientists to deal with uncertain conditions.

1.4.3 Risk Based Approach to Water Security

The OECD presented the risk-based approach of water security in the report "Water Security for Better Lives" (OECD, 2013). According to this approach, the water security is defined as "Learning to live with an acceptable level of water risk". This approach induced a great change in the water security by moving from reactive to proactive policies. The OECD risk-based approach includes three stages (Figure 1.2):

- Risk assessment.
- Risk evaluation.
- Risk management

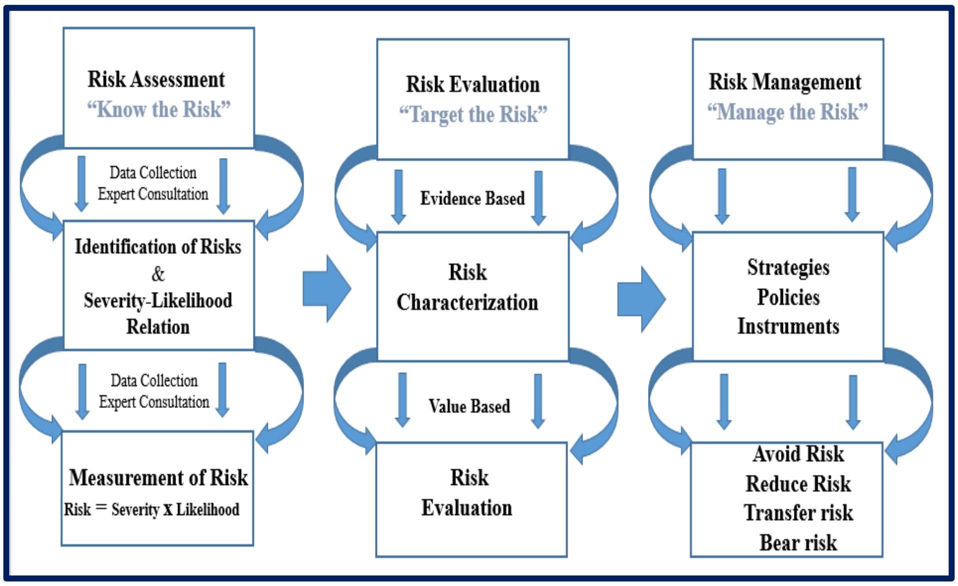

Figure 1.2: Risk Based Approach Framework (OECD, 2013)

The first stage (Risk assessment) concerns the identification of main challenges of the water security, such as population growth, urbanization, climate change, infrastructure aging and poor management. These challenges should be analyzed with the risk framework in terms of likelihood and severity (OECE, 2013). Risk likelihood designates the probability of occurrence of the risk, while risk severity measures the impact level of this factor. This stage combines the first and second steps in the ISO standard risk assessment. The risk identification requires a process supported by experts to identify the risk in terms of nature, location, current situation, future expectations, extents and impacts (Rovins et al., 2015). This stage requires huge amount of data. Government institutions, municipalities, water utilities have an important role in providing transparent and relevant data.

The second stage (Risk evaluation) aims at the evaluation of economic, social and environmental impacts of the risk. It provides also analysis of the level of risk acceptability according to risks scores. This stage needs to review strategies and policies used to reduce the impact of water risks. According to the ISO risk evaluation, the risk level includes 3 categories: acceptable, tolerable and intolerable (Rovins et al., 2015).

The third stage (Risk management) concerns high decision-making level. It focuses on risk management through taking actions, establishing new strategies and improving policies to avoid risk, reduce its impact, risk transfer, and risk bear.

1.5 Decision Making Process in the Urban Water Security Context

1.5.1 Overview

Decision making in security issues and future uncertainty aspects is critical and very important process, not only it's identify risks but also working to reduce the future losses, in most cases it requiring experts' opinions (Lee et al., 2019). Decision making in the urban water security concept is very complicated, since the optimal decision must satisfy the decision makers' objectives and views, as well the process should be supported in earlier stages by a huge amount of data in order to reach the optimum decision, and should be accurately implemented and carefully evaluated (Zolfani and Chatterjee, 2019).

Despite the fact that values, views, beliefs, observations and comprehension are stand behind all decision making activities (Kersuliene et.al, 2010). However most of the critical issues have a multi criteria, numerous alternatives, and conflicts of interest and objectives, which making decisions under this circumstances are very complicated and carrying high risk (Zolfani and Chatterjee, 2019).

As the assessment of alternatives is not an easy process, and the decision making about these alternatives is complex, Thus Multi Criteria Decision Making (MCDM) methods came to solve this problems and to manage the uncertainty issue inherent in it (Mulliner et al., 2015, You et al., 2015, Feng and Lai, 2014).

For few years ago, scholars have been showed an increasing understanding and consciousness of the importance of using the MCDM methods in decisions making in particular in critical issues. MCDM has been developing as a new concept used in many fields to select the best alternative and to achieve an optimum decision which could gain the biggest profit as well as decrease the future losses. Many scholars considered MCDM a complex process, with dynamic procedures linked to managerial and engineering aspects

The following sections will present the MCDM as new science and will highlight the usefulness of using this science in evaluating indicators. As well it will present how scientists were used MCDM methods in the context of water security.

1.5.2 Multi Criteria Decision Making (MCDM) Methods

MCDM is a science used to evaluate a number alternatives with multi criteria, the science was used in many fields related to management, engineering, risk assessment, computer science and medicine. By implementing MCDM users could determine the value, degree of important and the priority order for a number of alternatives, in order to select the best alternative (Mardani et al., 2017). MCDM methods are facilitate the process of selecting the best alternative and the optimum decision through using many techniques with mathematical algorithms in order to analyze and understand the criteria and attributes then to evaluate and select the best alternative (Hajiagha et al., 2016).

MCDM methods are different, varied and many to be suitable and applicable for a wide range of problems related to decision making issues which are carrying high diversity and multi different criteria and circumstances. Therefore MCDM methods used a combinations of mathematics, statistics, artificial neural networks, visualization and decision tree (Kersuliene and Turskis, 2011).

The simple additive weighting which was proposed by MacCrimmon in 1968 was the beginning of the theory of multi criteria decision making (Mardani et al., 2017). The aim of any decision making issue is ranking alternatives and then choosing the most important one, in this aspect weighting of decision criteria is of high importance (Zolfani et al., 2018). Weighting of criteria considered as the most critical stage in the whole process of decision making (Karabasevic et al., 2017). Weights classified as subjective and objective, where the subjective weights use the experts judgments, while the objective weights use the mathematical methods (Yazdani et al., 2016).

Because weighting is critical issue with great impacts on the final decision chosen, various methods were developed for weighting criteria, each method has its properties and abilities to use under certain conditions (Zolfani and Chatterjee, 2019). Choosing the most appropriate method is based on the objectives, data available, decision makers, and sometimes the cost of decision (Kersuliene and Turskis, 2011).

Mardani et al., (2017) published a systematic review for the development and application of the MCDM methods in the latest period with giving more focus for the

Step-wise Weight Assessment Ratio Analysis (SWARA) and Weighted Aggregated Sum-Product Assessment (WASPAS) as a new methods, they were presented a fast review for the Elimination and Choice Expressing Reality (ELECTRE), Complex Proportional Assessment (COPRAS), Pair-wise comparisons Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP), The Order Preference by Similarity to Ideal Solution (TOPSIS), Multi-objective Optimization by Ratio Analysis (MOORA), Additive Ratio Assessment (ARAS).Those methods are an examples about the MCDM methods, while there were many others, researchers continuously develop new methods. A complete clear details about these methods, its conditions, advantages and disadvantages, steps to implement were found in a novel book "New Methods and Applications in Multiple Attribute Decision Making (MADM)" by (Alinezhad and Khalili, 2019).

1.5.3 MCDM Methods for Weighting Water Security Indicators

The determination of the weight of indicator is very important to assess the impact value of the certain indicator in the proposed Systems, and to know the priority for each indicator, together with the degree of importance. Indicators weighting are very important for giving accurate results.

Although many researchers worked on evaluating the water security using indicators, however few of them used MCDM methods for weighting the indicators. Zolfani and Saparauskas, (2013), used the new Step-wise Weight Assessment Ratio Analysis "SWARA" method for making prioritization for the indicators used for assessment the sustainability of energy system, research results proved that SWARA method as a new MCDM method play an important role in weighting indicators especially when using experts opinions.

In (2019), Zhang et al. used the TODIM (an acronym in Portuguese for Interactive Multi-criteria Decision Making) and TOPSIS (The Order Preference by Similarity to Ideal Solution) methods for weighting the indicators that proposed to evaluate the water security. TODIM method was very useful for analyzing the impact of each indicator in the final decision, while the TOPSIS was used to verify the performance of TODIM, they conclude that using the MCDM method was very important and useful for accurately evaluating water security indicators. In the same context AHP (Analytic Hierarchy Process) and Delphi (The name refers to the Oracle of Delphi, a priestess at a temple of Apollo in ancient Greece known for her prophecies) methods were used for weighting the urban water security index which was proposed as multi-level evaluation system (Lu et al., 2016).

SWARA method was again used in 2019 for weighting a group of indicators and sub-indicators related to geotechnical, structural, socio-economic and physical groups used for assessing the seismic vulnerability, SWARA gave the assessment process an accurate results (Lee et al., 2019).

As presented above recent orientation was to use MCDM methods for giving the evaluation process more accurate and higher credibility results. While the evaluation of urban water security is highly complicated, carrying multi indicators and sub-indicators, and using number of levels or groups, urban water security evaluation current applications started to use MCDM methods for rising the reliability, especially that water security issues carrying high uncertainty and in many cases it's based on experts opinions which have some bias.

1.6 Conclusion

This literature review showed clearly an increasing concern of local, national and regional authorities to the water security issue. The question is how these authorities can (and continue to) provide water supply to meet the social and economic needs of the population at an affordable price? This question is becoming critical because of the increasing pressure on the water resources, infrastructures and governance.

The risk assessment approach provides a powerful framework and tools for the analysis of the water security and for establishing strategies for the water security. Powerful frameworks for assessing water security are supported by a set of indicators. The literature review shows that the combination of the risk concept, indicators systems and the MCDM method constitutes a new trend in the field of water security assessment.

The following chapters will present the methodology followed in this research and its application to the Palestinian Territory.

Chapter Two: Research Methodology

Chapter 2: Research Methodology

2.1 Introduction

This chapter presents the methodology followed in this research including methods, materials, technologies and tools used to achieve the research goals. It presents a comprehensive presentation of methods used in; data collection, indicators identification, weighting and ranking, risk analysis, water security assessment, and the water security index.

The research methodology is based on a mixed approach, which combines quantitative and qualitative methods. These methods are based on the use measurable values for some observable evidence in order to monitor changes, assess outcomes and predict the future expectations.

2.2 Research Approach

As indicated in the previous chapter researchers gave water security various meanings with different methods for analysis, and several models for assessment. Different methods have been proposed to evaluate water security. The majority of these methods are based on qualitative methods (Zhang et al., 2018, van Beek and Lincklaen Arriens, 2014). As well recent papers focused on using the risk concept for evaluating the water security (Mason and Calow, 2012, Hall and Borgomeo, 2012, Grey et al., 2013, OECD, 2013, and Garrick et al. 2014).

The methodology of this research follows the OECD risk-based approach, the methodology begins by collecting data. Indeed, huge amount of data are needed for a comprehensive water security approach. Researcher conduct diagnosis of urban water security. Indicators are determined according to the literature review and water experts. Similar methodology is used for indicators weighting, together with the implementation of the SWARA method. Then, water security assessment is conducted using semi-quantitative method. At this stage the index of urban water security could be estimated. Finally urban water security evaluation and management is making.

Figure 2.1 summarizes the research approach. It includes 7 stages: data collection, identification of risk factors, indicators weighting and ranking, risk assessment, estimation of urban water security index, urban water security risks evaluation, and finally risk management. Below a detailed description of each stage.

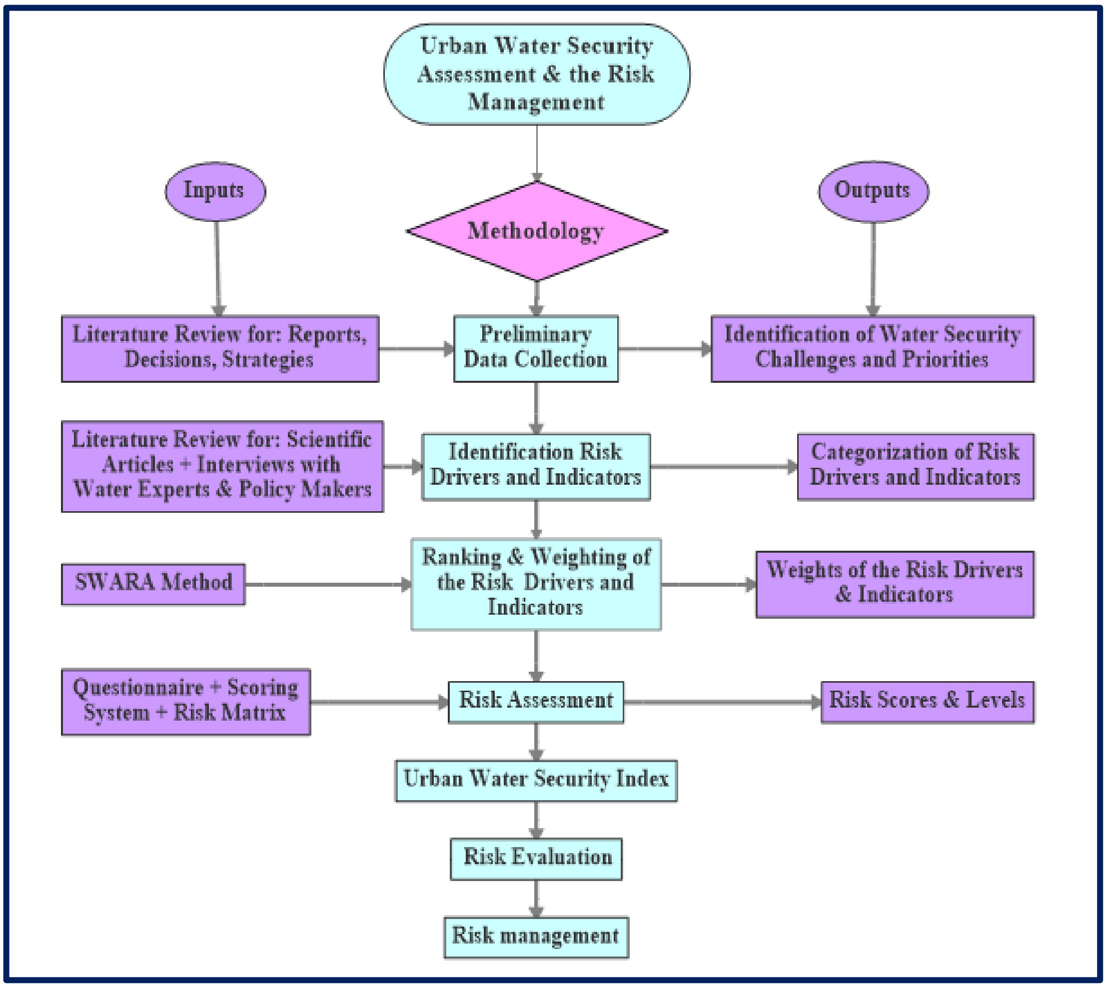

Figure 2.1: Research Approach

Stage # 1: Data Collection

Data and information about urban water security challenges, risks, factors, drivers and indicators are collected using a broad survey, deep review of national and international reports, policies and strategies. It includes also visits to governmental and non-governmental water institutions, municipalities, water utilities and water providers. The outcome of this step includes:

- Water challenges
- Water sector priorities
- Water policies weak points and limitations.

Stage # 2: Identification of Risk Drivers and Indicators

This stage aims at identifying the risk factors for the water security. These factors describe the water security status and driver factors, which are the origin and cause of water insecurity . Risk factors in this research defined as "risk drivers", they will clearly defined, as well as its determination and relationship and its linking with other factors or indicators. This work is based on both literature review and experts' recommendations. It results in the list of risk indicators, their significance, definition, determination and role.

Stage # 3: Indicators Weighting and Ranking

This stage concerns the process of weighting and ranking of the risk indicators. It is based on experts' recommendations, as well as on (SWARA method) as a powerful new Multi Criteria Decision Making MCDM method when the system be supported by experts opinion.

Stage # 4: Risk Assessment

Risk assessment is used as a tool for evaluating urban water security. The process is based on the method proposed by the OECD. The risk is described by its impact severity and occurrence likelihood. The outputs of this step includes a score and level of risk for each urban water security indicator and driver.

Stage # 5 Estimation of Urban Water Security Index

Based on the results of the risk assessment (4th stage), risk scores and levels be converted into water security scores and levels, which defined in this research as urban water security index.

Stage # 6 Risk Evaluation

This stage concerning the process of risk evaluation, the process is based on evidences and values (second & 4th stages), the process also concerned the judgement regarding the degree of acceptability of the urban water security risks (acceptable, tolerable, or intolerable), as well as targeting the risks, through suggesting urgent actions or suitable measures.

Stage # 7 Risk Management

Based on the results that was obtained from the assessment and evaluation stages (4th and 6th stages) risks are managed, through building a new coherent management framework to deal with all urban water security risks. The new management system transforms the management mechanism to proactive one, in order to adapt with the dynamic characteristics of water issues at urban level.

2.3 Data Collection

2.3.1 Overview

Collection of reliable and accurate data constitutes a significant part in any research work. Particular attention is given to data sources including formal and informal stakeholders, participants and contributors.

Data collection process used in this research is shown in figure 2.2. It includes document analysis through reviewing reports, strategies, archives data, as well as stakeholders and experts' interviews. Data collection is conducted in two stages. The first one concerns data and information from governmental and non-governmental institutions as well as interviews of water experts. The second stage is conducted through questionnaire and interviews of a water focus group including policy makers and water experts.

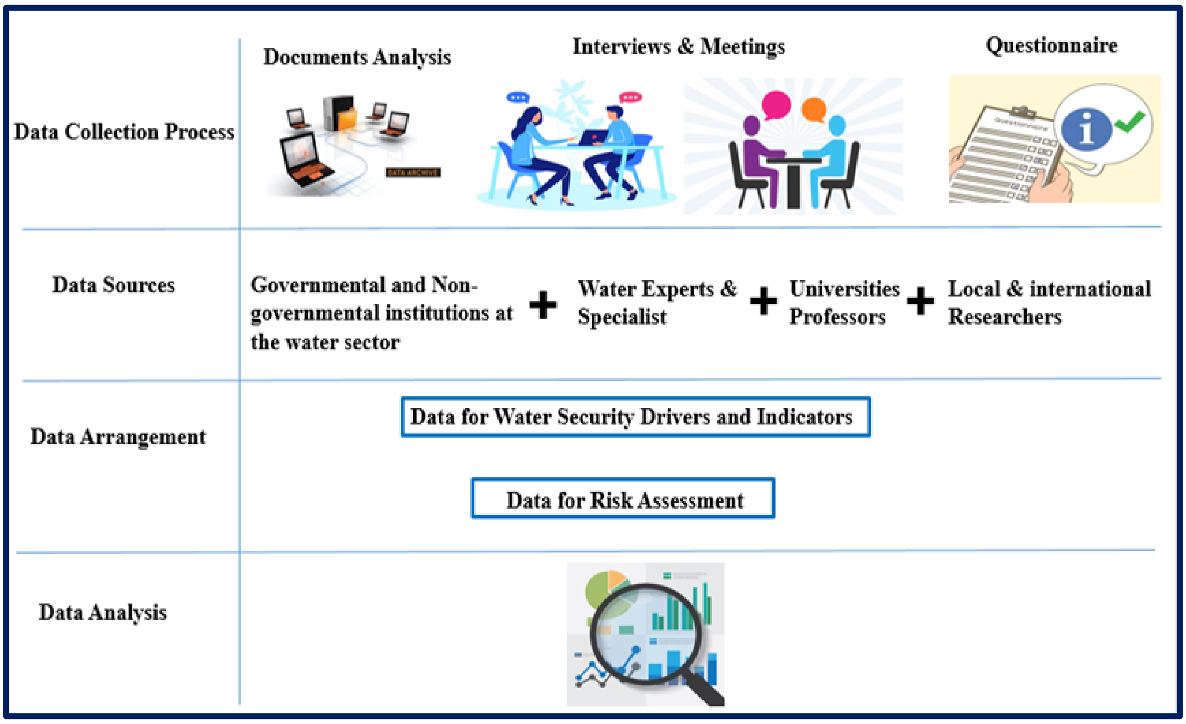

Figure 2.2: Data Collection Process Outline

2.3.2 Documents Analysis

Documents analysis is important to assess data needs, data resources and data availability (IHE, 2018). Primary data and information are collected from governmental and non-governmental institutions in the water sector, archives and historical data, international reports, official statistics, monitoring programs, workshops and meetings and policy documents.

2.3.3 Interviews and Meetings

Interviews and meetings are certified tools in qualitative researches. They are useful for gathering data about the research topic and exploring opinions, experiences and views of experts, processes based on face to face, telephone and new social media. Usually researcher prepare interview topics list, context, questions and details in order to collect the needed data. Interviews may be structured, unstructured or semi-structured (Oltmann, 2016, Williamson & Johansonm, 2018).

2.3.4 Questionnaire

Questionnaire is a tool for collecting quantitative data through a group of questions oriented to individuals or for gathering additional qualitative data regarding opinions and views of stakeholders (CDC, 2018).

2.3.5 Qualitative and Quantitative Data Analysis

The qualitative data analysis aims at establishing systematic classification of security topics with references to themes and categories. While quantitative data requires data cleaning to check data accuracy and relevance as well as removal of un-correct data and un-necessary data, without researcher's bias (Williamson & Johansonm, 2018).

Qualitative data analysis concerns exploring data patterns, input data correlations, data ranking, and relationships between drivers' factors and indicators' factors. It allows to build a conceptual framework.

2.4 Multi Criteria Decision Making for Weighting Water Security Risk Drivers and Indicators

2.4.1 Overview

Security assessment includes an important step concerning the indicators weights (Zolfani and Chatterjee, 2019). It allows identification of the degree of importance and the prioritization of each driver factor on the water security (Tayyar and Durmus, 2017). This phase is fundamental for the research work (Zolfani et al., 2018).

Multi criteria techniques are used for indicators weighting and ranking. Scholars highlighted the importance of choosing the most suitable technique (Kersuliene et al., 2010). Multi Criteria Decision Making (MCDM) techniques are based on developing weights and/or ranks of a group of criteria or a set of alternatives (Zolfani and Chatterjee, 2019). Many techniques were proposed in the last few decades like the AHP and ANP (Saaty, 2016) and Delphi approaches (Hwang and Lin, 1987). New techniques were proposed in the last few years such as SWARA by (Kersuliene et al., 2010), FARE (Ginevicius, 2011) and KEMIRA (Krylovas, 2014).

2.4.2 Urban Water Security Criteria

Urban water security challenges be identified by reference to the literature review. It includes identification of risk drivers, as well as the linked indicators. The risk drivers and the related indicators are the criteria and sub-criteria of the urban water security, they are discussed with water experts to check the relevance and importance of each risk driver and indicator. Then data related to selected indicators are collected and analyzed. Figure 2.3 shows the methodology used for urban water security evaluation criteria.

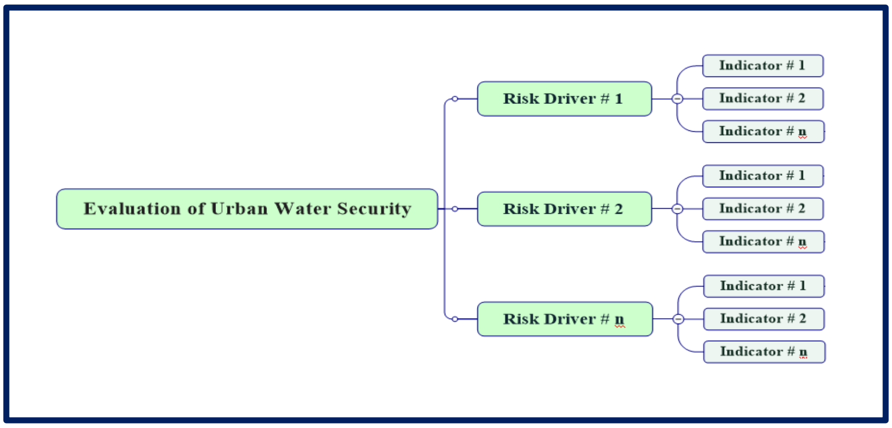

Figure 2.3: Urban Water Security Evaluation Criteria

2.4.3 Step-wise Weight Assessment Ratio Analysis (SWARA)

Step-wise Weight Assessment Ratio Analysis method (SWARA) was proposed by Kersuliene in 2010, the first application was in dispute analysis (Zolfani and Saparauskas, 2013, Zolfani et al., 2018). According to this method, the criterion with the highest rank is assigned as the most important, while the criterion that has the lowest rank is assigned as the least important. The method uses the average value of ranks to determine the overall ranks (Keršulienė and Turskis, 2011).

SWARA method uses the experts' opinion for criteria weighted (Keršuliene et al., 2010). The method is considered as policy- based method; experts and policy makers determine the importance and priority of the criteria according to future scenarios, experience in the current regulations, and knowledge in the strategic plan (Zolfani and Chatterjee, 2019).

Engaging experts' opinions is the powerful character of this method as it assigns experts to arrange the degree of importance of the criterions which directly effect on the significant ratio of the criteria and consequently on the weights and ranks (Karabasevic et al., 2017). Furthermore, SWARA method is suitable in conditions where priorities are established along with countries policies and strategies. In other words, SWARA gives experts and policy makers an opportunity to improve the decision making process in a harmonize way with the country substantial goals (Zolfani and Saparauskas, 2013). Figure 2.4 details the process of SWAR method application *Kersuliene et al., 2010, Kersuliene and Turskis, 2011*, Zolfani and Bahrami, 2014, Lee et al, 2019 , and Zolfani and Chatterjee, 2019). It includes the following steps:

Step 1: Criteria and sub-criteria ranked from the most important to the less importance based on expert opinion, inventory data and/or certain standards.

Step 2: Experts give the relative importance of criteria (j) in relation to the previous criteria (j-1). This value known as the comparative importance of the average value (sj). It's calculated according the average values of differences of criteria importance according to experts' opinions. (sj) is determined as follows:

$$sj = \sum_{i}^{n} \frac{Ai}{n} \qquad (2.1)$$

"Ai" designate the rank given by experts for each criterion, while "n" expresses the number of experts

Step 3: Calculate the coefficient (kj):

$$kj = \begin{cases} 1 & j = 1 \\ sj + 1 & j > 1 \end{cases} \qquad (2.2)$$

Step 4: Recalculate the weight (qj):

$$qj = \begin{cases} 1 & j = 1 \\ \frac{xj-1}{kj} & j > 1 \end{cases} \qquad (2.3)$$

Step 5: Calculate the final criteria weight (wj):

$$wj = \frac{\text{qj}}{\sum_{k=1}^{n} qk} \qquad (2.4)$$

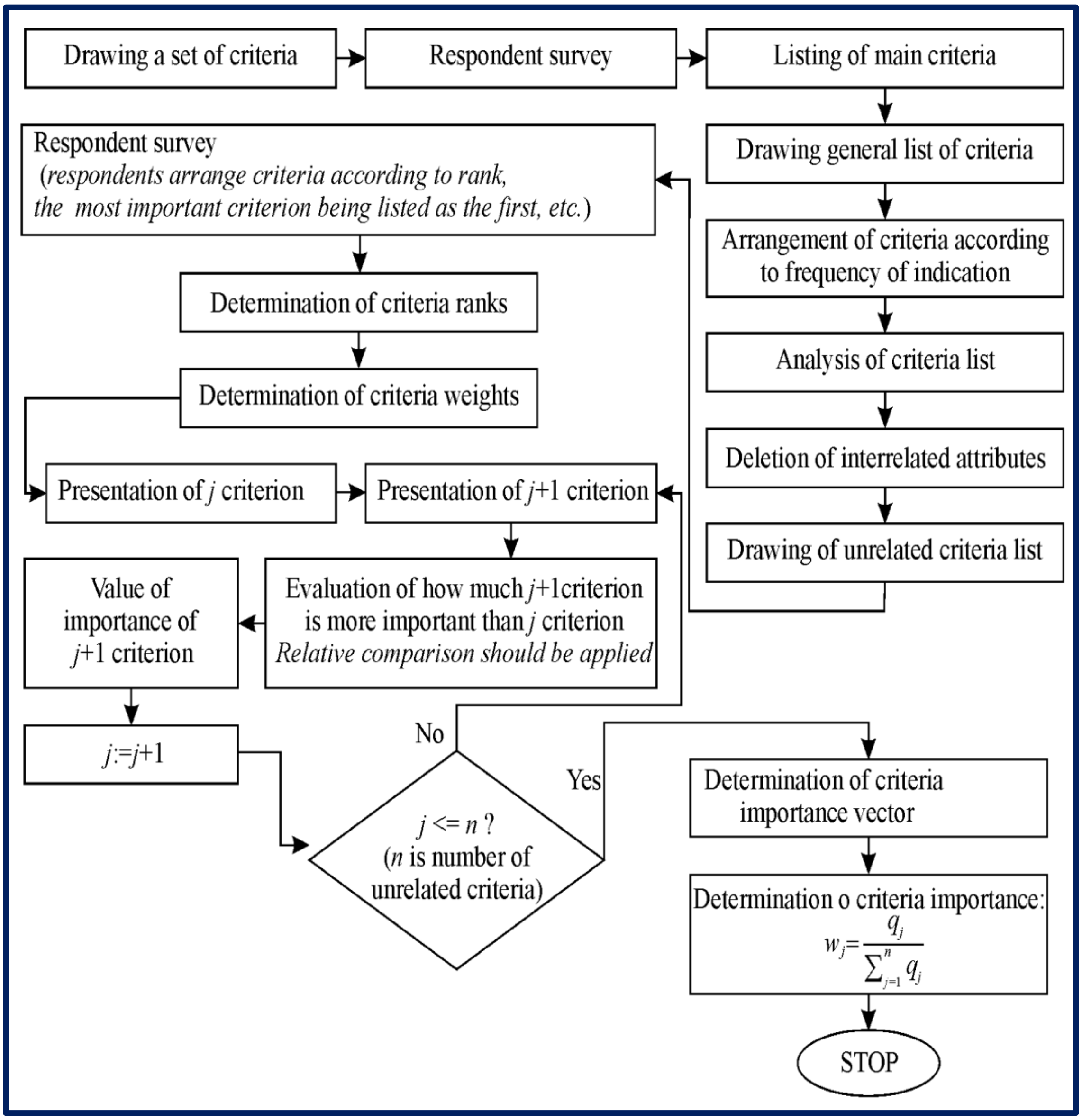

Figure 2.4: Criteria Weighting Steps Based on SWARA Method (Kersuliene et al., 2010)

2.5 Risk Assessment Process

Risk assessment is a scientific, transparent and independent process that determines the risk nature and extent. Risk assessment process could provide clear identification, estimation and ranking for the risks. For this reason, it's considered as the most important part in the risk management process (Rovins et al., 2015). Figure 2.5 shows the basic steps of the risk management process based on the International Standard Organization (ISO).

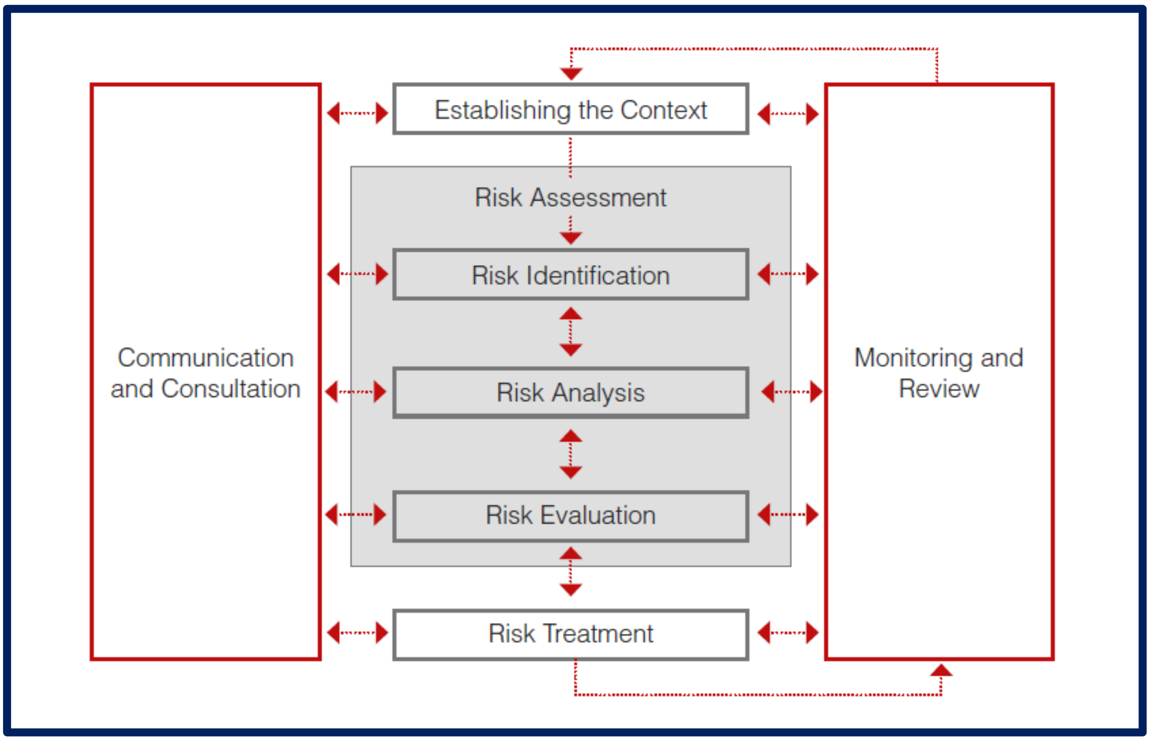

Figure 2.5: International Standard on the Risk Management Process (AS/NZS, 2009)

According to ISO (2009) risk is defined as "the effect of uncertainty on objects". In other literatures, risk is defined as the tolerance of a negative occurrence, or the occurrence of loss with associated uncertainties (SRA, 2015). It is a probability of future negative event which is associated with uncertainty (Duijm, 2015). Zio (2018) defined risk as the probability that an event may happen with unfavorable impacts.

Definitions have the same meaning with links and relations between events probability, consequence and uncertainty. Magnitude risk is a combination of probability and consequence (Aven, 2016).

The methodology of this research uses the OECD risk-based approach. Where risk is defined as a function of the event severity and likelihood (OECD, 2013). The term severity defined as "the magnitude of damage". Sometimes the term "consequences" is used, which means the impacts of an activity on something valuable. It has positive or negative effects, but with a more focus on negative effects. It may be expressed in qualitative or quantitative methods. While the term likelihood defined as "the chance of something happening". It may be expressed using definitions, measurements, subjective or objective estimations and qualitative or quantitative determinations. It may described using mathematical or linguistic terms. It has the same meaning of probability, however probability is most near to express in mathematical forms (ISO, 2009 and SRA, 2015).

Risk could be assessed using qualitative, quantitative or semi-quantitative methods (Purdy, 2010). Each method has its usefulness and limitations. Data availability and the context of the risk assessment process impact the choice of the risk evaluation method.

Qualitative methods are used when data are limited or the time to make risk assessment is short. Risks severity and likelihood are described using linguistic terms (non-numerical) to represent numerical range. Risk matrix and experts' opinions are the key component in this method. While quantitative method are used to calculate the risk level**.** Likelihood and severity are described using numerical values with level of uncertainty. This method is complex. It needs huge amount of data, accurate information and computation time. Although quantitative methods provide accurate results, qualitative method rise the precision using risk matrix and expert opinions. Semi-quantitative methods are based on relative scales, where risks are classified into categories and categories are classified into levels. Likelihood and severity are estimated by different scales with no requirements for accurate mathematical data (Rovins et al., 2015, Ramona, 2011, and Radu, 2009).

The methodology used in this research is based on semi-quantitative risk assessment methods. It used the following steps:

Step 1: Development of Risk Severity and Likelihood Scoring System

Studying and understanding the behavior of risks by revising the past records provide water managers with a good risk perceptions and support creating indicators. The availability of data and information provide a very good opportunity for water managers to understand the behavior of water sector systems, and to propose acceptable solutions that can response to the future conditions.

The monitoring systems which provide water managers and engineers with a large quantity of data and information is a very good procedure to achieve water risk assessment. It provides a clear picture about the risks, water security and other important issues. It allows water policy makers opportunity to create new and comprehensive perspectives.

A scoring system for the severity score is proposed for each indicator according to its significance and impact, while one scoring system is proposed for the indicators likelihood scores. The scoring system is based on previous literature. Experts' opinions are added using a questionnaire to know the degree of importance of the drivers and indicators in the local context and strategy. The final scoring system fixed after making analysis for the questionnaire findings and taking all comments and notes in account.

Step 2: Use of Semi-quantitative Risk Matrix

Risk matrix is a popular technique, which is widely used in risk estimation (Shapiro and Koissi, 2015). This research uses a semi-quantitative risk matrix (Figure 2.6) certified by the WHO and IWA (2001).

Risk Matrix			SEVERITY				
			insignificant	Minor	Moderate	Major	Catastrophic
Score			1	2	3	4	5
LIKELIHOOD	Almost Certain	5	5	10	15	20	25
	Likely	4	4	8	12	16	20
	Moderate	3	3	6	9	12	15
	Unlikely	2	2	4	6	8	10
	Rare	1	1	2	3	4	5
Risk Score				1-5	6-9	10-15	16-25
Risk Level				Low	Medium	High	Extreme

Figure 2.6: Semi- quantitative Risk Matrix (WHO & IWA, 2001)

Colors reflect a certain category, red color reflect larger risk than orange and consequently orange larger than yellow as well yellow larger than green, in addition to that moving between green and red categories must pass through other colors, equal risk score will have the same color (Levine, 2012, Flage and Roed, 2012).

Each cell in the risk matrix has its value either by color or by numerical score which is calculated by mathematical algorithms, in some cases both color and numerical score are used to present the cell value or level, in this case colors and scores must be consistent (Duijm, 2015).

Event severity and likelihood are the key features in the risk matrix (Shapiro and Koissi, 2015 and Duijm, 2015). A proposed ranking system is proposed for the risk matrix. Table 2.1 and Table 2.2 details the ranking system.

Table 2.1: Severity and Likelihood Ranking System

Severity Score	**Severity level**	**Likelihood Score**	**Likelihood level**
1	Insignificant	1	Rare
2	Mainor	2	Unlikely
3	Moderate	3	Moderate
4	Major	4	Likely
5	Catastrophic	5	Almost Certain

Table 2.2: Ranking System Parameters

Severity	Level	Score
Indicator value in the last year is within the acceptable standard range No negative impact or negligible negative impact	Insignificant	1
Indicator value in the last year is slightly out of acceptable standard range Little negative impact.	Mainor	2
Indicator value in the last year is out of acceptable standard range Medium negative impact.	Moderate	3
Indicator value in the last year is far out of acceptable standard range High negative impact.	Major	4
Indicator value in the last year is sharply out of acceptable standard range Severe negative impact.	Catastrophic	5
Likelihood	Level	Score
If the indicator values in the study period are within the acceptable range every year. Probability of negative impact is too little	Rare	1
If the indicator values in the study period are within the acceptable range along the last four years. Probability of negative impact is little	Unlikely	2
If the indicator values in the study period are within the acceptable range along the last three years. Probability of negative impact is possible	Moderate	3
If the indicator values in the study period are within the acceptable range just in one to two years. Probability of negative impact is highly possible	Likely	4

If the indicator values in the study period are out of the acceptable range every year. Probability of negative impact is sure	Almost Certain	5

Risk score for each indicator is estimated as follows:

$$R.S = S.S \times L.S \quad \text{(Eq. 2.5)}$$

- R.S: Risk Score (has a value from 1 to 25)
- S.S: Severity Score (has a value from 1 to 5)
- L.S: Likelihood Score (has a value from 1 to 5)

2.6 Urban Water Security Index

Estimation of urban water security index is based on four basic aspects (Figure 2.5): Urban water security challenges, indicators, SWARA method and the risk matrix. These aspects are coupled with four instruments: intensive literature review, experts' opinion and consultation, indicators likelihood and severity and the scoring systems. Aspects and instruments are used in an innovative way to create an urban water security index.

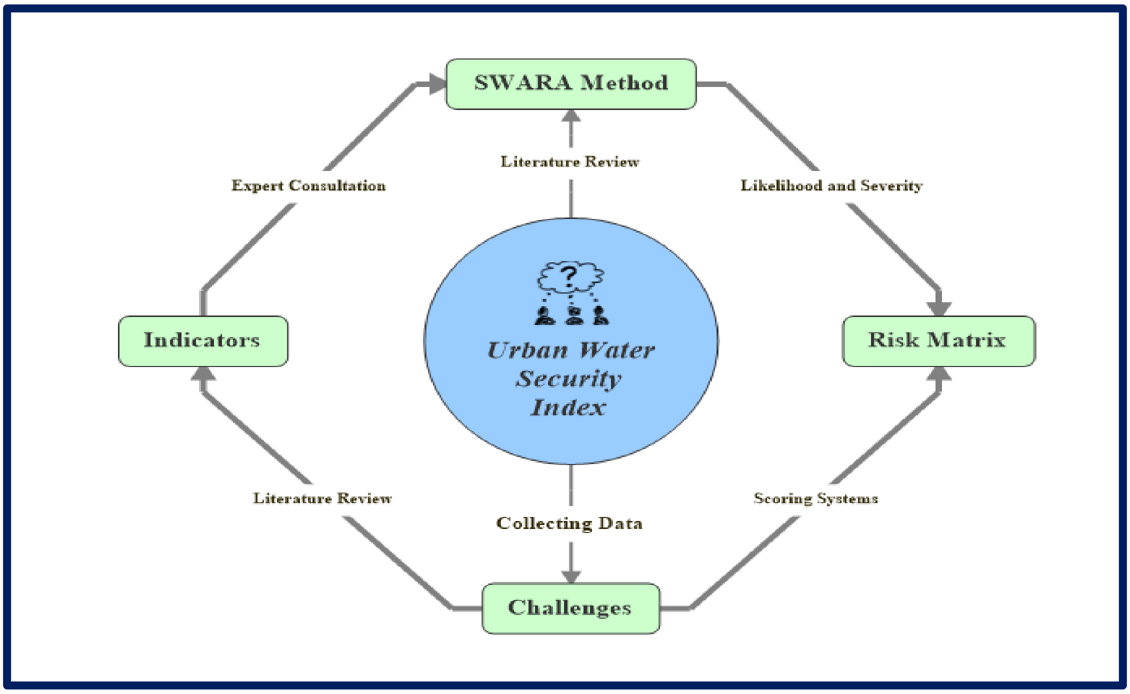

Figure 2.7: Urban Water Security Index Framework

The proposed methodology includes the following steps:

- Determination of the water security challenges, risk drivers, and linked indicators.
- Determination of the weights of each risk driver and indicator using SWARA method.
- Determination of the risk score for each indicator by using the severity likelihood relation, as well as the risk matrix technique.
- Indicators weights, scores, and levels use in calculating the risk score and level for each driver.
- Drivers' weights, scores, and levels use for calculating the overall risk score and level.
- Convert the overall risk scores and levels to water security score and level using the proposed translation system (Table 2.3). Urban water security scores and levels are represent the innovative index.

Table 2.3: Urban Water Security Translation System

Risk Score	Risk Level	Urban Water Security Score	Urban Water Security Level
(RS)	(RL)	(UWSS)	(UWSL)
$1 \leq RS < 6$	Low	4	Good
$6 \leq RS < 10$	Medium	3	Challenging
$10 \leq RS < 16$	High	2	Poor
$RS \geq 16$	Extreme	1	Alarming

Where,

Good: means urban water security has low level of risks in all risk driver (overall risk score is low), the city has a satisfied management system for dealing with water security issues.

Challenging: means urban water security has medium level of risks, the city has some gaps in some or all water security drivers, by little efforts, the city able to improve and very close to be good in the near future.

Poor: means urban water security has high level of risks, the city has major shortcoming in all water security drivers.

Alarming: means urban water security has an extreme level of risks, the city is failed in providing the customers with the basic needs.

2.7 Risk Evaluation Process

Risk evaluation is the second step within the risk based approach, the step is divided into four tasks:

Task #1 Risk Characterization based on evidences

Task #2 Risk evaluation based on values .

Evidences and values of risks are taken from the results of the first step "risk assessment."

Task # 3: making Judgements of the degree of acceptability of the water risks. This task involving on an argumentative and challenging tasks for the differentiation between the acceptability, tolerability and intolerability of water risks. According to the risk based approach urban water security could be achieved if an Acceptable level of risks are maintained at current and future time. Acceptable level achieved if the likelihood and the severity of impact of the risk are low. On the contrary water risk will be intolerable if it has a very high likelihood and/or a very high severity of negative impact (OECD, 2013).

Task # 4: Targeting the risks, through proposing urgent actions for intolerable risks, measures for tolerable risks, while no actions for acceptable risks.

2.8 Risk Management Process

Risk management begins by making revision for all data, information, outcomes, feedbacks, and results generated in the two steps (risk assessment and risk evaluation). Strategies for managing the risks are involving on; avoid, reduce, transfer or bear the risk. This means that some activities and actions should handle to prevent, mitigate, adapt or sharing the risk. The important point that the new proposed management system should transforms the management mechanism to proactive one, in order to adapt with the dynamic characteristics of the urban water security risks.

2.9 Conclusion

This chapter presented the methodology used in this research. It includes 7 stages: challenges identification, determination of risk drivers, indicators weighting and ranking, risk assessment, estimation of urban water security index, risk evaluation, and finally risk management. This mythology has the following strengths:

- It is well adapted for regions with low data availability and poor data quality.

- It provides a good and transparent understanding of the urban water security.
- It is based on a good monitoring system to observe and control changes in the water security.
- It provides good classification of risks.
- It has the ability to provide a quantitative expression using qualitative as well as quantitative methods.

This methodology will be applied in the next chapter to analyze the urban water security in the Palestinian territory.

Chapter Three: Application to the Palestinian Territory- Data Collection

Chapter 3: Application to the Palestinian Territory - Data Collection

3.1 Introduction

This chapter presents an application of the methodology presented in chapter 2 to the Palestinian territory, with a focus on urban area. First, it presents this territory, water resources, water governance, and the water monitoring system. Then the chapter presents the water challenges in Palestine, in particular the shortage in water supply, demographic growth, urbanization, climate change, high non-revenue water, water governance, lack of investment and water quality.

The chapter includes identification of the urban water security risk drivers as well as the urban water security indicators. Comprehensive information about each indicator is presented including its significance, definition, source, determination, and scoring systems for both risks severity and likelihood.

This chapter also presents experts consulting: how they were chosen? Their opinions, and the consideration of their opinion in this research. Finally, the chapter presents the data needed for application of security assessment to major ten Palestinian cities.

3.2 Presentation of the Water Sector in the Palestinian Territory

3.2.1 General Presentation

Palestine is located in the Middle East, historically it is defined as the geographic region located between the Mediterranean Sea and the Jordan River (History, 2018). This research concerns the West Bank, which includes the following major cities: Jenin, Tubas, Tulkarm, Nablus, Qalqilya, Salfit, Ramallah and Al-Bireh, Jericho, Jerusalem, Bethlehem, and Hebron (Figure 3.1). The elevation in the West Bank varies between 420 m below sea level and 1020 m above sea level. The climate is characterized as Mediterranean climate with hot and dry summer and short, cool and rainy winter. Rainfall intermittent events starts from October till April (PEQA, 2015). The British mandate ruled Palestine until 1948, then the State of Israel was declared on the Palestinian lands. The West Bank was ruled by Jordan and the Gaza strip by Egypt. In 1967, both the West Bank and Gaza strip were occupied by Israel. By the mid of 1990s, the Palestinian Liberation Organization (PLO) and Israel signed the "Oslo Agreement”. Under this agreement, the West Bank was divided into three areas: Area A (8% of the West Bank), which includes the

Palestinian city centres except Hebron. This area is under the Palestinian civil and security control. Area B (18% of West Bank area), which includes the Palestinian built up area. This area is under Palestinian civil control, while the security is shared between Palestinian and Israeli. Area C (62% of the West Bank area), which is under military control of Israel. Building activities in this area require approval of the Israeli civil administration (ARIJ, 2015).

Figure 3.1: Palestinian Territories (Main Cities)

3.2.2 Water Resources in the Palestinian Territory

Groundwater is the main water source for the West Bank. It includes three shared basins: the western, eastern and the north-eastern basin. The western basin has rich quantity of water with high quality (Koppelman & Alshalalfeh, 2012 and ARIJ, 2015). The mountain aquifer has around 130 km long and 35 km wide. 80% of the recharge areas are located within the Palestinian territory as shown in Figure 3.2 (Lazarou E., 2016). According to Oslo II agreement, 20% of the aquifer are allocated to the Palestinians while 71% are allocated to Israel (Table 3.1) (World Bank, 2018).

Table 3.1: Allocation of Groundwater Resources (Oslo II Accord, Article 40)

Aquifer	Estimated Potential	Total Palestinian	Total for Israeli	Unallocated
Western	362	22	340	
North-eastern	145	42	103	
Eastern	172	54	40	
Eastern	--	20.5	--	75.5
Total (MCM)	679.0	138.5	483	57.5
Total (%)	100%	20%	71%	9%

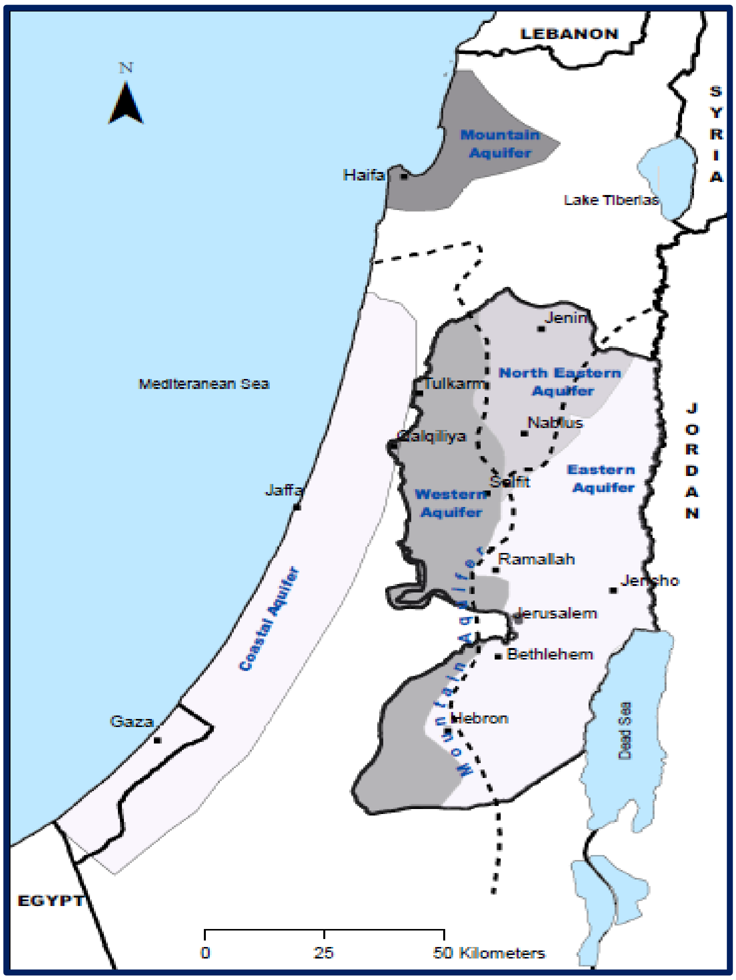

Figure 3.2: Mountain Aquifer System in the Palestinian Territory

Regarding the surface water, Israel controls the Jordan River since 1967 (Koppelman & Alshalalfeh, 2012). The surface water runoff constitutes good water resource in Palestinian territory. In the season 2011/2012, it reached 179 MCM (million cubic meter). But, Palestinians do not have capacity to collect and use this water. In some cities and villages, population harvest the surface water runoff for domestic or agricultural use at an individual scale (ARIJ, 2015).

39 water utilities provide the water service for the population in the Palestinian Territories. 6 of them have their own water resources, 28 purchase water from Israel and 5 depend on mixed resources. Water utilities purchased 16.5 MCM from Israel in 2015. This quantity is about 50% of the water supply.

3.2.3 Water Governance

The water sector in the Palestinian Territory has three main actors (Figure 3.3) divided into three main levels. The Central level is represented by the Palestinian Water Authority (PWA), the regulatory level is represented by the Water Sector Regulatory Council (WSRC). The service level concern the bulk and retail service providers (SPs) (World Bank, 2018). These bodies represent the main sources of data collected in this research.

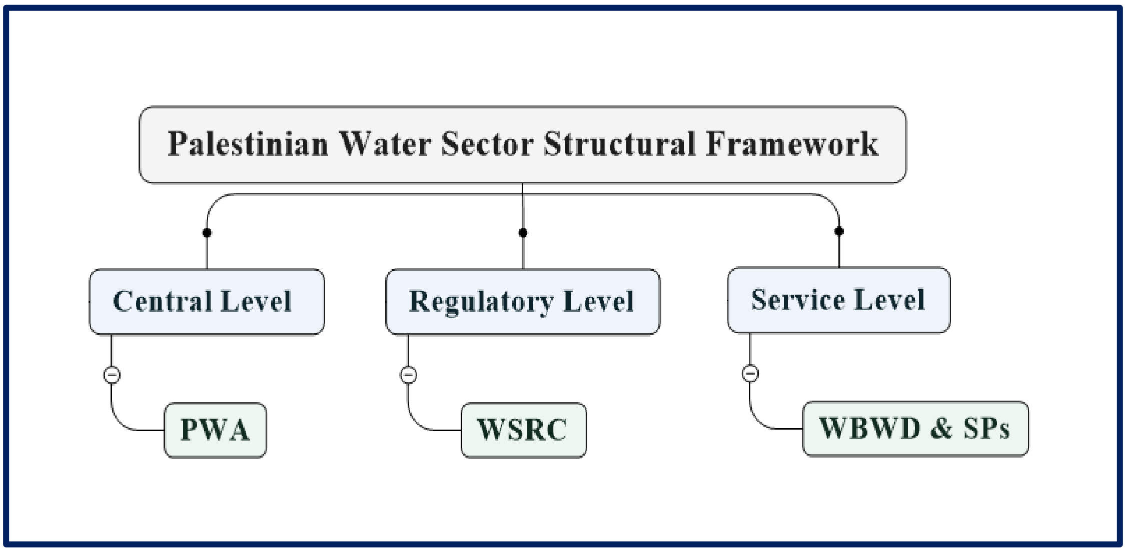

Figure 3.3: Water Governance in the Palestinian Territory

The Palestinian Water Authority (PWA) was founded in 1994 as a regulator of the water sector in Palestine. It was considered as policy maker and responsible for managing water and wastewater, restructuring and establishing the water utilities in Palestinian cities and villages (PWA, 2011).

In 2014 the water low considered the Palestinian Water Authority (PWA) as the Palestinian water ministry, responsible for water policy legislation and strategy, investment planning and development (Murrar et al, 2017).

The Water Sector Regulatory Council (WSRC) was established in 2014 as an independent regulator. The main task of this council was to regulate the providers of water supply and wastewater services. This council is responsible for water tariffs, licensing, regulating and monitoring performance for service providers and protect consumers (WSRC, 2016, PWA, 2013 and World Bank, 2018). It established performance indicators to promote accountability, social equity and autonomy (PWA, 2014).

Bulk water provider and retail water service providers ensure the water service level, together with the private providers such as NGO's Providers. The West Bank Water Department (WBWD) distributes and sells bulk water to water providers. The "2014 Water Law" defined the service providers as "any water utility, including local authorities and joint services councils and associations that provide water or waste water services". Based on this definition and according to the 2016 performance report, 39 water service providers work in the West Bank. They provide water service for 74 % of the population (WSRC, 2018). They operate under different conditions related to institutional, administrative, operational and financial conditions, besides the availability of water, infrastructure strength and the financial resources (WSRC, 2016). According to the World Bank (2018), Murrar (2016) and WSRC (2016), the water service providers can be classified into three categories (Table 3.2):

- Regional utilities as the Jerusalem Water Undertaking (JWU), which provides water services to East Jerusalem, Ramallah and Al Bireh governorate, and the Water Supply and Sewerage Authority (WSSA), which provides water service to Beit Sahour, Beit Jala and Bethlehem governorate in addition to other near localities.
- Municipal water departments (WDs) in large and medium Palestinian municipalities, which ensure water and sanitation services, such as the municipalities of Tulkarem, Qalqilya, Nablus, Jericho, Hebron, Yatta, Dura, Salfit, Kufr Rai and Qabatia.
- The Joint Service Councils (JSCs), which provide water and in some cases waste water service such as Northwest Jenin Joint Service Council, Maythaloun Joint Service Council, Tubas Joint water service council, Joint Services Council for Planning and Development Southeast of Nablus, and Joint Service Council Northwest Jerusalem, those are examples about the (JSCs).

Table 3.2: Water Service Providers in the Palestinian Territory (WSRC, 2016)

		Service Provider
Category 1	1	Jerusalem Water Undertaking
	2	Water supply and Sewerage Authority of Bethlehem, Beit Jala and Beit Sahour
Category 2	3	Water supply and sanitation Department– Nablus Municipality
	4	Water supply and sanitation Department– Tulkarm Municipality
	5	Water supply and sanitation Department– Qalqilya Municipality
	6	Water supply and sanitation Department– Salfit Municipality
	7	Water supply and sanitation Department– Jenin Municipality
	8	Water supply and sanitation Department– Jericho Municipality
	9	Water and sewage Department – Hebron Municipality
	10	Water supply and sanitation Department– Anabta Municipality
	11	Water supply and sanitation Department– Dura Municipality
	12	Department of water and sewage- Za'tara Municipality
	13	Department of water and sewage- Tuqu' Municipality
	14	Department of water and sewage- Al 'Auja Municipality
	15	Water supply and sanitation Department– Attil Municipality
	16	Water supply and sanitation Department– Deir al Ghusun Municipality
	17	Water supply and sanitation Department– Illar Municipality
	18	Water supply and sanitation Department- Ya'bad Municipality
	19	Department of water and sewage- Arraba Municipality
	20	Water supply and sanitation Kafr Ra'I Municipality
	21	Water supply and sanitation Department– Bani Na'im Municipality
	22	Water supply and sanitation Department– Tarqumiya Municipality
	23	Water supply and sanitation Department– Beit Ummar Municipality
	24	Water supply and sanitation Department– Halhoul Municipality
	25	Water supply and sanitation Department– Sa'ir Municipality
	26	Water supply and sanitation Department– Yatta Municipality
	27	Water supply and sanitation Department– Azzun Municipality
	28	As Sawahira Ash Sharqiya Municipality
	29	Water supply and sanitation Department– Al 'Eizariya Municipality
	30	Water supply and sanitation Department– Qabatiya Municipality
	31	Water supply and sanitation Department– Beituniya Municipality
	32	Water supply and sanitation Department– Biddya Municipality
Category 3	33	Tubas Joint Services Council
	34	Northwest Jenin Joint Services Council
	35	Mythaloun Joint Services Council
	36	Northwest Jerusalem Joint Services Council
	37	Joint Services Council for Planning and Development – South East Nablus District
	38	Abu Dis Cooperative Society for Water
	39	Wadi Al-Far'a Village Council

The water law organized the water service providers in the West Bank into three reginal utilities: In the North to serve municipalities in the north area, in the Middle (Jerusalem Water Utility) to serve municipalities in the middle and in the South to serve Hebron and Bethlehem governorates (PWA, 2015).

3.2.4 Water Monitoring System

The Palestinian Water Authority (PWA) started in 2011 a major initiative to monitor water providers' performances using key performance indicators (KPIs). Ten service providers participated in the monitoring program (PWA, 2011). The number of service providers involved in this monitoring increased to 39 in 2016 (WSRC, 2016 &2018). New Key performance indicators (KPIs) were introduced every two years to achieve more accurate monitoring program (WSRC, 2016). The latest program was launched by the end of 2018, by giving service providers the opportunity to upload their data using on-line connection (WSRC, 2018).

In this research, the majority of data was collected from the Palestinian Water Authority (PWA), Water Sector Regulatory Council (WSRC) and some service providers. Although the monitoring system started in 2011, available data do not cover all the years since 2011.

3.3 Water Challenges

According to the World Bank, Palestinians face a serious challenges concerning access to drinking water services (World Bank, 2018), which are due to geo- climatic conditions, population and urbanization trends, suboptimal management, bad governance and political situation (GWP-Med, 2015). According to the international standards, Palestinian have low access to water resources resulting in poor water services and high-water cost (World Bank, 2009). Water crisis in Palestine has been severe for decades without serious strategic actions plans (McKee, 2012). According the World Development Indicators report, access to improved water sources was classified as very good indicator (90 -95%) in Palestine between 1995 and 2000. Then the water service deteriorated to 58% in 2014. Due to this sharp deterioration, the water service in Palestine was considered in 2015 as one of the worst in the Middle East (World Bank, 2018).

Recent reports of national and international organizations classified Palestine as a very water scarce territory with economy partially dependent on water (World Bank, 2018 and WSRC, 2018). They pointed out the high vulnerability of the water sector in Palestine due to the political situation and general water challenges in the region. Indeed, Palestine suffers since long time from occupation, which leads to huge water challenges. This occupation constitutes a major obstacle for the development of the water sector in Palestine (ARIJ, 2015).

3.3.1 Water Shortage

Figure 3.4 shows the daily water consumption in some cities in Palestine in 2016 (WSRD, 2018). The average water consumption was 80 l/c/d (litter per capita per day). This value is about 53% of the limit defined by the World Health organization (150 l/c.d) (Chenoweth, 2008). In some cities like Jenin and Tubas, the daily water consumption was 74 l/c/d and 66 l/c/d, respectively, while in Hebron and Bethlehem it dropped to 59 l/c/d and 56 l/c/d, respectively. The situation was worse in some rural areas like Yatta where the daily water consumption was 23 l/c/d.

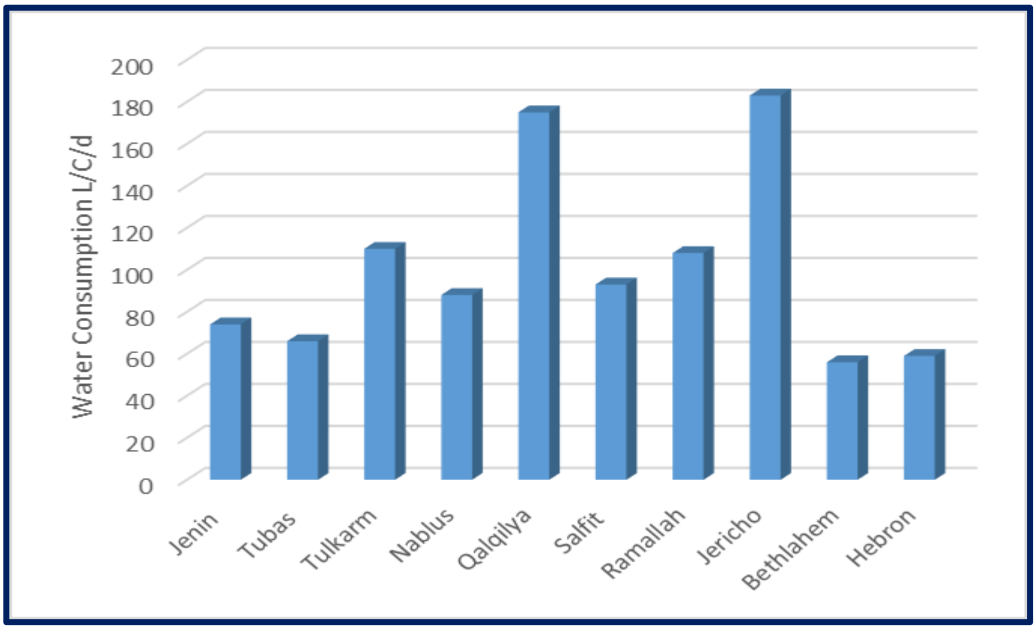

Figure 3.4: Average Daily Water Consumption in Palestinian Cities in 2016 (WSRC, 2018)

According to the Water Sector Regulatory Council (WSRC), the variation in the water consumption is due to some factors such as the water availability, the efficiency of the water service, and the investments in water infrastructure and services (WSRC, 2016). Palestinian cities suffering from high water shortage purchase water from Mekorot (Israeli Water Company) (World Bank, 2018). Figure 3.5 shows the quantities of water purchased from Mekorot by some cities. This purchase leads to increased water service costs and risks (WSRC, 2017). In addition to the water shortage, customers use tankers services at high cost: the tanker water cost is equal to 3.75 – 7.50 €/m^3 to be compared to 0.75 -1.25 €/m^3 by the public water service (WSRC, 2016, 2017). Moreover, methods used in water storage are unsafe, because of the pollution risk (ARIJ, 2015, World

Bank, 2018). Data from Water Sector Regulatory Council (WSRC) show that purchasing water tankers increased regularly in Palestinian cities (Figure 3.6).

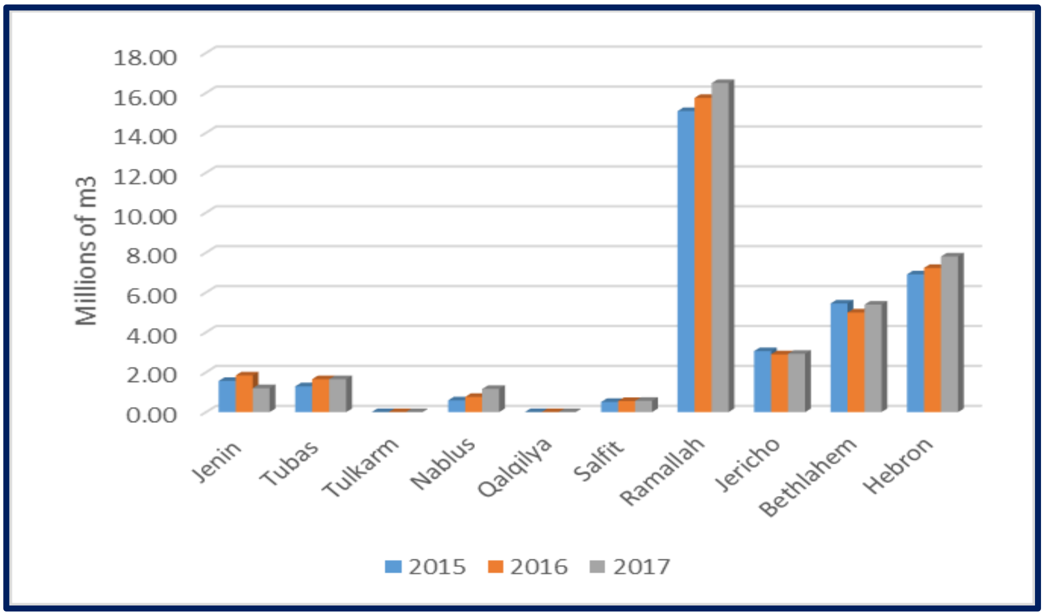

Figure 3.5 Quantities of Water Purchased from Mekorot (WSRC, 2016, 2017)

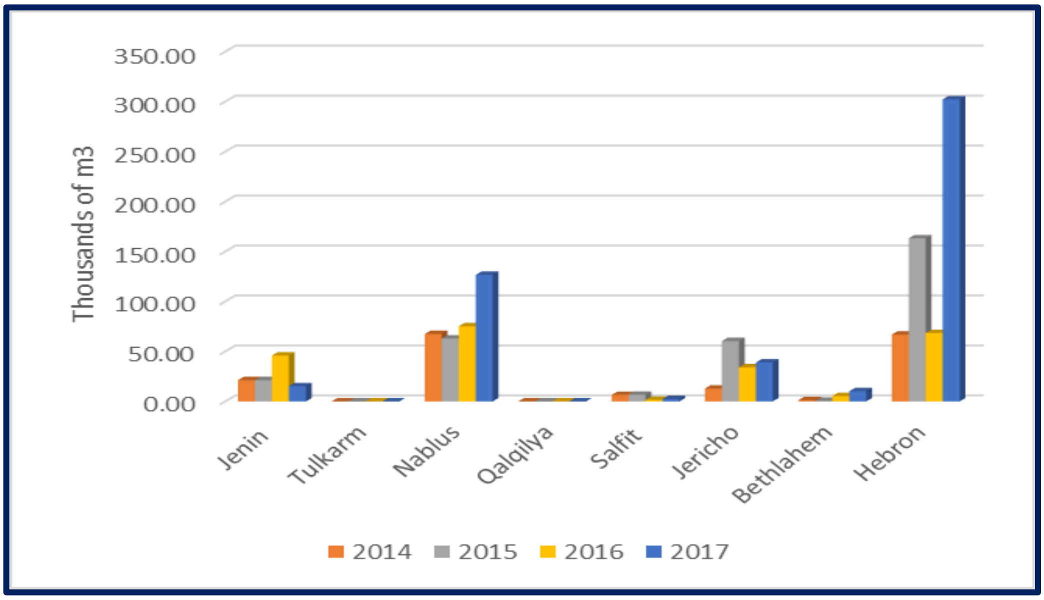

Figure 3.6: Quantities of Water Tankers Purchased in Palestinian Cities

3.3.2 Demographic Growth and Urbanization

Palestinian population has grown at a very high rate in the last ten years. In 2017 Palestine registered the highest population growth in MENA regions (Hameed et al., 2019). According to the Palestine Central Bureau of Statistics (PCBS), the total Palestinian population in the West Bank was approximately 2.5 million in 2010 and

2.75 million in 2015. In 2019, this number exceeds 3 million. With an average annual population growth of 3.5%, the number of Palestinian population is expected to double in the coming years. About 74% of the population live in urban areas, 17% in rural areas and 9% in refugee camps (PCBS web site). Figure 3.7 shows the variation of the number of the population in ten major cities in the West Bank. It confirms the high rate increase of the Population and the large concentration of this population in main cities such as Hebron, Nablus, Ramallah and Jenin. The high demographic growth and urbanization in Palestine result in an increase in the demand for water supply and sanitation.

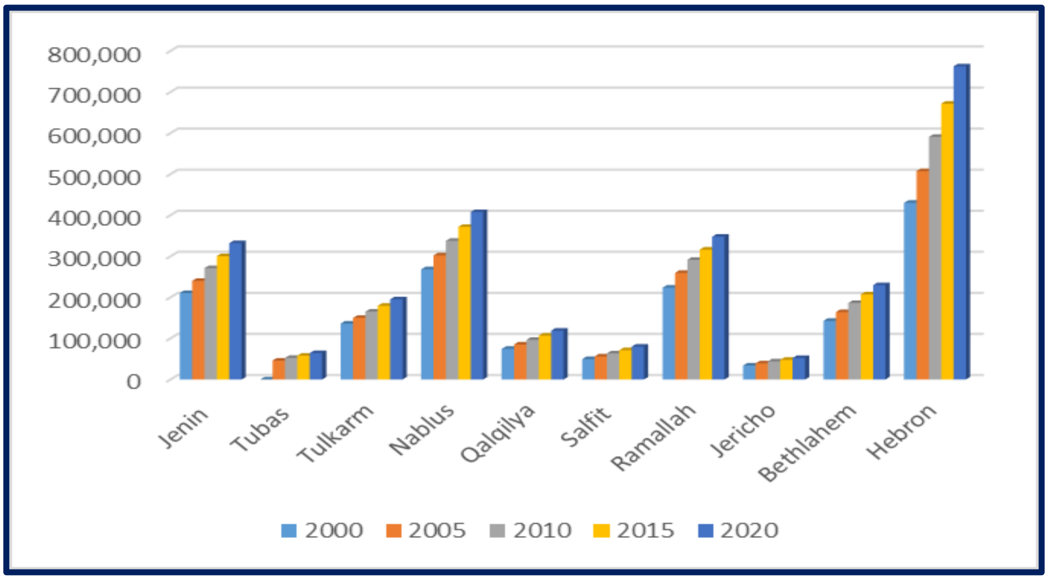

Figure 3.7: Number of Population in the Palestinian Cities

3.3.3 Climate Change

In the context of the climate change, Palestinian Territories are subjected to critical changes regarding annual precipitation, seasonal temperature, precipitation decrease and increase in drought seasons and flood events (UNDP, 2010). In the last ten years, Palestine suffered from low quantities of rainfall and frequent droughts which resulted in a reduction in the recharge of aquifers as well as in the deterioration of the quality of groundwater (Barghouthi and Gerstetter, 2012). The Annual rainfall in the past 35 years has decreased to 4.1 % with more significant effects in the south part of the West Bank, which is classified as arid to semi-arid regions (Hamrasheh and Abu-Madi, 2012). Table 3.3 shows the rainfall variation between 1845 and 2012. According to this table, the rainfall amount before 1920 varied between 206 and 1091mm, while after 2001, it varied between 340 and 690 mm (ARIJ, 2012).

Table 3.3: Rainfall Decrease in the Palestinian Territory (ARIJ, 2012)

Period	Highest Rainfall Season (mm)	Lowest Rainfall Season (mm)	Rainfall Decrease by Year (mm)
1845 - 1920	1091	206.3	1.4
1964 - 2001	910	230	3.3
2001 - 2011	690	340	23.2

Figure 3.8 shows the classification of the Palestinian territory according to the aridity index. It includes 6 categories: arid, extremely arid, hyper arid, semi-arid, humid and sub-humid ***(LRC, 2007).***

In the last decades, Palestinian Territories suffered from extreme events such as heat waves, sandstorms, high rain intensity, low precipitation and short winter. As a result, water resources, water supply, and agriculture became more vulnerable with increased water and food insecurity (UNDP, 2010 & IPCC, 2008).

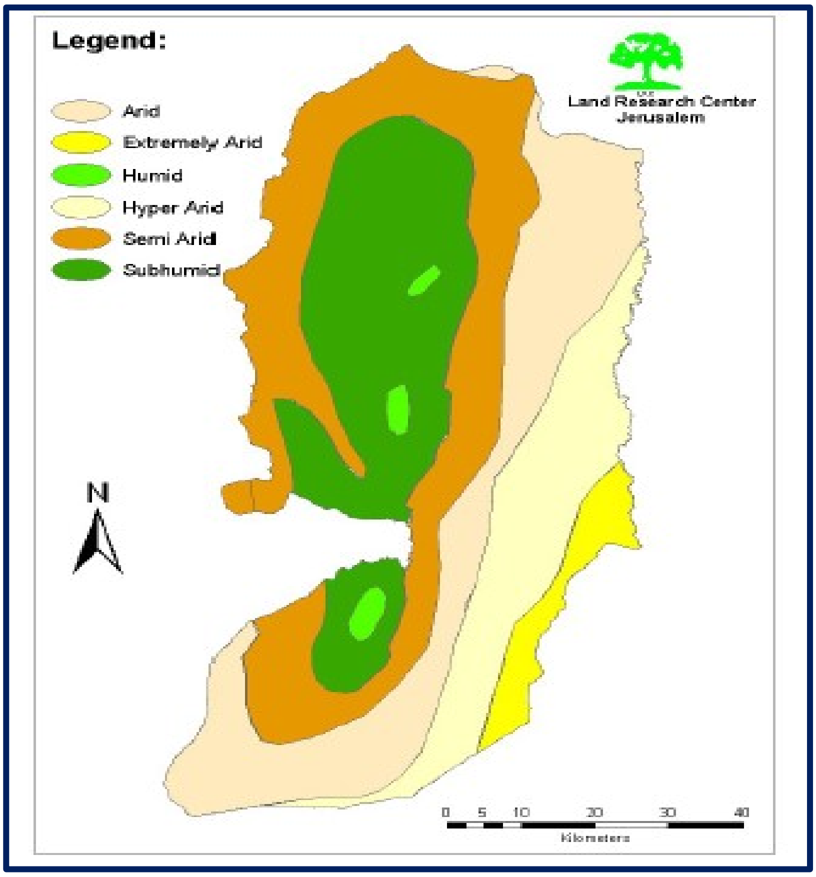

Figure 3.8: Classification of the Palestinian Territory According to the Aridity Index (LRC, 2007)

3.3.4 High Non-Revenue Water (NRW)

In 2009, the World Bank estimated that one third of the water supply in Palestinian territory were lost (World Bank, 2009). A recent report of the WSRC confirmed this dramatic situation (WSRC 2017). According to this report, the average of the non-revenue water (NRW) in main West Bank cities is equal to 36% (Figure 3.9). This NRW is equal to around 56 million cubic meters (€ 40 million). In the city of Tulkarm, the NRW reached 50%. This high NRW aggravates the pressure on water resources as well as on the quality and cost of the water service (Murrar et al, 2017 and GWP-Med, 2015). The high NRW is due to water aging infrastructures and low capacity building in the water sector (GWP-Med, 2015). In some cities, the age of the water infrastructures exceeds 70 years (USAID, 2014).

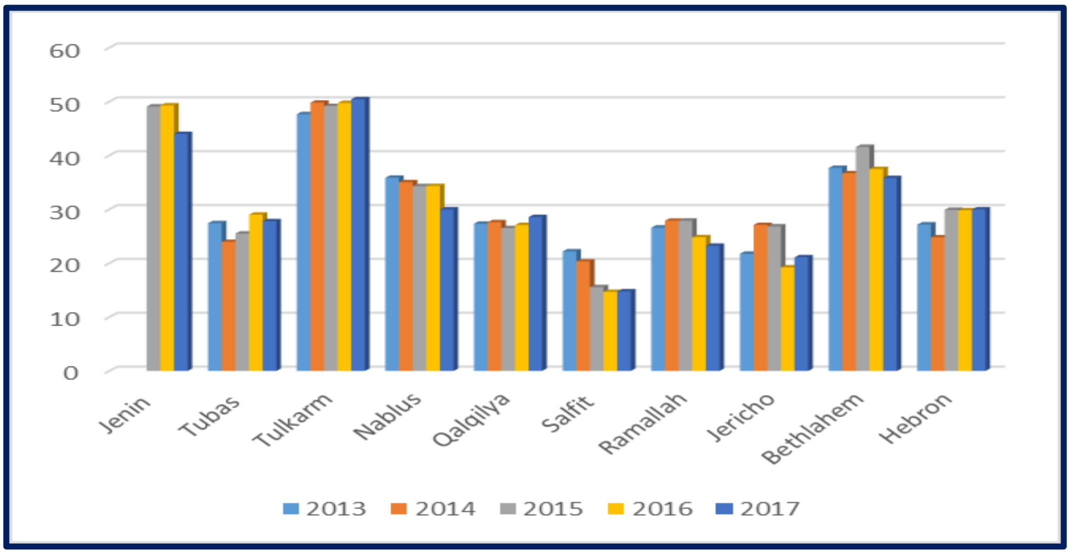

Figure 3.9: NRW in West Bank Major Cities

3.3.5 Water Governance

The water governance system was established in 1995 by the Oslo II agreement (Article 40). According to this agreement, any project concerning water infrastructures and management is subjected to the Israeli approval through the Joint Water Committee (JWC) (World Bank, 2009). Since Israel acts as an occupant authority, this dramatic clause constitutes a "huge" obstacle in the development of the water sector in Palestine. In short, Palestinians do not have the authority to establish and implement their water policy. In addition to the occupation restrictions, the Palestinian water governance suffers from weak accountability and management system, which aggravate the water governance (ARIJ, 2015 & PWA, 2013).

3.3.6 Lack of Investment

Investment in the water sector depends on international donors (ARIJ, 2015) such as the United States Agency for International Development (USAID), the American Near East Refugee Aid (ANERA), the French Development Agency (AFD) and the German development Bank (KFW). The international aid covers 76% of the total investment in the water sector (World Bank, 2018). 80% of the PWA budget was allocated to water infrastructures such as reservoirs construction, wells rehabilitation, network expansion, pump stations, valves and fittings provision (Table 3.4). Investment concerned also some projects related to capacity building and information technologies (PWA, 2016). According to water experts, despite these investments, the water service in Palestine is still below expectations (USAID, 2014 & GWP-Med, 2015).

Table 3.4: Investments in the Palestinian Water Sector

Project Type	Location	Cost (€)	Donor	Duration
Construction Reservoir and Pumping Station	Tubas	1,896,239	AFD	2010-2016
	Bethlehem	104,141	PWA	2017
Construction Reservoir and Water Network	Ramallah	1,405,685	ANERA	2014-2016
	Tulkarm	917,346	USAID	2014-2015
	Qalqilya	780,646	ANERA	2014-2015
		311,909	PWA	2016-2017
	Salfit	21,162	PWA	2015
	Jenin	11,772,212	USAID	2017
	Jericho	344,150	PWA	2017
Water and Sanitation Emergency Program	Nablus	18,230,061	KFW	2012-2017
	Bethlehem	4,954,546	WB + PWA	
Water Networks	Nablus –Jenin	6,235,493	USAID	2012-2015
	Hebron	19,068,227	USAID	2013-2015
	Yatta -Hebron	3,930,359	ANERA	2014-2017
	Dura-Hebron	54,660	PWA	2016-2017
	Bethlehem	11,104,441	USAID	2013-2015
	Jenin	10,040,909	USAID	2015-2016
	Nablus	548,346	PWA	2016-2017
	Tubas	255,067	PWA	2016-2017
	Qalqilya	1.109,757	PWA	
Water Network Rehabilitation and Expansion	Tubas	3,966,807	AFD	2013-2016
SCADA –First Phase	West Bank	4,500,891	USAID	2013-2015
Wells Rehabilitation	Jenin	20,391,469	USAID	2013-2016
	Jericho	63,842	PWA	2016-2017
Construction of Pump stations	Tulkarm	71,775	PWA	2016-2017
Providing with water valves and fittings	All cities	2,064,615	PWA	2016-2017

3.3.7 Water Quality

Data show that the majority of wells in the Jordan valley have high concentration in chloride exceeding 250 mg/l, while in Tulkarm and Qalqilya the nitrate concentration exceeds 50mg/l (PWA, 2013 and ARIJ, 2016). Use of agricultural fertilizers and pesticides, cesspits, disposal of raw sewage and industrial discharge deteriorate the water quality (Jaradat, 2016 and ARIJ, 2015).

3.3.8 Resume of Water Challenges in Palestine

Table 3.5 and figure 3.10 summarize the challenges of the water sector in Palestine. Clearly, the Palestinian territory faces great challenges combining occupation, climate change, degraded infrastructures with high NRW, water governance, lack of investments and water quality threats. Under these circumstances, the Palestinian water security is facing a real challenges.

Table 3.5 Palestinian Water Challenges

Challenge	Information
Occupation	1- Huge restriction on the development of the water sector 2- Restriction on the exploitation of water resources 3-Illegal exploitation by Israel of the Palestinian water resources
Demographic growth and urbanization	1- Average annual population growth = 3.5% 2- 74% of the population live in urban area
Climate change	1- Precipitation decrease 2- Temperature increase 3- Water Shortage 4- Desertification 5- Frequent occurrence in extreme events
High Non-Revenue Water (NRW)	1- NRW = 36% 2- In some cities, it attains 50% 3- Aged water infrastructures, in some cities more than 70 years
Water governance	1- Complete control by the occupation authority (OSLO II) 2- Unclear national governance model 3- Role overlapping
Lack of investment	1- More projects were needed. 2- Additional international support were required 3- Water harvesting large scale projects were needed.
Water Quality	1- Increase the concentration of chloride and nitrate in some areas 2- BOD pollution in some special conditions

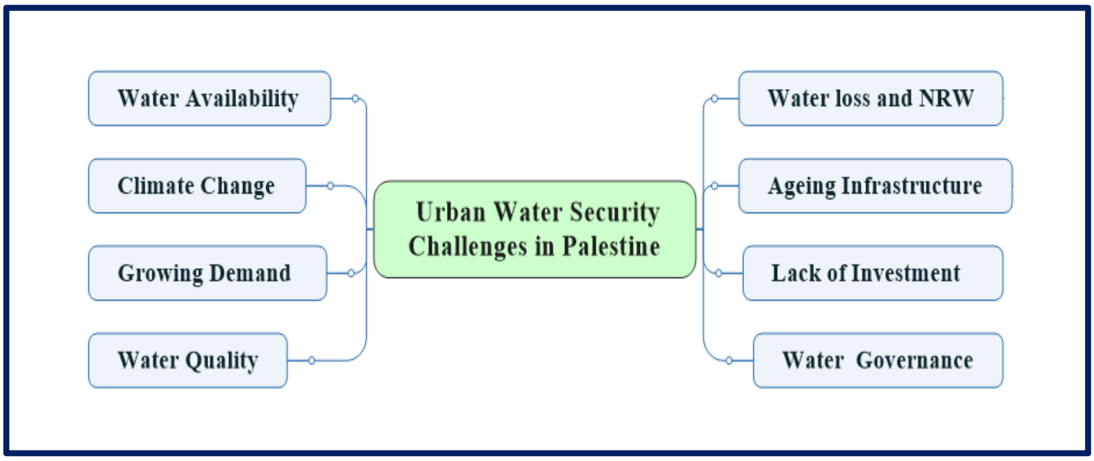

Figure 3.10: Urban Water Security Challenges in the Palestinian Territory

3.4 Urban Water Security Indicators

This section is based on data collected from different sources and discussions with water experts.

3.4.1 Initial Set of Water Security Indicators

This set of indicators was fixed according to literature review and reports concerning the water challenges and security in Palestine.

Figure 3.11 shows risk drivers in Palestine. They are classified into three categories: water resources, water services and water governance. Table 3.6 summarizes the indicators related to each category. The category "Water Resources" uses three indicators: water resources availability, annual precipitation and ratio of treated wastewater. The category "Water Services" is described using three indicators: water coverage, water losses and continuity of the water supply. Finally, the category "Water Governance" is based on three indicators: clear roles and responsibilities, access to data and information and stakeholders' engagement.

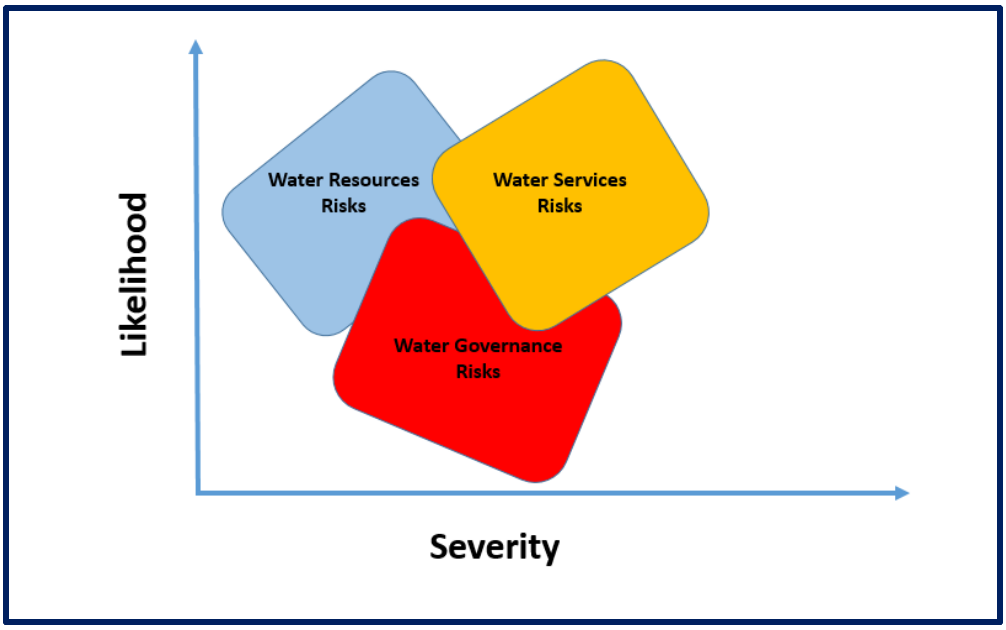

Figure 3.11: Water Security Risk Drivers in Palestinian Territory

Table 3.6: Risk Drivers and Linking Indicators

Risk Driver	Indicators
Water Resources	Water Resources Availability
	Annual Precipitation
	Ratio of Treated Wastewater
Water Services	Water Coverage
	Water Losses
	Continuity of Supply
Water Governance	Clear Roles and Responsibilities
	Access to Data and Information
	Stakeholders Engagement

For each indicator, data and information are provided such significance, source, definition, calculation method and risk scoring systems, as well as justification of the proposed scoring system. Detailed information for each indicator shown in the followings:

Indicator # 1: Water Resources Availability (WRA)

Significance: Cities with insufficient freshwater resources are subjected to high water stress (Ginkle et al., 2018). Consequently they use alternative solutions such as water transport or import, reuse of treated waste water and desalination of sea water (McDonald et al, 2014 and Wen et al., 2017).

WRA is important for utilities, but frequently difficult to assess, especially when the service provider has multiple. High values of WRA means the use of available water resources and low level of water security (IWA, 2017).

Source: IWA, 2017

Definition: Percentage of available water that enters the system

Calculation: (System input volume during the assessment period x 365 / assessment period)/ (annual yield capacity of own resources + annual imported water allowance) x 100%.

Proposed Severity Scoring System: Shown in table 3.7

Table 3.7: WRA Severity Scoring System

Severity Score	proposed range
1	50 < WRA ≤ 60 %
2	60 < WRA ≤ 70%
3	70 < WRA ≤ 80%
4	80 < WRA ≤ 90%
5	90 <WRA ≤ 100%

Justification of the Scoring System: According to the (IWA, 2017), the value 100% means that available water resources were used, and this is the worst case. The availability of water resources should be more than the system input, that marginal water quantities required to be available to maintain adequate security of supply.

Accordingly the proposed severity scoring system give the severity score 5 which ranking as catastrophic case to the indicators that have values more than 90% and equal to or less than 100%, since this range represents the case when the water available as margin or spare is too little and not exceed 10%, the rest scoring ranges were built based on this range.

Indicator # 2: Annual Precipitation (AP)

Significance: The amount of yearly precipitation (rainfall) determines the total availability of water resources and consequently the water stress (OECD, 2013). Precipitation shortage is a critical situation and constitutes as urban water insecurity indicator (Ginkel et al., 2018).

Source: (Ginkel et al., 2018).

Definition: Total accumulated precipitation over one year

Calculation: Gathering the annual rainfall data from a trustful local department.

Proposed Severity Scoring System: Shown in Table 3.8

Table 3.8: AP Severity Scoring System

Severity Score	proposed Range
1	AP ≥1000 mm/y
2	600 ≤ AP < 1000 mm/ y
3	400 ≤ AP < 600 mm/ y
4	200 ≤ AP < 400 mm/ y
5	AP < 200 mm/ y

Justification of the Scoring System: by reference to Palestine Meteorological Department (PMD) website and database and the Applied Research Institute-Jerusalem report ARIJ, (2012) the maximum annual precipitation in Palestine was 1091 mm, while the minimum was 230. Accordingly severity score 1 was fixed for AP exceeding 1000 mm, while score 5 was fixed for AP inferior to 200 mm.

Indicator #3: Ratio of Treated Waste Water (RTWW)

Significance: The quality of water resources are highly affected by sanitary services, since this kind of services have a great impact on water aquifer and availability (Burn, Shiroma Maheepala, & Sharma, 2012). The Millennium Development Goals highlighted the same meaning as they focused on the importance of sanitation access as it's essential for human health and water resources protection (UN, 2015).

Absence or ineffective waste water treatment services could lead to high risk to environment and water resources (Ginkel et al., 2018).

The indicator RTWW describes the waste water coverage, the treatment level, and also the state of sewers.

It has a direct influence on the environment and population health. Moreover it gives an idea about the level of the city regarding the infrastructure investments and the economic capacity.

Source: Researcher proposition

Definition: The indicator is represented by three sub-indicators: (i) Waste Water Coverage (WWC) which is the population percentage that is connected to a sanitary system within the city", (ii) The State of Sewers (SoS) which describes the current conditions of the sewer system according to the age and maintenance program, (iii) Treatment Level (TL) which represents the adequacy of waste water treatment as the presence of any level of wastewater treatment.

Calculation: Sum of the three weighted indicators. Where;

WWC = (Population connected to the sewer systems managed by the service provider / total population served) * 100 %.

SoS and TL are estimated as shown in table 3.9

Proposed Severity Scoring System: Shown in table 3.9

Table 3.9: RTWW Severity Scoring System

Severity Score	proposed Range
1	$95 < WWC \leq 100\%$
2	$85 < WWC \leq 90\ \%$
3	$75 < WWC \leq 80\ \%$
4	$65 < WWC \leq 70\%$
5	$WWC \leq 65\ \%$
1	SoS = Good State with age less than 10 years
2	SoS = Regular Maintenance with age more than10 years
3	SoS = Intermittent Maintenance with age more than 10 years
4	SoS = No Maintenance with age more than 10 years
5	SoS = Poor state, no maintenance, age more than 10, leaks and inappropriate diameter.
1	TL= Primary, secondary, tertiary and sludge recycle
2	TL= Primary, secondary and tertiary
3	TL= Primary and secondary
4	TL= Only Primary
5	TL= Absence

Justification of the Scoring System: 1) severity score 1 for WWC means that there is no or neglected negative impact, these state could be achieved when the waste water coverage within the city is close to 100%.

2) The scoring system for the SoS is based on sewer age and regular maintenance activities.

3) Severity scoring system for TL is based on the availability of Primary, secondary, tertiary and sludge recycle.

Indicator # 4: Water coverage (WC)

Significance: Supplying communities by water through piped network is a key element for ensuring water security. This service, called "services of general interest", is essential for, public health, security of populations, economic activities and environmental preservation (IWA, 2017). Usually water services in any country render a public service that highly influences in society, economy, environment, policy, and human health, for these reasons it's classified as sensitive domain (Nafi, 2015).

Source: IWA, 2017

Definition: Percentage of the population served by water utility

Calculation: Resident population served by the water undertaking through service connections / total resident population x 100%

Proposed Severity Scoring System: Shown in table 3.10

Table 3.10: WC Severity Scoring System

Severity Score	proposed Range
1	$95 < WC \leq 100\%$
2	$90 < WC \leq 95\ \%$
3	$85 < WC \leq 90\ \%$
4	$80 < WC \leq 85\%$
5	$WC \leq 80\ \%$

Justification of the Scoring System: Since covering the whole city with water services is the best state, the risk severity score 1 was attributed to WC close 100 %.

Indicator # 5: Water losses (WL)

Significance: Water losses is linked to pipe leaks, breaks and illegal connections. It impacts the non-revenue water (ITU, 2014). Water losses have two components; real losses and apparent losses. Real losses are related to physical losses caused by leakage in distribution mains, service connections, and storage tanks. Apparent losses are related to all kinds of inaccuracy, metering inaccuracy, reading errors, human inaccuracy, in addition to the unauthorized connections (World Bank, 2016).

Water losses are affected by many factors such as, pipes material and age, metering accuracy, pressure in pipes, technical tools and human experience used in water management.

Source: IWA, 2017

Definition: Water losses during the assessment period

Calculation: Water losses / system input volume x 100%

Proposed Severity Scoring System: Shown in table 3.11.

Table 3.11: WL Severity Scoring System

Severity Score	proposed Range
1	WL≤ 10%
2	10 < WL ≤ 20
3	20 < WL ≤ 30
4	30 < WL ≤ 40
5	WL > 40 %

Justification of the Scoring System:

Score 1 is selected for WL equal to or less than 10%. While score 5 is selected for WL more than 40%, because many cities in developing countries have a WL exceeding this ratio.

Indicator # 6: Continuity of Water Supply (CWS)

Significance: This indicator measures the continuity of a basic urban services. Disturbance in water services leads to deterioration in the water quality, decrease the pipe age, increased pipe pressure, and raise the cost of the service with negative impacts on low income citizens.

Source: IWA, 2017

Definition: Percentage of hours when the (intermittent supply) system is pressurized.

Calculation: Number of hours with water service supply during the assessment period/24/Assessment period x 100%.

Proposed Severity Scoring System: Shown in table 3.12.

Table 3.12: CS Severity Scoring System

Severity Score	proposed Range
1	$90 < CWS \leq 100\%$
2	$80 < CWS \leq 90\ \%$
3	$70 < CWS\ \leq 80\ \%$
4	$60 < CWS \leq 70\%$
5	$CWS\ \leq 60\ \%$

Justification of the Scoring System: Where supplying communities with water services over the whole 24 hours is the best case, so the risk severity score 1 attributed to CS close to 100%.

Indicator # 7: Clear Roles and Responsibilities (CRR)

Significance: good governance is required for achieving good level of water security, clear divisions of tasks among water actors, as well as responsibilities identification.

This indicator is relevant for decision-making and accountability and for clarifying who does what? (OECD, 2018).

Source: OECD, 2018

Definition: "Clearly allocate and distinguish roles and responsibilities for water policy making, policy implementation, operational management and regulation, and foster co-ordination across these responsible authorities"

Calculation: Qualitative measurement

Proposed Severity Scoring System: Shown in table 3.13.

Table 3.13: CRR Severity Scoring System

Severity Score	proposed Range
1	In place, functioning and fully implemented.
2	In place, partially implemented.
3	In place, not implemented.
4	Framework under development
5	Not in place.

Justification of the Scoring System: Answering the big question "who is responsible for?" is very important, to what range, without gaps, without overlaps, and without conflicts of interest between all levels, bodies and actors.

The scoring system was established as follows: Score 1 is attributed for the situation of existing and application of the water with clear responsibilities.

Measuring the indicator answering the questions what, who and how?

Indicator # 8: Access to Data and Information (ADI)

Significance: The availability and sharing of data and information between water stakeholders are very important for good water management (OECD, 2016). Water security requires water information systems related to resources, quality of services as well as decisions-making and policies. Data is also necessary for strategies evaluation (OECD, 2018).

Source: OECD, 2018

Definition: "Produce, update and share timely, consistent, comparable, and policy-relevant water and water-related data and information, and use it to guide, assess and improve water policy".

Calculation: Qualitative measurement

Proposed Severity Scoring System: Shown in table 3.14

Table 3.14: ADI Severity Scoring System

Severity Score	proposed Range
1	In place, functioning and fully implemented.
2	In place, partially implemented.
3	In place, not implemented.
4	Framework under development
5	Not in place.

Justification of the Scoring System: Score 1 is attributed to situation with existing operational information system about water, while score 5 is given for the absence of this system, because of its dramatic impact on water security.

Indicator # 9: Stakeholder Engagement (SE)

Significance: involvement of citizens, local community institutions, and non-governmental organizations (NGOs) is crucial for creating good governance. (IWA, 2016). Stakeholder Engagement measures the level of stakeholder involvement in water related projects, polices and decisions (OECD, 2018).

Source: OECD, 2018

Definition: "Promote stakeholder engagement for informed and outcome-oriented contributions to water policy design and implementation"

Calculation: Qualitative measurement

Proposed Severity Scoring System: Shown in table 3.15

Table 3.15: SE Severity Scoring System

Severity Score	proposed Range
1	In place, functioning and fully implemented.
2	In place, partially implemented.
3	In place, not implemented.
4	Framework under development
5	Not in place.

Justification of the Scoring System: Since stakeholders' engagement allows to involve stakeholders in water management and policies, the existence of an operational SE increases the water security (score = 1), while its absence deteriorates the water security (score = 5).

Proposed Likelihood Scoring System

Based on the research methodology likelihood defined as "chance of something happening", it may be expressed using definitions, measurements, subjective or objective estimations, qualitative or quantitative determinations, and may be described using mathematical or linguistic terms (ISO, 2009 and SRA, 2015). The proposed score system for likelihood shown in table 3.16.

Table 3.16: Proposed Likelihood Scoring System

Likelihood Score	proposed Range
1	If the indicator values in the study period are within the acceptable range every year
2	If the indicator values in the study period are within the acceptable range along the last four years
3	If the indicator values in the study period are within the acceptable range along the last three years
4	If the indicator values in the study period are within the acceptable range just in one to two years
5	If the indicator values in the study period are out of the acceptable range every year

Notes: 1) study period = five years (2013-2017).

2) The acceptable range: the range that has severity score =1.

Justification of the Scoring System: Risk likelihood determination is an important step within the risk assessment process. Although it's carrying uncertainty, however uncertainty exists in each risk assessment step, what's important is to decrease the uncertainty as well as to make the process steps practical and simple.

By reference to a study done in Australia about water supply systems subjected to microbiological contaminants, risk likelihood was giving scores from 1 to 5, where the score 1 was given to risks that happening one time every 5 years, then the score 2 was given to risks that happening yearly, the score 3 was given to risks happening monthly, the risk 4 was given to risks that happening weekly, while the score 5 was given to risks that happening daily (WHO & IWA, 2001).

The proposed likelihood scoring system presented in table 3.16 uses scores from 1 to 5 to rank the risks likelihood. Score 1 indicates as an acceptable value along the five years (study Period). Likelihood score 2 indicates values within the acceptable range along the last 4 years, while likelihood score 5 indicates values out of the acceptable range in the last five years (study period).

3.4.2 Revision of the Water Security Indicators after Discussion With Water Experts

25 water experts were consulted about the indicators for the water security in Palestine as well as the scoring systems proposed in the previous section. Consultations were implemented through one oriented questionnaire to water experts (available in annex-A), in addition to several meetings and interviews. Table 3.17 provides information about the experts. They are classified in 5 categories: governmental, non-governmental, policy makers, academic and municipalities employees. Experts cover the North, Middle and South areas of the West Bank.

Table 3.17: Experts Consulted in this Research

No. of Category	Sample Category	Organizations	Number of respondent
(1)	Governmental Organization	Palestinian Water Authority (PWA) Water Sector Regulatory Council (WSRC) Union of Palestinian Water Service Providers (UPWSP) Ministry of Agriculture	4
(2)	Non-governmental Organizations	Palestinian Hydrology Group (PHG) Applied Research Institute- Jerusalem (ARIJ) Global Environmental Services (GES) German Corporation for International Cooperation GmbH (GIZ)	4
(3)	Policy Makers	Minister- former head of Palestinian water authority Palestinian Water Authority (PWA) Water Sector Regulatory Council (WSRC)	3

(4)	Academic	Palestinian Technical University- Kadoorei-Palestine An-Najah National University- Palestine Birzeit University- Palestine Palestine Polytechnic university- Palestine Polytechnic University of Valencia- Spain Indiana University of Pennsylvania, USA	10
(5)	Municipalities	Nablus Municipality Hebron Municipality	4

Regarding the severity and likelihood scoring systems, experts had the possibility to modify the proposed system according to their experience. Most experts strongly agreed with the proposed scoring system, few of them suggested some modifications, one of experts disagreed for one system. Table 3.18 and figure 3.12 give details about experts' participations. Regarding the likelihood scoring systems all experts strongly agreed with the proposed scoring system.

Table 3.18: Experts Participations in Modifying Indicators Severity Scoring Systems

Indicator	Strongly Agree	Agree with	Dis-Agree	Neutral
WRA	20	--	--	5
AP	14	6	1	4
RTWW	12	7	--	6
WC	20	--	--	5
WL	21	--	--	4
CS	15	5	--	5
CRR	20	--	--	5
ADI	21	--	--	4
SE	18	--	--	7

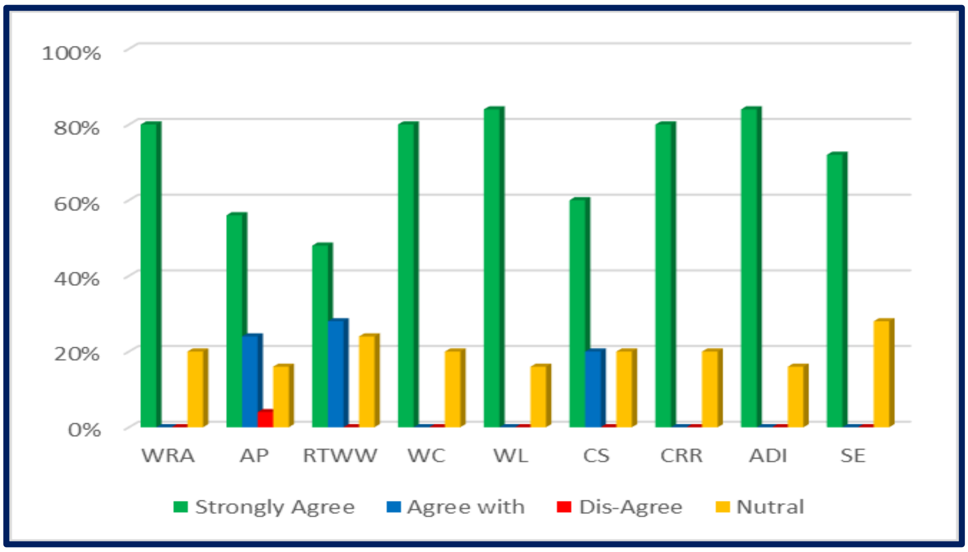

Figure 3:12 Expert Participations Ratio in Modifying Indicators Severity Scoring Systems

Experts' opinions results were considered as follows:

Water Resources:

According to the experts opinions, annual precipitation in cities subjected to high water stress rarely reach 1000 mm, and this was the case in the Palestinian cities especially in the last ten years, so the severity score (1) was attributed to AP higher than 800 mm. (Table 3.19)

Table 3.19 Modifications of the Annual Precipitation Severity Scores According to Experts Opinions

Score	Initial Values	Values According to Experts
1	AP ≥1000 mm/y	AP ≥ 800 mm/y
2	600 ≤ AP < 1000 mm/ y	600 ≤ AP < 800 mm/ y
3	400 ≤ AP < 600 mm/ y	400 ≤ AP < 600 mm/ y
4	200 ≤ AP < 400 mm/ y	200 ≤ AP < 400 mm/ y
5	AP < 200 mm/ y	AP < 200 mm/ y

Concerning the ratio of treated wastewater; Modifications of the waste water coverage were done to expand the range in each class. While regarding the state of sewers (SoS) modifications were done to classify the state of sewers into: very good, good, acceptable, bad, and very bad. Very good state represents the state of sewers with age less than 10 years, no leakage and/ or flood plus regular maintenance, while good state represent the state of sewers with age between 10 and 20 years with occasional leakage and/or flood and regular maintenance. Acceptable state of sewers with age between 10 and 20, and intermittent maintenance. Bad state of sewers with age between 20 and 30 years, and occasional leakage and/or flood without maintenance. Very bad state of sewers with age more than 30 years, frequent leakage and/or flooding without maintenance. Table 3.20 summarizes these modifications.

Table 3.20 Modifications of the Ratio of Treated Waste Water Severity Scores According to Experts

Score	Initial Values	Values According to Experts
1	95 < WWC ≤ 100%	90 < WWC ≤ 100%
2	85 < WWC ≤ 90 %	80 < WWC ≤ 90 %
3	75 < WWC ≤ 80 %	70 < WWC ≤ 80 %
4	65 < WWC≤ 70%	60 < WWC≤ 70%
5	WWC ≤ 65 %	WWC ≤ 60 %
1	SoS = Good State with age less than 10 years	SoS = Very Good
2	SoS = Regular Maintenance with age more than10 years	SoS = Good
3	SoS = Intermittent Maintenance with age more than 10 years	SoS = Acceptable
4	SoS = No Maintenance with age more than 10 years	SoS = Bad
5	SoS = Poor state, no maintenance, age more than 10, leaks and inappropriate diameter.	SoS = Very Bad

Water Services

Experts gave a score of 5 for the continuity of water supply for CWS inferior to 40%. (Table 3.21).

Table 3.21 Modifications of Continuity of Supply Severity Scores According to Experts

Score	Initial Values	Values According to Experts
1	90 < CWS ≤ 100%	85 < CWS ≤ 100%
2	80 < CWS ≤ 90 %	70 < CWS ≤ 85 %
3	70 < CWS ≤ 80 %	55 < CWS ≤ 70 %
4	60 < CWS ≤ 70%	40 < CWS ≤ 55%
5	CWS ≤ 60 %	CWS ≤ 40 %

The "Water Governance" scoring system was not modified.

3.5 Data Collection

Data for water resources and services were collected for ten cities in the West Bank (Jenin, Tubas, Tulkarm, Qalqilya, Salfit, Nablus, Ramallah and Al-Bireh, Jericho, Bethlehem, and Hebron) (Figure 3.13), while data for the water governance were collected for the whole West Bank, because this issue concerns the national level.

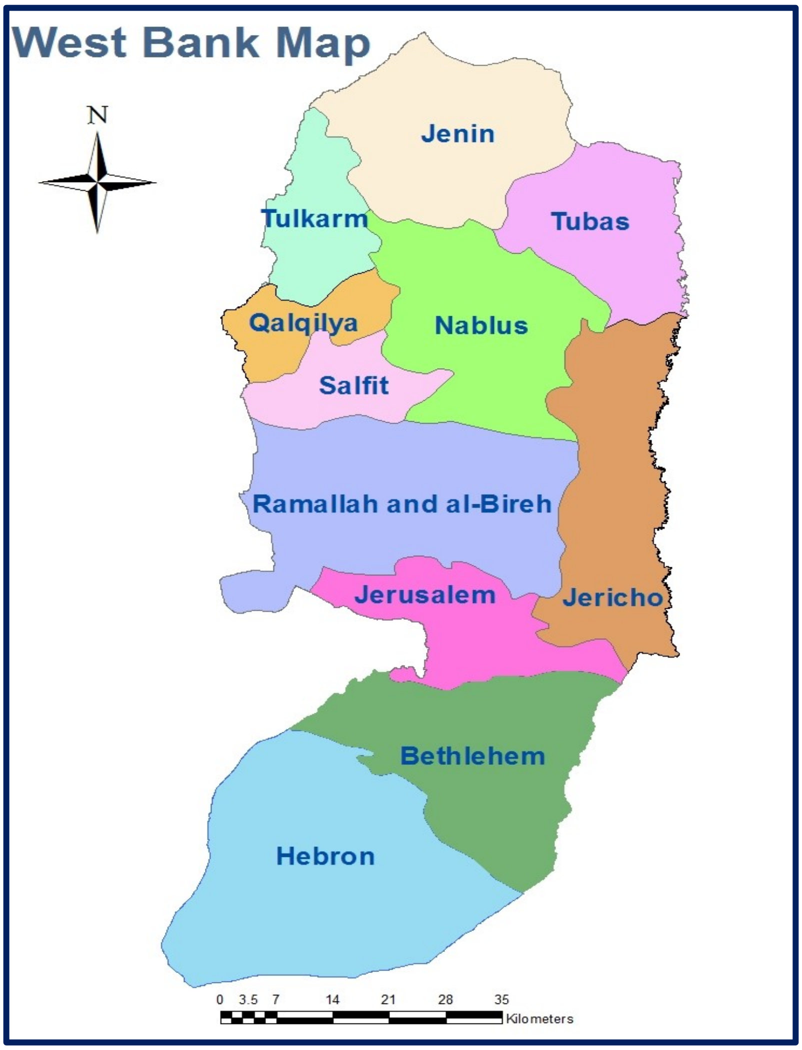

Figure 3.13: West Bank 10 Main Cities

Collection of data in the Palestinian territory was a complex task, because many bodies share responsibilities, with segmented data. Sometimes data was conflicting. Meetings and interviews with experts effectively raised the quality of collected data.

So first of all, data was collected for determining the value of each indicator in the ten cities for the last five years. Some data for the first years was not found because of the absence of the monitoring system.

Some indicators were proposed in this research and were not found or used in the Palestinian monitoring system. Calculations of those indicators are available in annex-B.

A- Water Resources and Water Services Indicators

Tables 3.22 – 3.28 show data concerning water availability (WRA), annual precipitation (AP), Waste water coverage (WWC), state of sewers (SoS), treatment level (TL), water coverage (WC), water loss (WL) and the continuity of supply (CWS) for the period 2013 – 2015 for the ten cities.

Water Resources Availability (WRA):

This indicator is not included in the Palestinian monitoring system. Table 3.22 present the collected data for the ten cities. It shows high values of WRA for the ten cities (close to 100%), which indicate total consumption of available resources and high risk on water availability.

Table 3.22: Data Concerning Water Resources Availability (%)

City	2013	2014	2015	2016	2017
Jenin	No Data	100	100	100	100
Tubas	No Data	No Data	99.8	99.8	99.8
Tulkarm	99.9	99.9	99.90	99.94	99.9
Qalqilya	99.9	99.9	99.9	99.9	99.9
Salfit	99.8	99.8	99.7	99.8	99.8
Nablus	99.9	99.9	99.9	99.9	99.9
Ramallah and Al-Bireh	No Data	No Data	100	100	100
Jericho	99.8	99.8	99.8	100	100
Bethlehem	100	100	100	100	100
Hebron	100	100	100	100	100

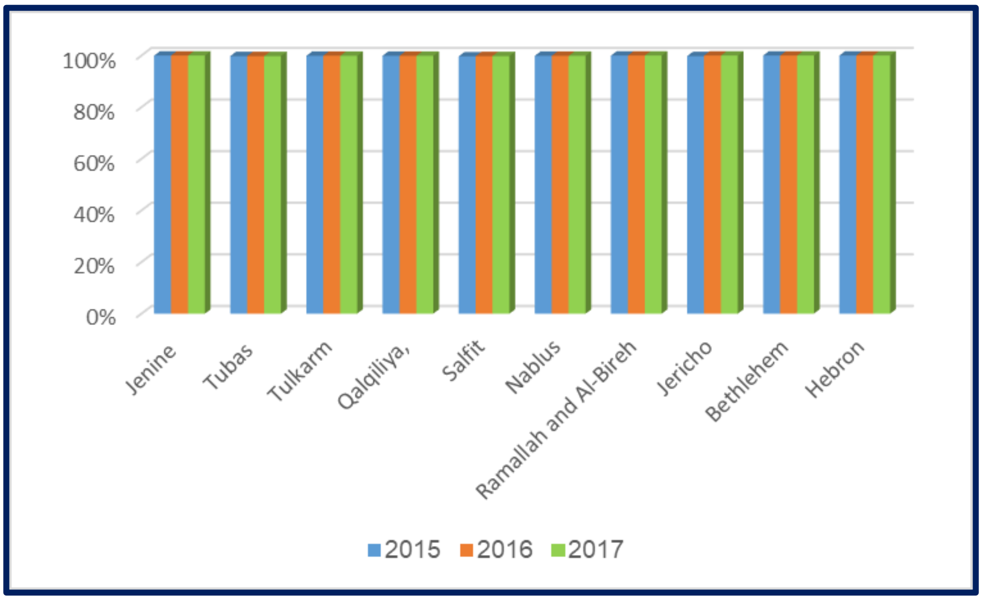

Figure 3.14: WRA (%) Values in the Palestinian Cities

Annual Precipitation (AP):

Table 3.23 and figure 3.15 show the values of AP for the period 2013-2017. We observe fluctuation of the AP: an increase between 2013 and 2014, followed by a decrease in 2015 and 2016 then an increase in 2017. AP is very low in Jericho: less than 229 mm. In other cities, the average value of varied between 422 mm (in 2013) and 646 mm in 2014.

Table 3.23: Data Concerning Annual Precipitation (mm/year)

City	2013	2014	2015	2016	2017
Jenin	289	580	383	283	538
Tubas	239	532	254	294	345
Tulkarm	461	720	428	419	547
Qalqilya	426	624	645	501	477
Salfit	539	691	594	512	518
Nablus	539	691	594	512	518
Ramallah and Al-Bireh	454	675	533	403	482
Jericho	134	229	131	71.9	143
Bethlehem	376	656	519	313	408
Hebron	476	572	618	411	523

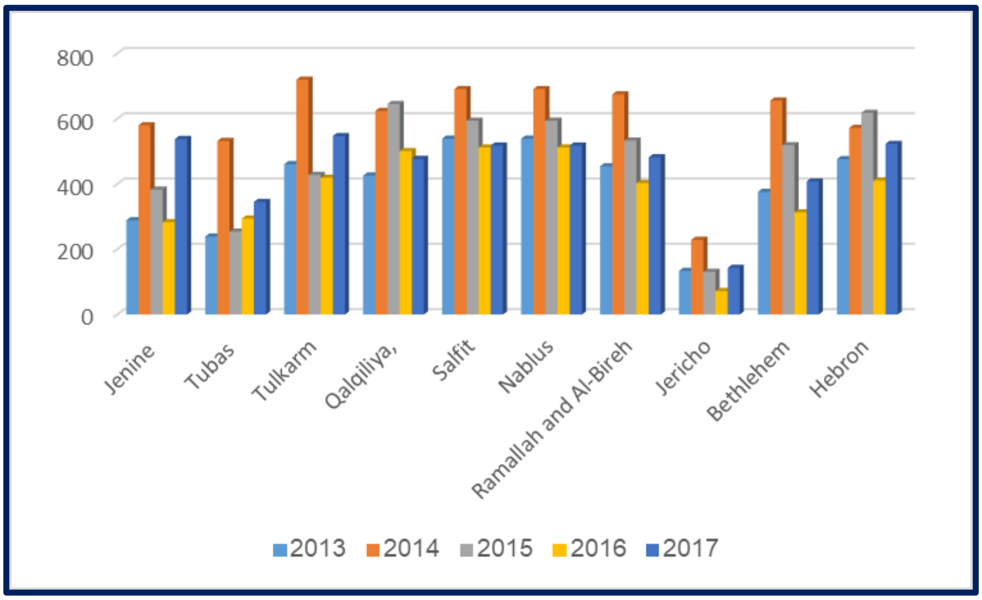

Figure 3.15: AP (mm/year) in the Palestinian Cities

Waste Water Coverage (WWC)

Table 3.24 and figure 3.16 show the values of WWC for the period 2013-2017. The decrease of WWC in some cities such as Jericho is due to the city extension. In some cities such as Nablus and Qalqilya we observe high values of WWC (close to 100%), in Tulkarm and Jenin, WWC is close to 80%, in some other cities WWC is very low in 2017, in particular in Salfit and Jericho.

Table 3.24: Data Concerning Waste Water Coverage (%)

City	2013	2014	2015	2016	2017
Jenin	NO Data	78	78	81	82
Tubas	--	--	--	--	--
Tulkarm	80	82	85	75	77
Qalqilya	96	96	97	97	98
Salfit	44	60	61	36	37
Nablus	98	98	98	98	98
Ramallah and Al-Bireh	No Data	No Data	No Data	No Data	86.5
Jericho	0.00	27	55	19	8
Bethlehem	80	69	69	50	70
Hebron	56	66	66	70	70

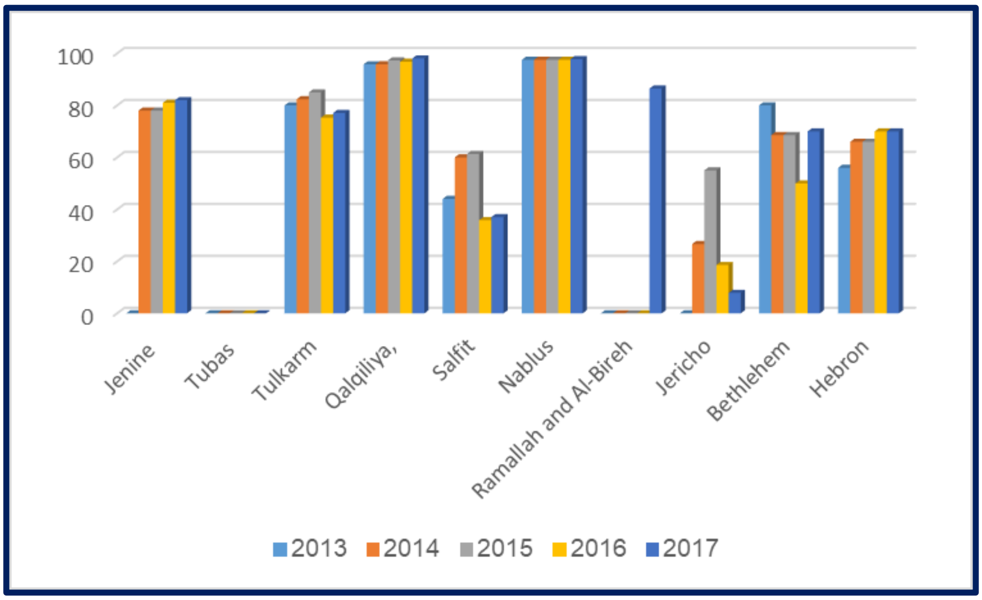

Figure 3.16: WWC (%) in the Palestinian Cities

State of Sewers and the Level of Treatment (SoS & TL)

This indicator is not included in the Palestinian monitoring system. Data was collected through field works as well as reviewing PWA, WSRC and some municipalities' reports.

Data concerned two indicators: State of sewers and level of the waste water treatment plants (Table 3.25).

Table 3.25: Data Concerning the State of Sewers & the Treatment Level

City	State of Sewer	Treatment Level
Jenin	Bad	Primary, secondary and tertiary
Tubas	Absence	Absence
Tulkarm	Very Bad	Absence
Qalqilya	Bad	Absence
Salfit	Acceptable	Absence
Nablus	Acceptable	Primary, secondary and tertiary
Ramallah and Al-Bireh	Acceptable	Primary, secondary and tertiary
Jericho	Very Good	Primary, secondary and tertiary
Bethlehem	Acceptable	Absence
Hebron	Acceptable	Absence

State of sewers in some cities is classified as good or very good due to the young age of the sanitary system and the good maintenance, in other cities, the state of sewers is classified as bad or very bad due to some factors such as; ageing, leakage, insufficient diameters, insufficient maintenance, and poor implementation of the sewer networks. While the sanitary system was absence in Tubas city.

Regarding the "treatment level", 6 cities do not have any system, while 4 cities (Jenin, Nablus, Ramallah and Al-Bireh, Jericho) have good treatment system. Raw sewage from the Palestinian communities, Israeli settlement and the industrial discharge deteriorate the quality of water resources (Jaradat, 2016 and ARIJ, 2015). According to the WSRC 43 % of the collected waste water arrive to treatment plants, 26% go to valleys and 31% cross the green line to be treated in Israeli waste water treatment plants (WSRC, 2019).

Water Coverage (WC)

This indicator is included in the Palestinian monitoring system. Data was collected from WSRC documents. (Table 3.26 and figure 3.17). We observe the absence of data for the majority of cities before 2017. Data collected in 2017 show generally a high water coverage (close to 100%), except in Jericho (WC = 89%) and Hebron (WC = 86%).

Table 3.26: Data Concerning the Water Coverage (%)

City	2013	2014	2015	2016	2017
Jenin	No Data	No Data	No Data	No Data	92
Tubas	No Data	100	100	100	100
Tulkarm	No Data	No Data	No Data	No Data	98
Qalqilya	No Data	No Data	No Data	No Data	100
Salfit	No Data	No Data	No Data	100	100
Nablus	No Data	No Data	No Data	No Data	100
Ramallah and Al-Bireh	No Data	No Data	No Data	No Data	100
Jericho	No Data	No Data	No Data	No Data	89
Bethlehem	No Data	No Data	No Data	No Data	100
Hebron	No Data	No Data	No Data	No Data	86

Water coverage indicator assess the quality of water services, it's provide a good idea about the service extent and the performance of the service provider in each city**.** The indicator water coverage was recently adopted in the Palestinian monitoring system, accordingly data available for the year 2017 as shown in table 3.26, water service available in all Palestinian cities with ratio between 80 -100 % which reflect that good quantity of water infrastructure projects were implemented in the last few years. Figure 3.17 presents the differences in the values of this indicators in the Palestinian cities.

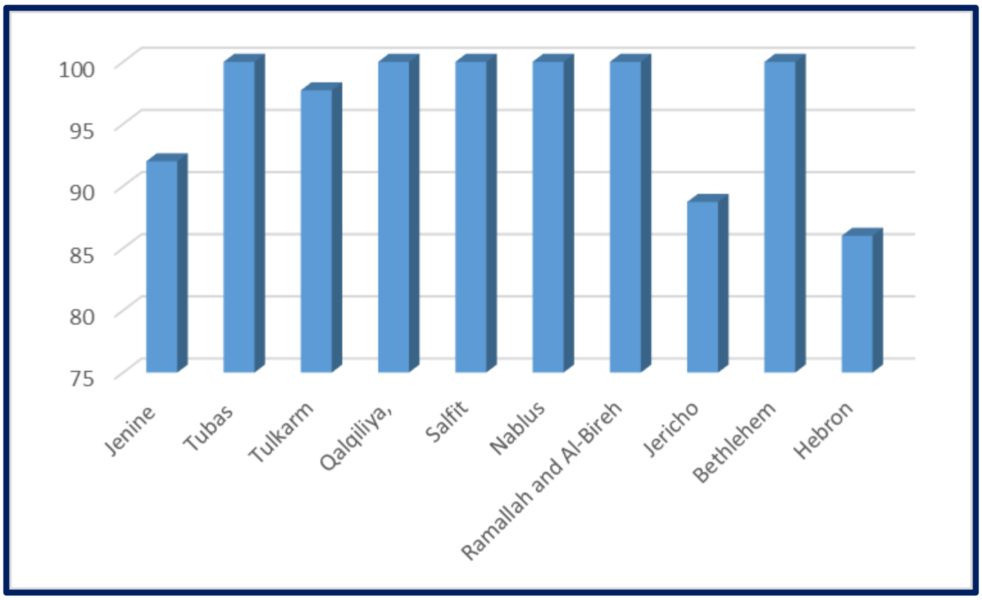

Figure 3.17: WC (%) in the Palestinian Cities for the Year 2017

Water Losses (WL)

This indicator is not included in the Palestinian monitoring system. Table 3.27 and figure 3.18 show the collected data. Data were missing in 2013 and 2014. In the period 2015 – 2017, some cities reduced the water losses (Jenin, Nablus, Ramallah, and Bethlehem), while in Tulkarm and Qalqilya the water losses increased; in the other cities we do not observe important change. Water losses in some cities such as Jenin and Tulkarm are very high (44% and 40%), while in other cities such as Salfit and Jericho WL is acceptable (around 14%).

Table 3.27: Data Concerning the Water Losses (%)

City	2013	2014	2015	2016	2017
Jenin	No Data	No Data	49	49	44
Tubas	No Data	No Data	25.5	29	28
Tulkarm	No Data	No Data	38	38.5	40
Qalqilya	No Data	No Data	24	25	26
Salfit	No Data	No Data	16	14	14
Nablus	No Data	No Data	34	34	30
Ramallah and Al-Bireh	No Data	No Data	28	25	23
Jericho	No Data	No Data	27	19	13
Bethlehem	No Data	No Data	34	37	29
Hebron	No Data	No Data	30	30	30

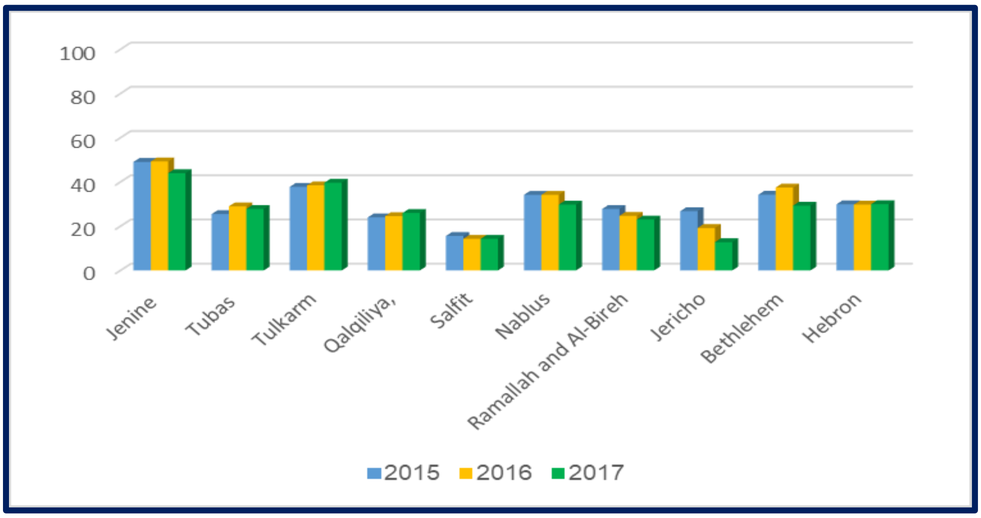

Figure 3.18: Water Losses (%) in the Palestinian Cities between Years 2015 - 2017

Continuity of Water Supply (CWS)

This indicator is not included in the Palestinian monitoring system. Table 3.28 and figure 3.19 show the collected data. We observe the absence of data for the majority of cities before 2017. According to data in 2017, the continuity of supply is excellent in three cities (Tubas, Qalqilya and Tulkarm), while it is very bad in Hebron (3%) and Jenin (17%) and bad in Nablus (31%), Bethlehem (46%) and Ramallah (54%).

Table 3.28: Data Concerning Continuity of Supply (%)

City	2013	2014	2015	2016	2017
Jenin	No Data	No Data	No Data	No Data	17
Tubas	No Data	No Data	No Data	No Data	100
Tulkarm	No Data	No Data	No Data	No Data	100
Qalqilya	No Data	No Data	No Data	No Data	100
Salfit	No Data	No Data	No Data	No Data	71
Nablus	No Data	No Data	No Data	No Data	31
Ramallah and Al-Bireh	No Data	No Data	No Data	No Data	54
Jericho	No Data	No Data	No Data	No Data	63
Bethlehem	No Data	No Data	No Data	No Data	46
Hebron	No Data	No Data	No Data	No Data	3

According to (IWA, 2017) this indicator may be unclear in some cities, because interruption in the water service could be related a to water shortage. This was the case in Hebron.

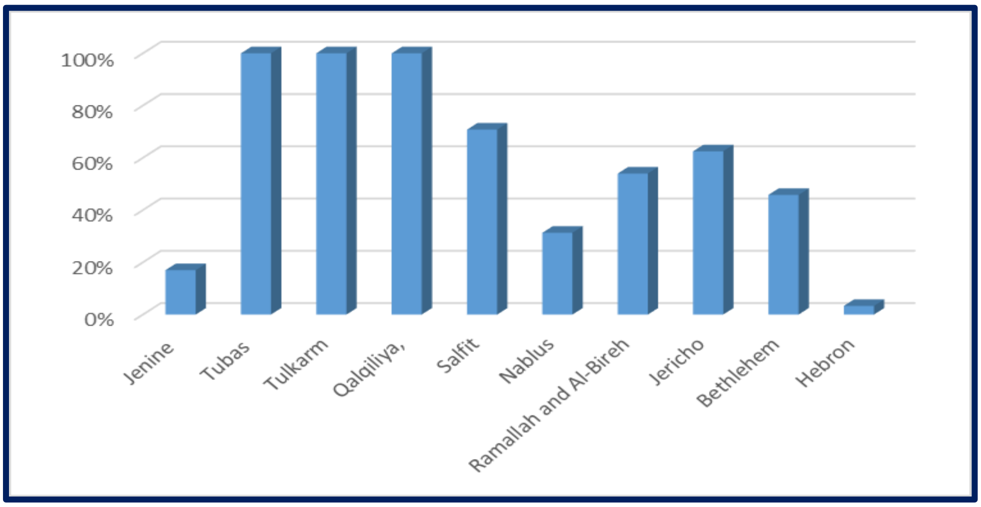

Figure 3.19: CWS (%) in the Palestinian Cities for the Year 2017

B- Water Governance Indicators

Data for this section was collected from previous reports, and interviews with water experts and policy makers. Table 3.29 summaries collected data. We note (i) the presence, but not yet the implementation of “Clear Roles and Responsibilities”, (ii), the on-going development of “Access to Data and Information”, (iii) the presence, but not yet the implementation of “Stakeholder Engagement”.

Table 3.29: Values of Water Governance Indicators in the Palestinian Water Sector

Indicator	Qualitative Value
Clear Roles and Responsibilities (CRR)	In place, not implemented
Access to Data and Information (ADI)	Framework under development
Stakeholder Engagement (SE)	In place, not implemented

Clear Roles and Responsibilities (CRR)

The Palestinian water sector suffers from lack of clear institutional mandates which was contributed to a situation of ineffective governance and weak capacity in the Palestinian water sector (ARIJ, 2015 and PWA, 2013). Up to now the Palestinian Water Authority (PWA) is the main regulator sector with responsibilities of planning, managing, regulating and evaluating of water and waste water sector, monitoring the water and waste water projects and coordinate the relations and cooperation with relevant agencies and donors (Murar et al., 2017). The role of all other bodies especially WSRC is weak.

Access to Data and Information (ADI)

Access to water data and information is still complex. Data is available but fragmented in many institutions and bodies. In some bodies data was described as black box, no body know what's include.

Stakeholder Engagement (SE)

According to the WSRC (2017) water sector in Palestine showed shortage in effective engagement of stakeholders in the water sector.

3.6 Conclusion

This chapter presented the first phase of the application of the water security risk assessment to the Palestinian territory. It focused on data collection about the water sector in Palestine including water resources, water services, water governance and water monitoring system. Then, it outlined water challenges such as occupation, demographic growth and urbanization, climate change, high Non-Revenue Water, water governance, lack of investment and water quality.

An important work was conducted to establish scores for severity and likelihood for water security indicators. Some of these scores were modified according to experts' opinion.

Data collection allowed us to gather 5-years data about the water security in ten major cities of the West Bank. Unfortunately, some indicators suffer from a high ratio of missing data. First analysis showed a critical situation for water resources availability, wastewater coverage in some cities, wastewater treatment, water losses, continuity of the water supply and the water governance. The following chapter will present analysis of these factors and their impact on the urban water security in Palestine.

Chapter Four: Results and Discussion

Chapter 4: Results and Discussion

4.1 Introduction

This chapter presents and discusses the results of the water security analysis in ten Palestinian cities. The presentation includes the followings:

- Determination of indicators' weights using the SWARA method.
- Risk assessment determination using (i) the score and level of risk for each indicator, based on the severity-likelihood relation, as well as the semi-quantitative risk matrix, (ii) the score and level of risk for each driver based on the indicators risk scores and weights, (iii) an overall risk score for each Palestinian city.
- Determination of the urban water security index using overall risk scores, together with the proposed translation system that was presented in chapter two.
- Evaluation of risk based on evidences as well as values, judgements regarding the degree of acceptability of each risk indicator, and targeting the risks through suggesting some urgent actions.
- Suggestion a new management system framework.

4.2 Determination of Weights of Risk Indicators

4.2.1 Overview

The Step-wise Weight Assessment Ratio Analysis (SWARA) is used to establish priorities and weights for the risk analysis from experts' opinion. The method is applied in two steps. The first step concerns the degree of importance of the criteria used in risk analysis, while the second includes determination of the weight of each criteria. The following sections present the application of these steps.

4.2.2 Prioritization of Criteria

Figure 4.1 shows the structure of the urban water security risk questionnaire presented to experts. It includes three risk drivers:

- (C1) "water resources"
- (C2) "water services"
- (C3) "water governance"

C1 includes the following sub-criteria:

- (C1.1) for water resources availability (WRA)
- (C1.2) for annual precipitation (AP)
- (C1.3) for the ratio of treated waste water (RTWW), which has three indicators:
    - (C1.3.1) for waste water coverage (WWC)
    - (C1.3.2) for state of sewers (SoS),
    - (C1.3.3) for treatment level (TL).

C2 includes the following sub-criteria:

- (C2.1) for water coverage (WC)
- (C2.2) for water losses (WL)
- (C2.3) for continuity of water supply (CWS)

C3 includes the following sub-criteria

- (C3.1) for clear roles and responsibilities (CRR)
- (C3.2) for access to data and information (ADI)
- (C3.3) for stakeholder engagement (SE).

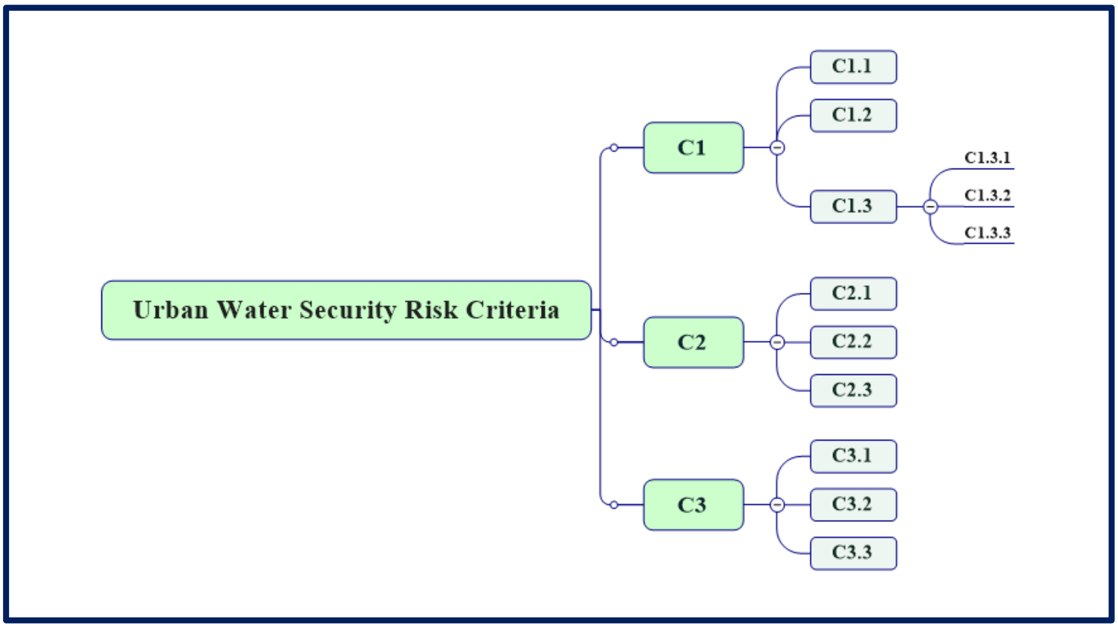

Figure 4.1: Urban Water Security Risk Criteria

Twenty five water experts participated in the ranking process. Experts gave the priority of the proposed criteria according to a score between 1 and 4. Score (1) means the criterion is not important, score (2) means the criterion has low importance, score (3) means medium importance, and score (4) means high importance. Tables 4.1 to 4.5 provide the experts’ responses.

Table 4.1: Experts Opinion for the Degree of Importance of Water Security Risk Drivers

Expert	C1	C2	C3
1	3	2	4
2	4	3	2
3	4	4	4
4	4	3	3
5	4	3	3
6	4	3	3
7	4	2	4
8	4	4	4
9	4	3	3
10	4	3	4
11	4	4	3
12	4	3	4
13	4	3	4
14	4	2	2
15	3	3	3
16	4	4	3
17	4	4	4
18	3	3	3
19	4	4	4
20	4	3	3
21	4	4	4
22	4	3	3
23	4	2	3
24	4	4	3
25	4	4	4
$\sum$	97	80	84

Table 4.2: Experts Opinion for the Water Resources Indicators

Expert	C1.1	C1.2	C1.3
1	3	2	2
2	4	3	2
3	4	4	4
4	4	3	3
5	3	2	4
6	4	4	2
7	4	3	4
8	4	4	2
9	4	3	3
10	4	4	4
11	3	3	3
12	4	3	3
13	4	2	3
14	4	3	4
15	4	3	2
16	4	4	4
17	4	4	3
18	4	2	2
19	4	3	3
20	4	3	3
21	4	3	3
22	4	3	3
23	4	3	2
24	4	4	3
25	4	3	3
$\sum$	97	78	74

Table 4.3: Experts Opinion for the Water Services Indicators

Expert	C2.1	C2.2	C2.3
1	3	3	4
2	2	4	4
3	3	4	4
4	3	3	4
5	3	4	4
6	3	4	2
7	3	3	3
8	4	4	4
9	3	3	3
10	4	4	4
11	2	3	2
12	3	4	4
13	3	4	4
14	3	2	4
15	3	3	4
16	2	2	3
17	4	4	4
18	3	3	3
19	4	4	4
20	3	3	3
21	3	4	3
22	3	4	4
23	3	4	3
24	4	4	3
25	4	4	3
$\sum$	78	88	87

Table 4.4: Experts Opinion for the Water Governance Indicators

Expert	C3.1	C3.2	C3.3
1	4	3	4
2	3	4	2
3	4	2	3
4	3	3	3
5	3	4	4
6	4	3	3
7	4	4	4
8	4	4	3
9	3	2	2
10	4	4	3
11	3	2	2
12	4	4	4
13	4	3	3
14	2	2	2
15	3	2	4
16	4	3	3
17	4	4	4
18	4	3	3
19	3	3	3
20	3	2	3
21	4	4	4
22	3	3	4
23	4	3	3
24	4	3	3
25	3	4	3
$\sum$	88	78	79

Table 4.5: Experts Opinion for the RTWW Sub- indicators

Expert	C1.3.1	C1.3.2	C1.3.3
1	2	2	2
2	3	2	2
3	4	4	4
4	3	3	2
5	4	4	3
6	2	2	2
7	4	3	4
8	1	1	3
9	3	2	3
10	4	4	3
11	3	3	3
12	4	3	3
13	3	2	3
14	4	4	4
15	2	2	2
16	4	4	4
17	3	3	3
18	2	2	2
19	3	3	3
20	3	2	3
21	4	3	4
22	4	4	3
23	2	2	2
24	3	3	4
25	4	3	4
$\sum$	78	70	75

Based on the experts' opinion, criteria were ranked as shown in Table 4.6. Ranking is based on the number of points given by the experts.

Table 4.6: Criteria Ranking According to Experts Opinions

Priority	Urban Water Security Risk Drivers	Water Resources Indicators	Water Services Indicators	Water Governance Indicators	RTWW Sub-indicators
1	C1	C1.1	C2.2	C3.1	C1.3.1
2	C3	C1.2	C2.3	C3.3	C1.3.3
3	C2	C1.3	C2.1	C3.2	C1.3.2

4.2.3 Criteria Weights Determination

The SWARA algorithm presented in chapter 2 (equations 2.1 to 2.4) is used for the determination of the criteria weights. Tables 4.7 to 4.11 show the obtained results. The parameter sj expresses the relative important between the criterion (n) and the criterion (n-1). Accordingly, the first criterion has no value for sj. According to SWARA calculations, table 4.12 and figure 4.2 show the weights of each water risk criteria.

Table 4.7 SWARA Calculations for Urban Water Security Risk Drivers

Criterion	Comparative Importance of Average Value	Coefficient	Recalculated Weight	Weight
	$sj = \sum_{i}^{n} \frac{Ai}{n}$	$kj = sj + 1$	$qj = \frac{xj-1}{kj}$	$wj = \frac{qj}{\sum_{k=1}^{n} qk}$
C1	--	1	1	0.39
C3	0.2	1.2	0.83	0.33
C2	0.16	1.16	0.72	0.28
			2.55	1

Table 4.8: SWARA Calculations for Water Resources Indicators

Criterion	Comparative Importance of Average Value	Coefficient	Recalculated Weight	Weight
	$sj = \sum_{i}^{n} \frac{Ai}{n}$	$kj = sj + 1$	$qj = \frac{xj-1}{kj}$	$wj = \frac{qj}{\sum_{k=1}^{n} qk}$
C1.1	--	1	1	0.405
C1.2	0.25	1.25	0.8	0.324
C1.3	0.19	1.19	0.67	0.271
			2.47	1

Table 4.9: SWARA Calculations for Water Services Indicators

Criterion	Comparative Importance of Average Value	Coefficient	Recalculated Weight	Weight
	$sj = \sum_{i}^{n} \frac{Ai}{n}$	$kj = sj + 1$	$qj = \frac{xj-1}{kj}$	$wj = \frac{qj}{\sum_{k=1}^{n} qk}$
C2.2	--	1	1	0.385
C2.3	0.15	1.15	0.87	0.334
C2.1	0.2	1.2	0.73	0.281
			2.6	1

Table 4.10: SWARA Calculations for Water Governance Indicators

Criterion	Comparative Importance of Average Value	Coefficient	Recalculated Weight	Weight
	$sj = \sum_{i}^{n} \frac{Ai}{n}$	$kj = sj + 1$	$qj = \frac{xj-1}{kj}$	$wj = \frac{qj}{\sum_{k=1}^{n} qk}$
C3.1	--	1	1	0.39
C3.3	0.2	1.2	0.833	0.33
C3.2	0.15	1.15	0.724	0.28
			2.557	1

Table 4.11: SWARA Calculations for RTWW Sub- indicators

Criterion	Comparative Importance of Average Value	Coefficient	Recalculated Weight	Weight
	$sj = \sum_{i}^{n} \frac{Ai}{n}$	$kj = sj + 1$	$qj = \frac{xj-1}{kj}$	$wj = \frac{qj}{\sum_{k=1}^{n} qk}$
C1.3.1	--	1	1	0.38
C1.3.3	0.12	1.12	0.89	0.33
C1.3.2	0.17	1.17	0.76	0.29
			2.65	1

Table 4.12: SWARA Results for the Weights of Urban Water Security Criteria

Criterion Name	Code	Weight
Water Resources	W.R	0.39
Water services	W.S	0.28
Water Governance	W.G	0.33
Water Resources Availability	WRA	0.405
Annual Participation	AP	0.324
Ratio of Treated Waste Water	RTWW	0.271
Waste Water Coverage	WWC	0.38
State of Sewer	SoS	0.29
Treatment Level	TL	0.33
Water Coverage	WC	0.281
Water loss	WL	0.385
Continuity of Water Supply	CWS	0.334
Clear Roles and Responsibilities	CRR	0.39
Access to Data and Information	ADI	0.28
Stakeholders Engagement	SE	0.33

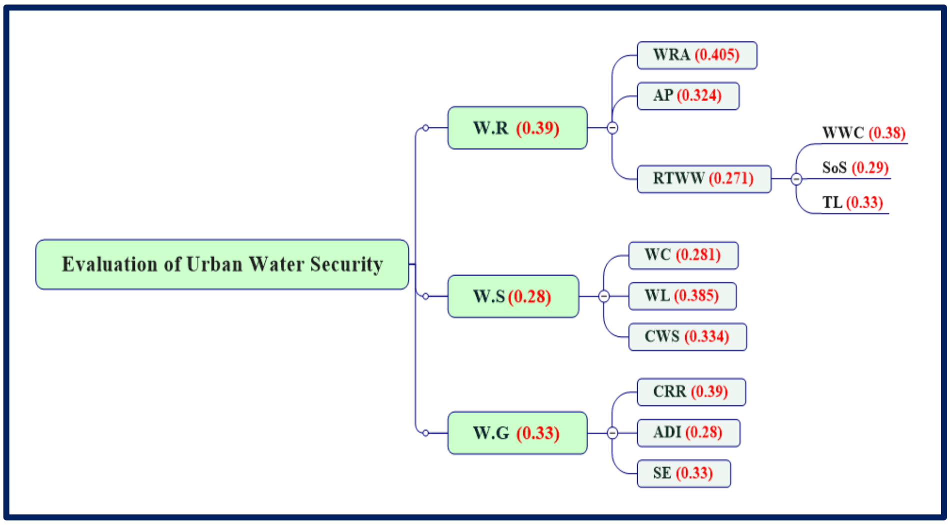

Figure 4.2: Weights of Urban Water Security Criteria

4.3 Risk-based Approach to Urban Water Security

As this research is based on risk-based approach, the determination of urban water security risk is conducted in three steps as shown in Figure 4.3: Risk assessment, Risk evaluation and Risk management. The following sections present these steps.

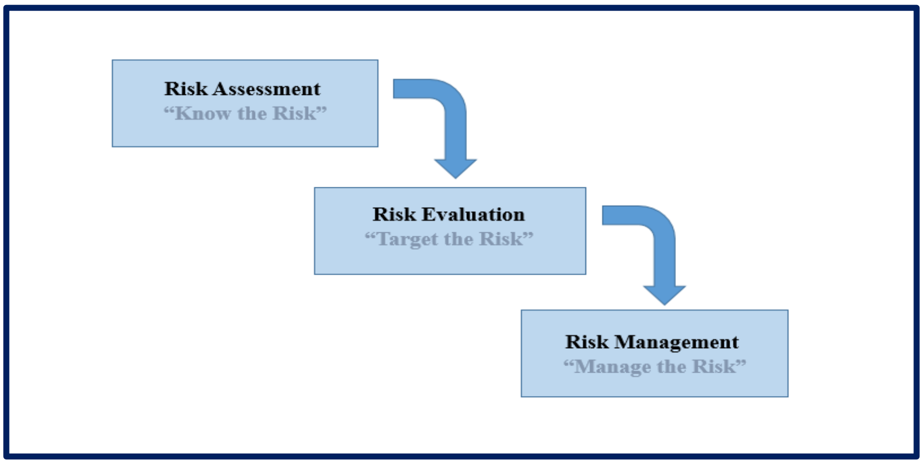

Figure 4.3: Risk-based Approach Steps

4.4 Risk Assessment

4.4.1 Overview

This section includes 3 steps:

- Determination of scores and levels of risk for urban water security indicators.
- Determination of scores and levels of risk for urban water security drivers.
- Determination of overall risk score of urban water security.

Risk assessment determination is based on the severity and likelihood scores for each indicator. Weights presented in section 4.2 are used to calculate the scores of each risk driver and the overall risk score for each city.

4.4.2 Scores and Levels of Risks for Urban Water Security Indicators

The risk score determination requires the severity and likelihood scores as discussed in chapter three. Tables 4.13 and 4.14 show the values used for the severity and likelihood scores in this research as determined according to the literature review as well as the experts' opinions.

Table 4.13: Severity Scoring System Adopted in the Research

#	Indicator Name	Indicator Code	Proposed Severity Scoring System	
1	Water Resources Availability	WRA	1	50 < WRA ≤ 60 %
			2	60 < WRA ≤ 70%
			3	70 < WRA ≤ 80%
			4	80 < WRA ≤ 90%
			5	90 <WRA ≤ 100%
2	Annual Precipitation	AP	1	AP ≥ 800 mm/y
			2	600 ≤ AP < 800 mm/ y
			3	400 ≤ AP < 600 mm/ y
			4	200 ≤ AP < 400 mm/ y
			5	AP < 200 mm/ y
3	Ratio of Treated Waste Water	WWC	1	90 < WWC ≤ 100%
			2	80 < WWC ≤ 90 %
			3	70 < WWC ≤ 80 %
			4	60 < WWC≤ 70%
			5	WWC ≤ 60 %
		SoS	1	SoS = Very Good
			2	SoS = Good
			3	SoS = Acceptable
			4	SoS = Bad
			5	SoS = Very Bad
		TL	1	TL= Primary, secondary, tertiary and sludge recycle
			2	TL= Primary, secondary and tertiary
			3	TL= Primary and secondary
			4	TL= Only Primary
			5	TL= Not Existing
4	Water Coverage	WC	1	95 < WC ≤ 100%
			2	90 < WC ≤ 95 %
			3	85 < WC ≤ 90 %
			4	80 <WC ≤ 85%
			5	WC ≤ 80 %
5	Water Loss	WL	1	WL≤ 10%
			2	10 < WL ≤ 20
			3	20 < WL ≤ 30
			4	30 < WL ≤ 40
			5	WL > 40 %
6	Continuity of Water Supply	CWS	1	85 < CWS ≤ 100%
			2	70 < CWS ≤ 85 %
			3	55 < CWS ≤ 70 %
			4	40 < CWS ≤ 55%
			5	CWS ≤ 40 %
7	Clear Role and Responsibilities	CRR	1	In place, functioning and fully implemented.
8	Access to Data and Information	ADI	2	In place, partially implemented.
9	Stakeholder Engagement	SE	3	In place, not implemented.
			4	Framework under development
			5	Not in place.

Table 4.14: Likelihood Scoring System Adopted in the Research

Likelihood Score	proposed Range
1	If the indicator values in the study period are within the acceptable range every year
2	If the indicator values in the study period are within the acceptable range along the last four years
3	If the indicator values in the study period are within the acceptable range along the last three years
4	If the indicator values in the study period are within the acceptable range just in one to two years
5	If the indicator values in the study period are out of the acceptable range every year

Tables 4.15 - 4.23 present the results obtained for 10 cities in the West Bank of Palestine using data collected for 5 years. The severity score (S.S), likelihood score (L.S) and the risk score (R.S) were estimated using the semi-quantitative risk matrix presented in chapter two (figure 2.6). The severity score is estimated by reference to the year (2017), while the likelihood score (L.S) is estimated by reference to data available for the last five years.

4.4.2.1 Water Resources

i) Water Resources Availability (WRA)

The risk level of Water Resources Availability (WRA) for the different cities is given in table 4.15. It could be observed that this risk is at the highest level, which confirms the dramatic situation of water availability in Palestine.

Table 4.15: WRA Severity, Likelihood & Risk Scores

City	2013	2014	2015	2016	2017	S.S	L.S	R.S
Jenin	No Data	100	100	100	100	5	5	25
Tubas	No Data	No Data	99.8	99.8	99.8	5	5	25
Tulkarm	99.9	99.9	99.90	99.94	99.9	5	5	25
Qalqilya	99.9	99.9	99.9	99.9	99.9	5	5	25
Salfit	99.8	99.8	99.7	99.8	99.8	5	5	25
Nablus	99.9	99.9	99.9	99.9	99.9	5	5	25
Ramallah and Al-Bireh	No Data	No Data	100	100	100	5	5	25
Jericho	99.8	99.8	99.8	100	100	5	5	25
Bethlehem	100	100	100	100	100	5	5	25
Hebron	100	100	100	100	100	5	5	25

***ii) Annual Precipitation** (AP)*

Table 4.16 summarizes the risk score of the Annual Precipitation (AP). It could be observed that it varies between 15 and 25. This variation is due to the variation of the severity score between 3 in the majority of cities to 5 in Jericho, which means that the latter is exposed to an extreme risk level.

Table 4.16: AP Severity, Likelihood & Risk Scores

City	2013	2014	2015	2016	2017	S.S	L.S	R.S
Jenin	289	580	383	283	538	3	5	15
Tubas	239	532	254	294	345	4	5	20
Tulkarm	461	720	428	419	547	3	5	15
Qalqilya	426	624	645	501	477	3	5	15
Salfit	539	691	594	512	518	3	5	15
Nablus	539	691	594	512	518	3	5	15
Ramallah and Al-Bireh	454	675	533	403	482	3	5	15
Jericho	134	229	131	71.9	143	5	5	25
Bethlehem	376	656	519	313	408	3	5	15
Hebron	476	572	618	411	523	3	5	15

iii) Ratio of Treated Waste Water (RTWW)

The Ratio of Treated Waste Water (RTWW) has three sub-indicators; waste water coverage (WWC), state of sewer (SoS) and the treatment level (TL).

Waste Water Coverage

Table 4.17 shows the risk level of the Waste Water Coverage (WWC). It could be observed that the related risk score varies between very low (WWC = 1) in Nablus and Qalqilya to extreme (WWC = 25) in Tubas, Salfit and Jericho. Jenin, Tulkarm, Ramallah and Al-Bireh have a score equal to 10, 15, 10, respectively. This result confirms the absence of wastewater systems in some major cities.

Table 4.17: WWC Severity, Likelihood & Risk Scores

City	2013	2014	2015	2016	2017	S.S	L.S	R.S
Jenin	No Data	78	78	81	82	2	5	10
Tubas	--	--	--	--	--	5	5	25
Tulkarm	80	82	85	75	77	3	5	15
Qalqilya	96	96	97	97	98	1	1	1
Salfit	44	60	61	36	37	5	5	25
Nablus	98	98	98	98	98	1	1	1
Ramallah and Al-Bireh	No Data	No Data	No Data	N0 Data	86.5	2	5	10
Jericho	0.00	27	55	19	8	5	5	25
Bethlehem	80	69	69	50	70	4	5	20
Hebron	56	66	66	70	70	4	5	20

State of Sewers (SoS)

Table 4.18 shows the risk score for the State of Sewers (SoS). It could be observed that this score is very low in Jericho, but extreme in Tubas, Tulkarm, Jenin and Qalqilya. The risk score in Salfit, Nablus, Ramallah and Al-Bireh, Bethlehem and Hebron is equal to 15. The main factor affecting the risk indicator in these cities concerns the absence of regular and /or preventive maintenance. The low risk in Jericho is due to the installation of a new wastewater collection system, which still have a low city coverage.

Table 4.18: SoS Severity, Likelihood & Risk Scores

City	5 Years	S.S	L.S	R.S
Jenin	Bad	4	5	20
Tubas	Absence	5	5	25
Tulkarm	Very Bad	5	5	25
Qalqilya	Bad	4	5	20
Salfit	Acceptable	3	5	15
Nablus	Acceptable	3	5	15
Ramallah and Al-Bireh	Acceptable	3	5	15
Jericho	Very Good	1	1	1
Bethlehem	Acceptable	3	5	15
Hebron	Acceptable	3	5	15

Treatment Level (TL)

Table 4.19 shows the risk score of the Treatment Level (TL). It varies between 10 and 25 (medium level to extreme). Indeed, some cities such as Tubas, Tulkarm, Qalqilya, Salfit, Bethlehem and Hebron do not have treatment plant. Other cities have already treatment plant, but without sludge recycling and reuse of treated waste water, that's why the score risk is medium in these cities.

Table 4.19: TL Severity, Likelihood & Risk Scores

City	5 Years	S.S	L.S	R.S
Jenin	Primary, secondary and tertiary	2	5	10
Tubas	Absence	5	5	25
Tulkarm	Absence	5	5	25
Qalqilya	Absence	5	5	25
Salfit	Absence	5	5	25
Nablus	Primary, secondary and tertiary	2	5	10
Ramallah and Al-Bireh	Primary, secondary and tertiary	2	5	10
Jericho	Primary, secondary and tertiary	2	5	10
Bethlehem	Absence	5	5	25
Hebron	Absence	5	5	25

Table 4.20 shows the risk score of RTWW, while figure 4.4 shows a comparison between the three sub-indicators of RTWW. The situation in Tubas is the worst, with a risk score of 25, because of the absence of wastewater collection system. The risk in Tulkarm, Salfit, Bethlehem and Hebron is extreme; these cities urgently need waste water treatment plants. The risk score is between 10 and 14 in Jenin, Qalqilya, Ramallah, Al-Bireh and Jericho. Jenin should improve the state of sewer, while Qalqilya should create a waste water treatment plant, Ramallah and Al-Bireh should improve the maintenance and develop treatment plants, while Jericho should increase the coverage of the waste water collection system.

The risk score in Nablus city is equal to 8, which reflects medium level of risk. Nablus could reach low level of risk with a regular maintenance and the installation of sludge recycling and wastewater reuse.

Table 4.20: RTWW Risk Scores

indicator	WWC	SoS	TL	RTWW
weight	0.38	0.29	0.33	
Jenin	10	20	10	13
Tubas	25	25	25	25
Tulkarm	15	25	25	21
Qalqilya	1	20	25	14
Salfit	25	15	25	21
Nablus	1	15	10	8
Ramallah and Al-Bireh	10	15	10	11
Jericho	25	1	10	13
Bethlehem	20	15	25	20
Hebron	20	15	25	20

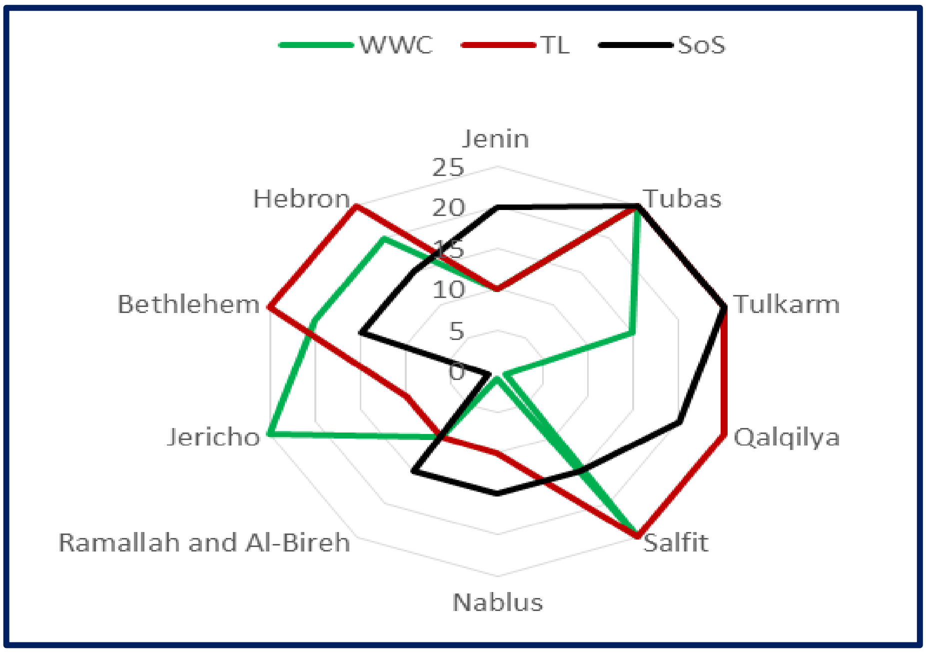

Figure 4.4: RTWW Sub-indicators in the Palestinian Cities

vi) Explanation

Figure 4.5 summarizes the risk level for the water resources for the ten cities. It confirms the critical situation for the water resources availability for the ten cities, the critical situation for the annual precipitation for Jericho and Nablus, while the critical situation for the treated wastewater for Nablus, Tulkarm, Salfit, Bethlehem, and Hebron.

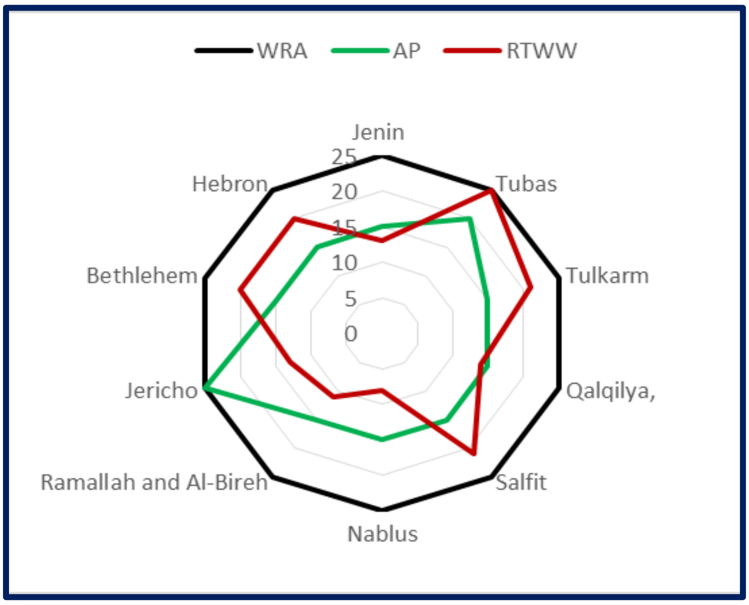

Figure 4.5: Water Resources Risk Indicators

4.4.2.2 Water Services

Water services includes the three criteria:

- Water coverage (WC)
- Water losses (WL)
- Continuity of Water supply (CWS)

i) Water Coverage (WC)

Table 4.21 shows the risk score of the Water Coverage (WC). The score was calculated according to data of 2017, except for Tubas, where data were available between 2014 and 2017. The situation in the majority of cities is very good with a score risk equals 1. The risk score in Jenin, Jericho and Hebron is high with a scores of 10 for Jenin and 15 for Jericho and Hebron.

Table 4.21: WC Severity, Likelihood & Risk Scores

City	2013	2014	2015	2016	2017	S.S	L.S	R.S
Jenin	No Data	No Data	No Data	No Data	92	2	5	10
Tubas	No Data	100	100	100	100	1	1	1
Tulkarm	No Data	No Data	No Data	No Data	98	1	1	1
Qalqilya	No Data	No Data	No Data	No Data	100	1	1	1
Salfit	No Data	No Data	No Data	100	100	1	1	1
Nablus	No Data	No Data	No Data	No Data	100	1	1	1
Ramallah and Al-Bireh	No Data	No Data	No Data	No Data	100	1	1	1
Jericho	No Data	No Data	No Data	No Data	89	3	5	15
Bethlehem	No Data	No Data	No Data	No Data	100	1	1	1
Hebron	No Data	No Data	No Data	No Data	86	3	5	15

ii) Water Losses (WL)

The risk scores for the indicator water losses are reported in table 4.22. The risk score in Jenin is extreme (25), because of the very high water losses (> 40%). In 2016 the ratio of water losses was 49% which means that around half quantity of the water inters to the system was lost. Tulkarm also has the same situation with a risk score of 20; the ratio of water losses increased during the last three recorded years. The risk score in Qalqilya is high, with an increase in water losses. The risk score in Nablus, Ramallah and Al-Bireh and Bethlehem is equal 15, but with a decrease in the ratio of water losses. The score in Tubas is equal to 15, but with an increase in water losses. In Salfit and Jericho the risk score is equal to 10. The water losses in Jericho decreased from 27% in 2015 to 13% in 2017, (52% reduction), while in Salfit it decreased from 16% in 2015 to 14 % in 2016 (8% reduction).

Table 4.22: WL Severity, Likelihood & Risk Scores

City	2013	2014	2015	2016	2017	S.S	L.S	R.S
Jenin	No Data	No Data	49	49	44	5	5	25
Tubas	No Data	No Data	25.5	29	28	3	5	15
Tulkarm	No Data	No Data	38	38.5	40	4	5	20
Qalqilya	No Data	No Data	24	25	26	3	5	15
Salfit	No Data	No Data	16	14	14	2	5	10
Nablus	No Data	No Data	34	34	30	3	5	15
Ramallah and Al-Bireh	No Data	No Data	28	25	23	3	5	15
Jericho	No Data	No Data	27	19	13	2	5	10
Bethlehem	No Data	No Data	34	37	29	3	5	15
Hebron	No Data	No Data	30	30	30	3	5	15

iii) Continuity of Water Supply (CWS)

Table 4.23 provides the risk score for the continuity of water supply (CWS) for the ten cities as calculated from data in 2017. It shows a great variation in this score. The risk is very low in Tubas, Tulkarm, Qalqilya, while it is extreme in Jenin, Nablus and Hebron. The latter has the worst situation. It is also extreme in Ramallah and Al-Bireh, and Bethlehem.

Table 4.23: CWS Severity, Likelihood & Risk Scores

City	2013	2014	2015	2016	2017	S.S	L.S	R.S
Jenin	No Data	No Data	No Data	No Data	17	5	5	25
Tubas	No Data	No Data	No Data	No Data	100	1	1	1
Tulkarm	No Data	No Data	No Data	No Data	100	1	1	1
Qalqilya	No Data	No Data	No Data	No Data	100	1	1	1
Salfit	No Data	No Data	No Data	No Data	71	2	5	10
Nablus	No Data	No Data	No Data	No Data	31	5	5	25
Ramallah and Al-Bireh	No Data	No Data	No Data	No Data	54	4	5	20
Jericho	No Data	No Data	No Data	No Data	62.50	3	5	15
Bethlehem	No Data	No Data	No Data	No Data	46	4	5	20
Hebron	No Data	No Data	No Data	No Data	3	5	5	25

vi) Explanation

Figure 4.6 summarizes the risk level for the water services for the ten cities. It confirms the critical situation for the water losses for Tulkarm and Jenin as well as the critical situation fir the continuity of water supply for Jenin, Nablus, Ramallah, Bethlehem, and Hebron.

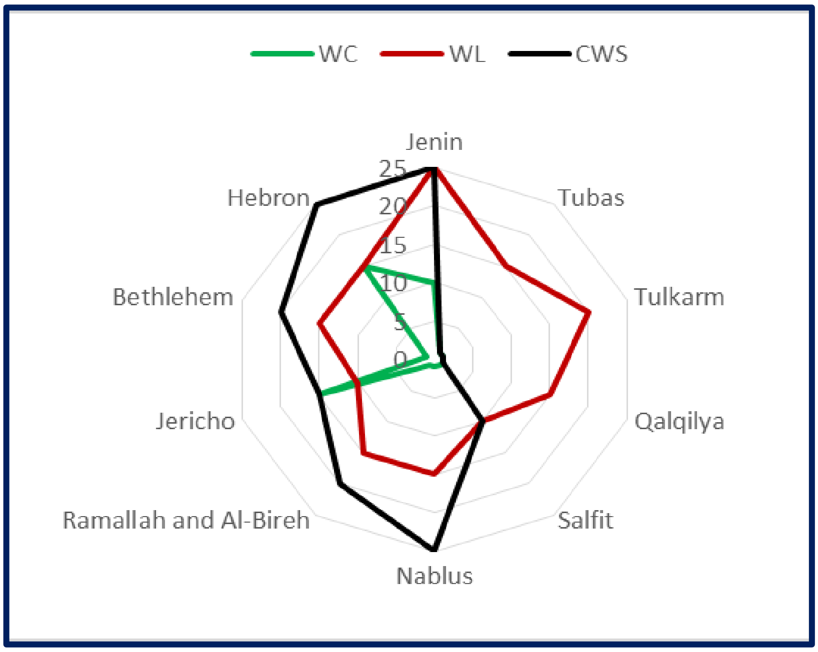

Figure 4.6: Water Services Risk Indicators

4.4.2.3 Water Governance

Table 4.24 shows the risk score for the water governance. The risk is high for Clear Role and Responsibilities (CRR) and Stakeholder Engagement (SE), but extreme for Access to Data and Information (ADI).

Table 4.24: Severity, Likelihood & Risk Scores for Water Governance Indicators

Indicator	Qualitative Value	S.S	L.S	R.S
CRR	In place, not implemented	3	5	15
ADI	Framework under development	4	5	20
SE	In place, not implemented	3	5	15

4.4.3 Analysis of Risks for Urban Water Security Drivers

This section presents risk score and level for the ten cities concerning the drivers (i) "Water Resources" and (ii) "Water Services". The risk driver for "Water Governance" is the same for all cities. Calculation is carried out according to risk scores calculated in the previous section (summarized in table 4.25) as well according to the weights of the indicators calculated in section 4.2.

Table 4.25: Values of Risks of Urban Water Security Indicators in the 10 Cities

Risks	WRA	AP	WWC	SoS	TL	RTWW	WC	WL	CWS
Jenin	25	15	10	20	10	13	10	25	25
Tubas	25	20	25	25	25	25	1	15	1
Tulkarm	25	15	15	25	25	21	1	20	1
Qalqilya	25	15	1	20	25	14	1	15	1
Salfit	25	15	25	15	25	21	1	10	10
Nablus	25	15	1	15	10	8	1	15	25
Ramallah and Al-Bireh	25	15	10	15	10	11	1	15	20
Jericho	25	25	25	1	10	13	15	10	15
Bethlehem	25	15	20	15	25	20	1	15	20
Hebron	25	15	20	15	25	20	15	15	25

The calculation of the risk level is illustrated through the example of city Jenin. Table 4.26 provides the details of the calculation. The risk score for the Water Resources is equal to 18.5. This high value is mainly due to the high score of WRA. The risk core for Water Services is equal to 20.8, this high value is due to the high risk score of WL and CWS.

The same methodology was applied for other cities. Results are summarized in table 4.27 and figure 4.7. It could be observed that the risk level for water resources is high to extreme for all cities, while the risk level for water services is extreme for Jenin and Hebron.

Table 4.26: Scores of Risk Drivers in Jenin City

Risk Driver	Water Resources			Water Services		
Risk Indicator	WRA	AP	RTWW	WC	WL	CWS
Indicator Weight	0.405	0.324	0.271	0.281	0.385	0.334
Indicator Initial Score	25	15	13	10	25	25
Indicator Final Score	10.13	4.86	3.52	2.81	9.63	8.35
Risk Driver Score	18.5			20.8		

Table 4.27: Scores of Risk Drivers for the Ten Cities

City	Water Resources (WR)	Water Services (WS)
Jenin	18.5	20.8
Tubas	23.4	6.4
Tulkarm	20.7	8.3
Qalqilya	18.8	6.4
Salfit	20.7	7.5
Nablus	17.2	14.4
Ramallah and Al-Bireh	18.0	12.7
Jericho	21.8	13.1
Bethlehem	20.4	12.7
Hebron	20.4	18.3

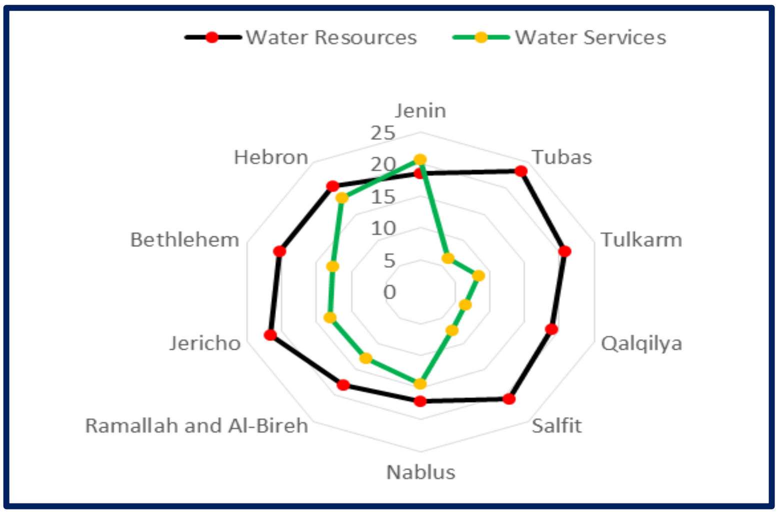

Figure 4.7: Comparison between Risk Drivers in all Palestinian cities

Table 4.28 provides the calculation of the risk driver score of the water governance. It shows that the situation of the water governance is critical with a risk score of 16.4.

Table 4.28: Water Governance Score

Risk Driver	Water Governance		
Risk Indicator	CRR	ADI	SE
Indicator Weight	0.39	0.28	0.33
Indicator Initial Score	15	20	15
Indicator Final Score	5.85	5.6	4.95
Risk Driver Score	16.4		

4.4.3 Overall Risk Score of Urban Water Security

An over scale risk score is determined from the risk drivers scores “water resources”, “water services” and “water governance”, which were determined in the previous section. Table 4.29 provides the details of the calculation of this score for the ten cities. Results show a very high overall risk score which varies from 14.5 for Qalqilya to 18.5 for Jenin and Hebron (Figure 4.8). This critical situation is due to the very bad situation for the water resources and water governance.

Table 4.29: Overall Score of Water Risk in the Palestinian Cities

Risk Driver	W.R	W.S	W.G	Overall Score
Driver Weigh	0.39	0.28	0.33	
Jenin	18.5	20.8	16.4	18.5
Tubas	23.4	6.4	16.4	16
Tulkarm	20.7	8.3	16.4	15.8
Qalqilya	18.8	6.4	16.4	14.5
Salfit	20.7	7.5	16.4	15.6
Nablus	17.2	14.4	16.4	16
Ramallah and Al-Bireh	18	12.7	16.4	16
Jericho	21.8	13.1	16.4	17.6
Bethlehem	20.4	12.7	16.4	17
Hebron	20.4	18.3	16.4	18.5

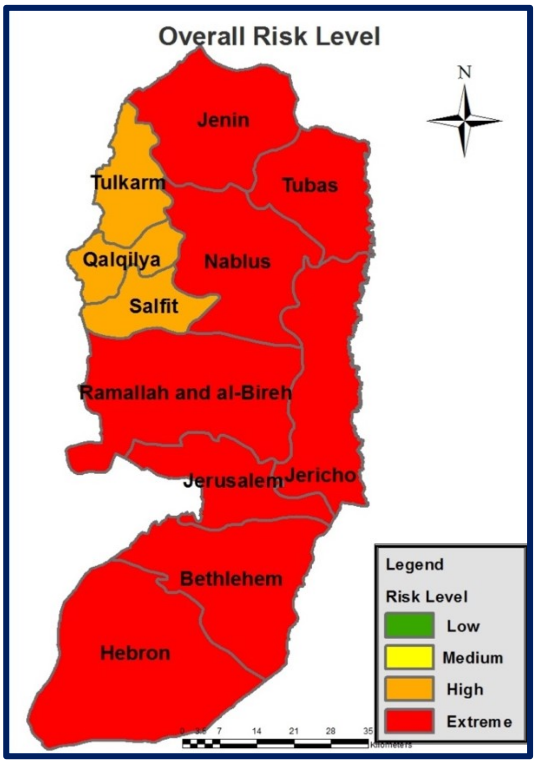

Figure 4.8: Overall Risk level in the Palestinian Cities

4.5 Urban Water Security Index

This section presents the determination of the urban water security index, which was presented in chapter 2. The methodology is based on the use of table 2.3 to convert the overall score of risk to a score of urban water security, called the "urban water security index". Table 4.30 and 4.31 summarize the obtained results. They show that the situation of urban water security in the Palestinian cities is very worrying. Most cities suffer from an alarming level of urban water security, with a water index between 1 and 2. Comprehensive strategies with urgent actions are required to cope with this critical situation.

Table 4.30: Urban Water Security index in the Palestinian Cities

City	Overall Score of Risk	Urban Water Security Index
Jenin	18.5	1
Tubas	16	1
Tulkarm	15.8	2
Qalqilya	14.5	2
Salfit	15.6	2
Nablus	16	1
Ramallah and Al-Bireh	16	1
Jericho	17.6	1
Bethlehem	16.73	1
Hebron	18.27	1

Table 4.31: Linguistic Evaluation of Urban Water Security in the Palestinian Cities

	Risk Level	Urban Water Security Level
Jenin	Extreme	Alarming
Tubas	Extreme	Alarming
Tulkarm	High	Poor
Qalqilya	High	Poor
Salfit	High	Poor
Nablus	Extreme	Alarming
Ramallah and Al-Bireh	Extreme	Alarming
Jericho	Extreme	Alarming
Bethlehem	Extreme	Alarming
Hebron	Extreme	Alarming

4.6 Risk Evaluation

4.6.1 Overview

Risk evaluation is an important step. It aims at the evaluation of the degree of acceptability of the water risks: acceptability, tolerability and intolerability. According to (OECD, 2013), the urban water security could be achieved if an acceptable level of risks maintained at current and future time. In this context the term acceptable level of risk should be identified as well as the way and mechanisms for maintaining the degree of acceptability of the risk. This issue was discussed by many schools (WHO & IWA, 2001). However, the risk-based approach adopted this issue as the following: the risk is acceptable if the likelihood and the severity of impact of the risk are low (Figure 4.9). In this case there is no need for reducing the level of risk. On contrary, the water risk will be intolerable if it has a very high likelihood and/or a very high severity of negative impact. In this case, urgent actions are required to reduce it to an acceptable level. What's important that measures and actions should be cost effective (OECD, 2013).

The risk evaluation was conducted in two steps: risk characterization using evidences, and risk evaluation using values.

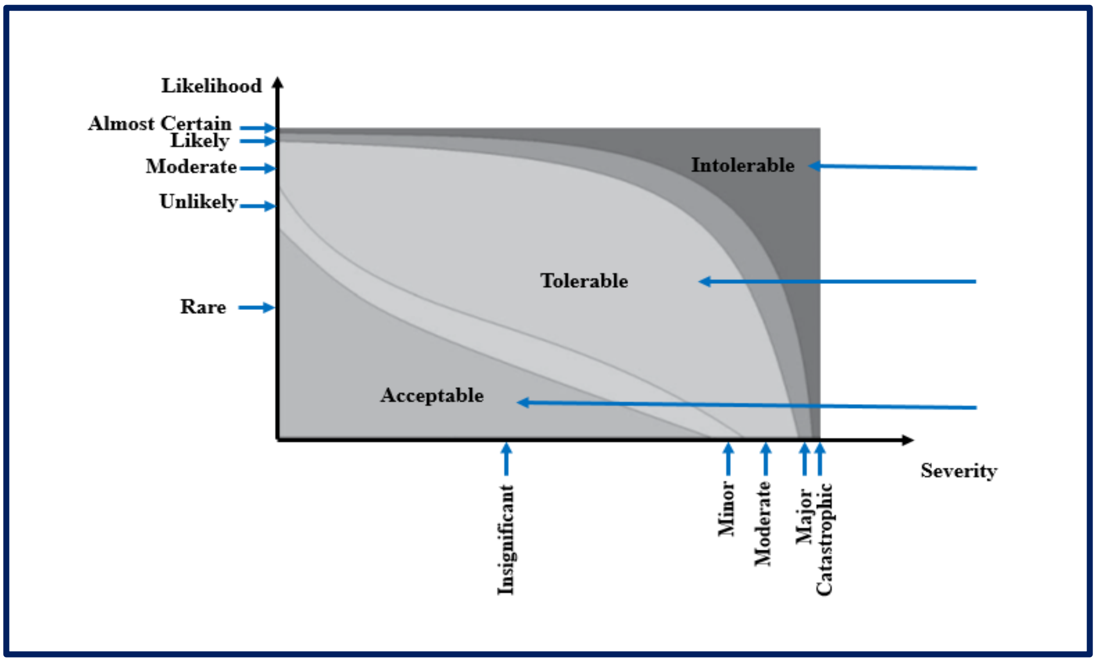

Figure 4.9: Acceptable, Tolerable and Intolerable Risks (Klinke and Renn, 2012)

4.6.2 Risk Characterization - Evidence Based

Water resources:

Water resources is linked to six indicators; water resources availability (WRA), annual precipitation (AP), wastewater coverage (WWC), state of sewer (SoS), treatment level (TL) and ratio of treated wastewater (RTWW).

Regarding the water availability, Palestinian territory suffers from great shortage in water resources. Large differences exist between supply and demand, at the same time water purchase was not possible except from Israeli water company. Moreover, it is not possible to access to unconventional water resources due to the occupation restrictions. Although water resources quantity varies from one city to other, the values of the indicator water resources availability (WRA) in all cities is almost equal to 100 %. This means that all water quantities entering the system from all resources owned or/and imported were used. There was no marginal quantities for any emergency. Which exposes cites to high state of insecurity.

Concerning the annual precipitation, rainwater in the Palestinian territory is the main and sole source of ground water recharge, it has a direct impact on the Palestinian water resources. If the situation is not yet critical, it could be negatively affected by the climate change.

Concerning the wastewater collection systems, the situation is critical in some cities, which do not yet have an adequate system. Under those circumstances, the quality of ground water is threaten and deteriorated and this was clear from the increasing concentration of some compounds like chloride and nitrate.

The state of sewers in some cities is good or very good due to the young age of the sanitary system and the effective maintenance regime that was adopted by municipalities, while in other cities the state of sewers is bad to very bad due to sewer ageing, leakage, insufficient diameters, insufficient maintenance, and poor implementation of the sewer networks.

Concerning the water treatment level, raw sewages are discharged in valleys without treatment. Raw sewage from the Palestinian communities, Israeli settlement and the industrial discharge deteriorate the quality of water resources. According to the WSRC, 43 % of the collected wastewater arrive to treatment plants, 26% disposed as raw sewage to valleys and 31% cross the green line to Israeli wastewater treatment plants. Regarding the quantities of waste water collected by tankers from cesspits and latrines, 76% are disposed to valleys, 17 disposed to wastewater treatment plants and the remaining quantities disposed to Palestinian sewer network connections. WSRC estimated the quantity of wastewater collected through sewer networks to about 29 MCM in 2017, and the quantity of wastewater treated in Palestinian treatment plants to 10 MCM. The Number of treatment plants in the Palestinian territories was equal 20, with low, medium and high capacities, and various technologies such as; activated sludge, constructed wetlands, sedimentation tanks, trickling filters, hydride system, aerobic and anaerobic stabilization bonds, membrane bioreactor, and rotating biological contractor. While 3 treatment plants were closed, however many others have many problems and challenges like; inability to handle the maintenance cost, shortage in qualified technical staff and lack of good equipment and tools (WSRC, 2019).

Water Services:

Water services is based on three indicators: water coverage (WC), water losses (WL), and continuity of water supply (CWS).

The water coverage is almost good with a ratio between 80 -100 % for the 10 cities.

The indicator concerning the ratio of water losses is alarming and chronic: in the majority of cities, this ratio is very high, because of pipes ageing, pipes poor material, intermittent operation practices, pressure fluctuation within pipes, low level of technology and maintenance in particular for water meters, absence of maps carrying the water networks details, poor management of water districts, and the illegal connections.

Concerning the continuity of the water supply. Even that 74% of the Palestinian population are covered with water services, the water service coverage is not related to this ratio, because only 36 % of the Palestinian population are supplied with continues daily water supply per month (World Bank, 2018). In many Palestinian cities, costumers are provided by water only few hours per day or per two days or even more. They use storage tanks facilities to have water all the time in their houses. The situation in Hebron is more than critical with a ratio of continuity of water supply was 3 %.

Water governance:

Three indicators were used for the water governance: clear roles and responsibilities (CRR), access to data and information (ADI), stakeholder engagement (SE). The major problem of governance is related to occupation.

Although the Palestinian law defines roles and responsibilities in the water sector, this law is not completely implemented. Access to data and information is not easy in the Palestinian territory. Data are fragmented in many institutions and bodies.

The role of the civil society in the water governance very restricted.

4.6.3 Risk Evaluation - Value Based

This section presents analysis of the risk acceptability according to the scale: acceptable, tolerable and intolerable. Analysis is based on severity and likelihood scores values as well as judgement impact. Analysis also covers measurements to be taken according to level of actions: no actions, measures or urgent actions.

Tables 4.32 to 4.41 summarize the evaluation for the ten cities for the water resources and water services. It could be observed that:

- The water resources situation is considered as “Intolerable” with “Urgent Actions” for almost all cities, except some particular cases such as Qalqilya and

Nablus for the indicator waste water coverage “WWC” and Jericho for the indicator state of sewer “SoS”.

- The water service situation is not uniform. The indicator water losses ‘WL” is considered “Intolerable” with “Urgent Actions” for all cities; the indicator water coverage “WC” is considered “Intolerable” with “Urgent Actions” for Jenin, Jericho and Hebron; the indicator continuity of water supply “CWS” is considered “Intolerable” with “Urgent Actions” for almost all cities, except Tubas, Tulkarm and Qalqilya.

Table 4.42 provides the evaluation of the governance risk. The situation is considered as “Intolerable” with “Urgent Actions” for the three indicators: “CRR”, “ADI” and “SE”.

Table 4.32: Indicators of Water Resources and Water Services in Jenin City

Jenin					
Driver	Indicators	Severity	Likelihood	Risk Evaluation	Target
W.R	WRA	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	AP	Moderate	Almost Certain	Intolerable	Urgent Actions
	WWC	Minor	Almost Certain	Intolerable	Urgent Actions
	SoS	Major	Almost Certain	Intolerable	Urgent Actions
	TL	Minor	Almost Certain	Intolerable	Urgent Actions
W.S	WC	Minor	Almost Certain	Intolerable	Urgent Actions
	WL	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	CWS	Catastrophic	Almost Certain	Intolerable	Urgent Actions

Table 4.33: Indicators of Water Resources and Water Services in Tubas City

Tubas					
Driver	Indicators	Severity	Likelihood	Risk Evaluation	Target
W.R	WRA	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	AP	Major	Almost Certain	Intolerable	Urgent Actions
	WWC	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	SoS	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	TL	Catastrophic	Almost Certain	Intolerable	Urgent Actions
W.S	WC	Insignificant	Rare	Acceptable	No actions
	WL	Moderate	Almost Certain	Intolerable	Urgent Actions
	CWS	Insignificant	Rare	Acceptable	No actions

Table 4.34: Indicators of Water Resources and Water Services in Tulkarm City

Tulkarm					
Driver	Indicators	Severity	Likelihood	Risk Evaluation	Target
W.R	WRA	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	AP	Moderate	Almost Certain	Intolerable	Urgent Actions
	WWC	Moderate	Almost Certain	Intolerable	Urgent Actions
	SoS	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	TL	Catastrophic	Almost Certain	Intolerable	Urgent Actions
W.S	WC	Insignificant	Rare	Acceptable	No actions
	WL	Major	Almost Certain	Intolerable	Urgent Actions
	CWS	Insignificant	Rare	Acceptable	No actions

Table 4.35: Indicators of Water Resources and Water Services in Qalqilya City

Qalqilya					
Driver	Indicators	Severity	Likelihood	Risk Evaluation	Target
W.R	WRA	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	AP	Moderate	Almost Certain	Intolerable	Urgent Actions
	WWC	Insignificant	Rare	Acceptable	No actions
	SoS	Major	Almost Certain	Intolerable	Urgent Actions
	TL	Catastrophic	Almost Certain	Intolerable	Urgent Actions
W.S	WC	Insignificant	Rare	Acceptable	No actions
	WL	Moderate	Almost Certain	Intolerable	Urgent Actions
	CWS	Insignificant	Rare	Acceptable	No actions

Table 4.36: Indicators of Water Resources and Water Services in Salfit City

Salfit					
Driver	Indicators	Severity	Likelihood	Risk Evaluation	Target
W.R	WRA	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	AP	Moderate	Almost Certain	Intolerable	Urgent Actions
	WWC	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	SoS	Moderate	Almost Certain	Intolerable	Urgent Actions
	TL	Catastrophic	Almost Certain	Intolerable	Urgent Actions
W.S	WC	Insignificant	Rare	Acceptable	No actions
	WL	Minor	Almost Certain	Intolerable	Urgent Actions
	CWS	Minor	Almost Certain	Intolerable	Urgent Actions

Table 4.37: Indicators of Water Resources and Water Services in Nablus City

Nablus					
Driver	Indicators	Severity	Likelihood	Risk Evaluation	Target
W.R	WRA	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	AP	Moderate	Almost Certain	Intolerable	Urgent Actions
	WWC	Insignificant	Rare	Acceptable	No actions
	SoS	Moderate	Almost Certain	Intolerable	Urgent Actions
	TL	Minor	Almost Certain	Intolerable	Urgent Actions
W.S	WC	Insignificant	Rare	Acceptable	No actions
	WL	Moderate	Almost Certain	Intolerable	Urgent Actions
	CWS	Catastrophic	Almost Certain	Intolerable	Urgent Actions

Table 4.38: Indicators of Water Resources and Water Services in Ramallah and Al-Bireh

Ramallah and Al-Bireh					
Driver	Indicators	Severity	Likelihood	Risk Evaluation	Target
W.R	WRA	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	AP	Moderate	Almost Certain	Intolerable	Urgent Actions
	WWC	Minor	Almost Certain	Intolerable	Urgent Actions
	SoS	Moderate	Almost Certain	Intolerable	Urgent Actions
	TL	Minor	Almost Certain	Intolerable	Urgent Actions
W.S	WC	Insignificant	Rare	Acceptable	No actions
	WL	Moderate	Almost Certain	Intolerable	Urgent Actions
	CWS	Major	Almost Certain	Intolerable	Urgent Actions

Table 4.39: Indicators of Water Resources and Water Services in Jericho City

Jericho					
Driver	Indicators	Severity	Likelihood	Risk Evaluation	Target
W.R	WRA	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	AP	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	WWC	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	SoS	Insignificant	Rare	Acceptable	No actions
	TL	Minor	Almost Certain	Intolerable	Urgent Actions
W.S	WC	Moderate	Almost Certain	Intolerable	Urgent Actions
	WL	Minor	Almost Certain	Intolerable	Urgent Actions
	CWS	Moderate	Almost Certain	Intolerable	Urgent Actions

Table 4.40: Indicators of Water Resources and Water Services in Bethlehem City

Bethlehem					
Driver	Indicators	Severity	Likelihood	Risk Evaluation	Target
W.R	WRA	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	AP	Moderate	Almost Certain	Intolerable	Urgent Actions
	WWC	Minor	Almost Certain	Intolerable	Urgent Actions
	SoS	Moderate	Almost Certain	Intolerable	Urgent Actions
	TL	Catastrophic	Almost Certain	Intolerable	Urgent Actions
W.S	WC	Insignificant	Rare	Acceptable	No actions
	WL	Moderate	Almost Certain	Intolerable	Urgent Actions
	CWS	Major	Almost Certain	Intolerable	Urgent Actions

Table 4.41: Indicators of Water Resources and Water Services in Hebron City

Hebron					
Driver	Indicators	Severity	Likelihood	Risk Evaluation	Target
W.R	WRA	Catastrophic	Almost Certain	Intolerable	Urgent Actions
	AP	Moderate	Almost Certain	Intolerable	Urgent Actions
	WWC	Major	Almost Certain	Intolerable	Urgent Actions
	SoS	Moderate	Almost Certain	Intolerable	Urgent Actions
	TL	Catastrophic	Almost Certain	Intolerable	Urgent Actions
W.S	WC	Moderate	Almost Certain	Intolerable	Urgent Actions
	WL	Moderate	Almost Certain	Intolerable	Urgent Actions
	CWS	Catastrophic	Almost Certain	Intolerable	Urgent Actions

Evaluation of Water Governance Indicators

Table 4.42: Water Governance Indicators in the Palestinian Water Sector

Driver	Indicators	Severity	Likelihood	Risk Evaluation	Target
W.G	CRR	Moderate	Almost Certain	Intolerable	Urgent Actions
	ADI	Major	Almost Certain	Intolerable	Urgent Actions
	SE	Moderate	Almost Certain	Intolerable	Urgent Actions

4.6.4. Risk Targeting

According to the evaluation presented in the previous section, urgent actions should be taken to achieve an acceptable level of risk. Table 4.43 summarizes the actions to be implemented for water resources at short term (coming 5 years) and long term for cities facing intolerable risks.

Urgent actions are required in the field of water resources availability "WRA" in four cities: Tulkarm, Qalqilya, Ramallah and al-Bireh, and Jericho to increase the availability of water resources by reducing the consumption to WHO recommendations (100 l/c.d). No other actions could be taken at short and long terms, because of the complicated conditions in the context of water resources.

Concerning the indicator annual precipitation "AP", at the short term rain water harvesting at individual level will be very useful, it was already used in some Palestinian communities, raising awareness programs can motivate the Palestinians in all cities to harvesting rain water. While at long term, preparing a hydrological studies for the most suitable places for building dams is very useful in order to orient the future international aids to this kind of useful infrastructure projects.

Regarding the indicator wastewater coverage "WWC", by reference to table 4.17, we note that waste water coverage ratio in some cities like Tulkarm, Salfit and Jericho decreases with time, because of the random urban expansion. Accordingly, good planning before making urban expansion is very important. It is important to improve the ratio of wastewater coverage and to adopt the principle of "Beneficiaries Contribution". At the long term, the coverage of the wastewater collection systems should be extended.

For the indicator state of sewers "SoS", utilities and municipalities should apply the regular and preventive maintenance regime and proceed to the rehabilitation and/or replacement of old sewers.

Concerning the treatment level "TL", at the short term, Jenin, Nablus, Ramallah and Al-Bireh, and Jericho, should focus on improving the performances of the waste water treatment plants through implementing the sludge recycling, disinfection, and reuse the treated waste water. At the long term, Tubas, Tulkarem, Qalqilya, Salfit, Bethlehem, and Hebron should build new treatment plants.

Table 4.43: Actions to Achieve an Acceptable Level of Water Resources Risks

Indicator	Short Term	Long Term
WRA	- Tulkarm, Qalqilya, Ramallah and Al-Bireh, and Jericho could increase their water resources availability by control the water consumption at 100 l/c.d.	
AP	- Harvesting water at individual level.	- Harvesting water at larger level (dams)
WWC	- Plan and mange before making urban expansions. - Beneficiaries Contribution	- Waste water collection system projects.
SoS	Apply the regular and preventive maintenance regime in all cities.	Rehabilitation and/ or replacement projects for systems that have more than 10 years ago of use.
TL	Focus on rising the efficiency of the existing plants	Building new plants.

For the cities that are facing intolerable water services risk, table 4.44 summarizes actions to be implemented.

Regarding the indicator water coverage, Jenin, Jericho and Hebron should implement the actions suggested for reducing the risk related to wastewater coverage.

Concerning the water losses "WL”, the following actions are suggested:

At short term:

1) Water Meters Calibration Program, where all water meters in the system should be calibrated by applying a program covering all the areas served by water networks.
2) Water Meters maintenance program, after making calibration for all water meters, regular maintenance program should implement over the whole area.
3) Immediate repair of leaks, as soon as possible, everywhere and at any time.
4) Data collecting and monitoring; installing meters in every water district area in order to measure the flow input, output, and pressure, and when possible connecting these meters with computers.
5) Creating a GIS maps that carrying a spatial and descriptive database, theses maps should express the position, number, type, characteristics of all connections, pipes, fittings, valves and meters.
6) Installing a water meters for all schools, mosques and playgrounds, because in the case of Palestine in most cities the data was available for estimating the real

and apparent losses, estimation of NRW was not clear because there was no data concerning the unbilled authorized consumptions.

7) Improve the management of the district areas, engineers should make periodic review for the data collected from each district area, write notes, points, and comments, and make site visits when it required. As well from year to year the division of water districts area may change according to the novelties.
8) Pressure control, especially in old or aged networks, engineers should be sure that the pressure in pipes neither increase nor decrease on the standard range according to the pipes types and age.
9) Activate SCADA system, for developing controlling, and enhancing monitoring.

At long term:

1) Meters replacement, where water meters in some cities should replace by more accurate ones, meters with sensors are preferable in order to develop the system to be computerized.
2) Computerized the whole system, by connect the whole water system with sensors and computers, implementing all controlling, monitoring, management process through these components.
3) Punishment for theft by clear text of the law, together with the use of police forces, as well as inform and warn people with the new measures using the media. This step is very important and crucial, since a portion of water loss in the Palestinian cities come from illegal connections.
4) Activating a monitoring and emergency room for water services working 24 hours, for repair leaks, monitor the whole system, and implement the regular maintenance program.
5) Municipalities should plan to use the mobile application for providing and collecting data about their water services. They should recruit qualified persons for achieving this target.

Actions for targeting the indicator continuity of water supply "CWS" are limited; good planning for the future urban expansion, good management of water district areas, and increase the quantity of water interring the system, those are actions were taken for targeting other risks, and could be also benefit for targeting this indicator.

Table 4.44: Actions to Achieve an Acceptable Level of Water Services Risks

Indicator	Short Term	Long Term
WC	- Planning for urban expansion - Apply small projects under the principle of "Beneficiaries Contribution"	Water supply network Projects (Large scale)
WL	- Meters Calibration Program - Meters maintenance program - Immediate repair of leaks - Data reporting and monitoring - GIS mapping -Meters for Schools, mosques, playgrounds - District area management - Pressure control - Activate SCADA system	- Meters replacement. - Computerized the whole system. - Rehabilitation and/ or replacement projects for aged water networks - Using the force of law - Monitoring and emergency room - Mobile application
CWS	- Planning for urban expansion - good management for network districts	- increase the quantity of water entering the system

As for water governance, table 4.45 presents the actions that urgently required. At short term, all bodies in the Palestinian water sector should make meetings and workshops to remove the fuzziness in their understanding of their roles and responsibilities, as well to effectively engage the water stakeholders.

Concerning access to data and information "ADI", the framework should be prescribed as soon as possible, while implementation should be established in reality.

Table 4.45: Actions to Achieve an Acceptable Level of Water Governance Risks

Indicator	Short Term	Long Term
CRR	Implement the law	Review the outcomes and develop if it's needed
ADI	Issuance clear law and start implementation	Review the outcomes and develop if it's needed
SE	Implement the law	Review the outcomes and develop if it's needed

4.7 Risk Management

The proposed method is based on the "Prevention- Mitigation- Adaptation- Cope", which is illustrated in figure 4.10. It includes the following strategies and actions to achieve urban water security:

1) Prevention strategy, which consists in turning off factors that deteriorate urban water security.
2) Mitigation strategy to reduce the level of risks to an acceptable one.

3) Adaptation strategy to improve the resiliency of the water sector and local community regarding urban water risks.
4) Cope strategy to be proactive to overcome future water risks.

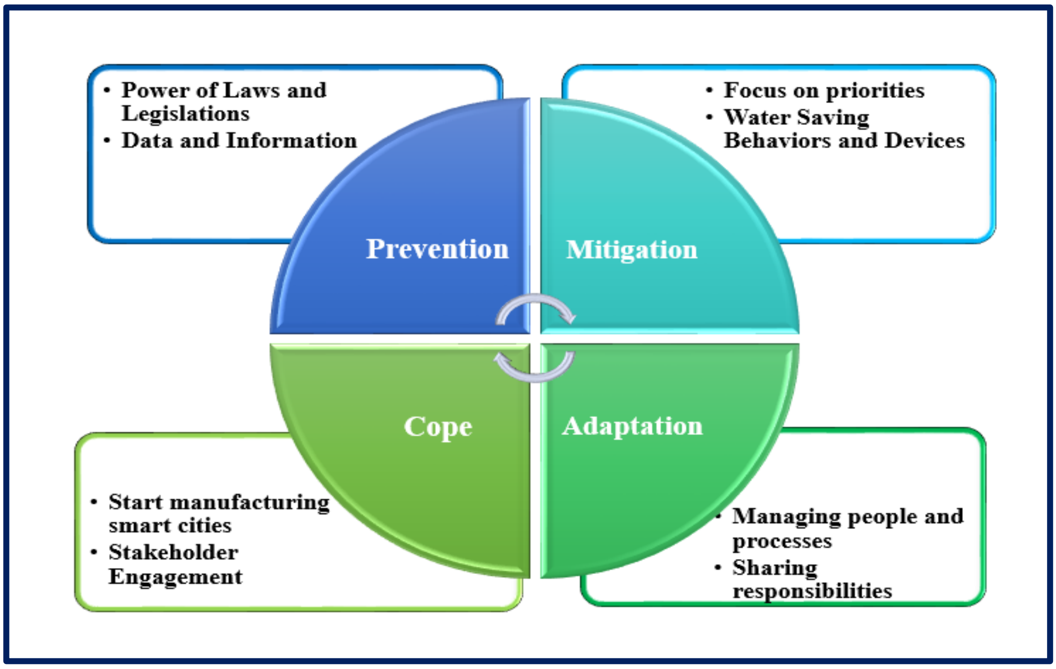

Figure 4.10: Management System Framework

Concerning strategy #1; using the power of laws and legislations is the suitable option to prevent more deterioration. Policy instruments, strong laws and coherent legislations should stand behind actions and decisions that could be used to stop practices that lead to more deteriorations in the water sector. Data and information are also important tool for assessing and evaluating the real situation, and then to make decisions regarding preventing risks and stopping deterioration. We have some example in Palestine, such as (i) Unauthorized water consumption is an important threat for the water losses, (ii) Unplanned expansion has an important impact on the ratio of water and waste water coverage, (iii) Lack of regulation for regular and preventive maintenance or calibration of water meter.

Regarding strategy #2; firstly, reducing the level of risk requires more focus on priorities, because some factors have a greater impact on risk than others. Secondly, citizens awareness could help in water saving and pollution reducing pollution.

For strategy #3; people and processes should be prepared to be resilience. It requires staff training and improvement in building capacities as well responsibility sharing between governments and local communities.

Finally, for the strategy #4; the smart city transformation could help to cope with future risks. Cities and policy makers should embrace the water city transformation, in particular the smart water technology including smart monitoring, data analysis to detect water leak and water contamination and to improve asset management.

4.8 Conclusion

This chapter presented a comprehensive analysis of the water security in ten Palestinian cities. Results show that, globally the water security in the Palestinian cities is very bad (poor to alarming). This result is mainly related to the bad situation of the water resources and the inadequate water governance. Water resources has the greatest risk score (between 17 and 23) in the ten Palestinian cities. While water services" has a risk score between 6 and 20. The risk score of the water governance is equal to 16.

The following short and long terms strategies were proposed to cope with the urban water security challenges in Palestine:

- Reinforcement of the legislation concerning the protection of water resources, the maintenance of water infrastructures and the share of responsibilities.
- Reinforcement of the pacification to figure out priorities and agenda for the water security.
- Use of latest innovations such as the smart water technology for the optimization of the water management and the improvement of the water resiliency.

General Conclusions

This research concerned a critical issue for our society, which related to water security. The importance of this issue increased in the last years because of the rapid population growth, intensive use of water, water resources contamination, lack of investment in water infrastructures, poor governance and lack of innovation.

The first step in improving water security consists of conducting a comprehensive assessment using a scientific approach together with pertinent data concerning causal factors and performance indicators. This analysis aims to understand the level of water security, analyze the influence of different factors on this security, and to establish and strategies to improve this security. This research work contributed to this issue through an extensive literature review concerning water security, elaboration of a comprehensive methodology for the water security assessment, and finally, the application of this methodology on ten Palestinian cities.

The literature review clearly showed an increasing concern of local, national, and regional authorities in the water security. It showed the pertinence of the risk assessment approach for the analysis of the water security and for establishing strategies including risk identification, analysis of risk drivers and impact, and finally, qualitative and quantitative evaluation of the risk. The literature review highlighted the dramatic water security in Palestinian territory, which is due to occupation, climate change, social and economic conditions.

The methodology used in this work for the water security assessment is based on the OECD risk-based approach, together with the SWARA method. It includes seven stages: challenges identification, indicators determination, indicators weighting and ranking, risk assessment, water security index estimation, risk evaluation, and risk management.

The application of the risk assessment approach on Palestinian cities started with an essential work of data collection in ten cities according to security indicators. These indicators were identified from the literature review and experts' opinions. Data concerned twelve indicators, which were classified into three categories: water resources, water services, and water governance. Data collection was challenging because of the data fragmentation and data missing. Risk analysis included establishing for each indicator the likelihood and severity scores as well as the risk scores and levels, which were discussed with water experts.

The risk level was estimated for “water resources”, “water services,” and “water governance”. Results showed that (i) water resources has high to extreme risk level in the ten cities, (ii) the risk level for the water services is extreme for two cities, and (iii) the situation of the water governance is critical. The overall risk score was determined. Results showed that globally the water security in the ten Palestinian cities is very bad because of the low water resources availability and poor water governance.

The following set of short and long terms strategies and actions was proposed to cope with the water security challenges: (i) reinforcement of the legislation concerning the protection of the water resources, the maintenance of the water infrastructures and the share of responsibilities, (ii) reinforcement of the planning to establish priorities and agenda for the water security and (iii) the use of latest innovation such as the smart water technology for the optimization of water management.

This work opens some perspectives, in particular exploring with cities the (i) best way to adapt the research recommendations to the local context, (ii) extend data collection (iii) integrate the suggestions in local and national strategies, (iv) monitor the implementation of the water security plan to measure progress and to update the water security strategy.

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Annex (A)

Research Questionnaire

University of Lille
Doctoral School "Engineering Science"
Laboratory of Civil Engineering and geo-Environment

Risk-based Analysis of Urban Water Security:

Application to Palestinian cities

This questionnaire is prepared within the PhD Research of Eng. Samah Jabari at Lille University in France

"Risk-based Analysis of Urban Water Security: Application to Palestinian cities"

The main purpose of this research is to understand the challenges facing the water sector in Palestine in order to develop innovation solutions to cope with these challenges with a focus on a smart technology.

The questionnaire includes 2 sections:

- Water challenges in Palestine and associated Indicators
- Water Risk Assessment

Note that all data contained in this questionnaire is for scientific research. Information provided will remain anonymous. Your contact details will be used only for verification or additional information.

The researcher is highly thankful of your contribution in completing this questionnaire. The outcome of this analysis will be provided to your institution.

Expert Information

Name		
Position		
Institution		
Contact Data	**Telephone**	
	Mobile	
	E-mail	

Part 1: Water challenges in Palestine and associated Indicators

Could you give a degree of importance for the following challenges, risk drivers and indicators?
Note that: (1 =Not Important, 2 = Low Important, 3= Medium Important 4= High Important)

1	Could you provide a degree of importance for the following water challenges	
	Availability and climate change	
	Growing demand	
	Water loss and NRW	
	Week investments	
	Week Management and Governance	
	Water Quality	
2	Could you provide a degree of importance for the following risk factors in the Palestinian water sector.	
	Water Resources	
	Water Services	
	Water Governance	
3	Could you provide a degree of importance for the following water resources indicators	
	Water Resources Availability	
	Annual Precipitation	
	Waste Water Coverage	
	State of Sewers	
	Level of Waste Water Treatment	
4	Could you provide a degree of importance for the following water services indicators	
	Water Coverage	
	Water Losses	
	Continuity of Supply	
5	Could you provide a degree of importance for the following water Governance indicators	
	Clear Roles and Responsibilities	
	Access to Data and Information	
	Stakeholder Engagement	

Part II: Water Risk Assessment

In this survey we consider the following scale for the risk severity.

1: Insignificant,
2: Mainor,
3: Moderate,
4: Critical,
5: Catastrophic

According to this scale and based on literature review and discussion, we have established the following ranges for the risk severity.

As expert in the water sector, we are highly interested by your expertise. Could you kindly check our proposal (column 2) and provide any change in the range (column 3)

Indicator 1: Water Resources Availability (WRA)

Source: IWA

Definition: Percentage of available water that enters the system

Calculation: (System input volume during the assessment period x 365 / assessment period)/ (annual yield capacity of own resources + annual imported water allowance) x 100%, note 100% means that all available resources are being used

Severity Scoring System:

Severity Score	proposed range	Your proposition
1	$50 < WRA \leq 60$ %	
2	$60 < WRA \leq 70$%	
3	$70 < WRA \leq 80$%	
4	$80 < WRA \leq 90$%	
5	$90 < WRA \leq 100$%	

Indicator 2: Annual Precipitation (AP)

Source: Palestine weather station

Definition: Total accumulated precipitation over one year

Calculation: Gathering the annual rainfall data from a trustful local weather authority.

Severity Scoring System:

Severity Score	proposed Range	Expert proposition
1	$AP \geq 1000$ mm/y	
2	$600 \leq AP < 1000$ mm/ y	
3	$400 \leq AP < 600$ mm/ y	
4	$200 \leq AP < 400$ mm/ y	
5	$AP < 200$ mm/ y	

Indicator 3: Ratio of Treated Waste Water (RoTWW)

Source: WSRC, 2016 and Ginkel, et al., 2018.

Definition: This indicator will define by considering three factors; waste water coverage (WWC), state of sewers (SoS) and the level of waste water treatment (TL).

Calculation: Average of the three factors.

Severity Scoring System:

Severity Score	proposed Range	Expert proposition
1	95 < WWC ≤ 100%	
2	85 < WWC ≤ 90 %	
3	75 < WWC ≤ 80 %	
4	65 < WWC≤ 70%	
5	WWC ≤ 65 %	
1	SoS = Good State with age less than 10 years	
2	SoS = Regular Maintenance with age more than10 years	
3	SoS = Intermittent Maintenance with age more than 10 years	
4	SoS = No Maintenance with age more than 10 years	
5	SoS = Poor state, no maintenance, age more than 10, leaks and inappropriate diameter.	
1	TL= Primary, secondary, tertiary and sludge recycle	
2	TL= Primary, secondary and tertiary	
3	TL= Primary and secondary	
4	TL= Only Primary	
5	TL= Not Exist	

Indicator 4: Water coverage (WC)

Source: IWA

Definition: Percentage of the resident population that is served by water utility

Calculation: Resident population served by the water undertaking through service connections / total resident population x 100%

Severity Scoring System:

Severity Score	proposed Range	Expert proposition
1	95 < WC ≤ 100%	
2	90 < WC ≤ 95 %	

3	85 < WC ≤ 90 %	
4	80 <WC ≤ 85%	
5	WC ≤ 80 %	

Indicator 5: Water losses (WL)

Source: IWA
Definition: Water losses during the assessment period
Calculation: Water losses / system input volume x 100%

Severity Scoring System:

Severity Score	proposed Range	Expert proposition
1	WL≤ 10%	
2	10 < WL ≤ 20	
3	20 < WL ≤ 30	
4	30 < WL ≤ 40	
5	WL > 40 %	

Indicator 6: Continuity of supply (CWS)

Source: IWA
Definition: Percentage of hours when the (intermittent supply) system is pressurized
Calculation: Number of hours when the system is pressurized during the assessment period/ 24 / Assessment period x 100%.

Severity Scoring System:

Severity Score	proposed Range	Expert proposition
1	90 < CS ≤ 100%	
2	80 < CS ≤ 90 %	
3	70 < CS ≤ 80 %	
4	60 < CS ≤ 70%	
5	CS ≤ 60 %	

Indicator 7: Clear Roles and Responsibilities (CRR)

Source: OECD
Definition: Clearly allocate and distinguish roles and responsibilities for water policy making, policy implementation, operational management and regulation, and foster co-ordination across these responsible authorities
Calculation: Qualitative measurement

Severity Scoring System:

Severity Score	proposed Range	Expert proposition

1	In place, functioning and fully implemented.	
2	In place, partially implemented.	
3	In place, not implemented.	
4	Framework under development	
5	Not in place.	

Indicator 8: Access to Data and Information (ADI)

Source: OECD

Definition: Produce, update and share timely, consistent, comparable, and policy-relevant water and water-related data and information, and use it to guide, assess and improve water policy.

Calculation: Qualitative measurement

Severity Scoring System:

Severity Score	proposed Range	Expert proposition
1	In place, functioning and fully implemented.	Insignificant
2	In place, partially implemented.	Mainor
3	In place, not implemented.	Moderate
4	Framework under development	Critical
5	Not in place.	Catastrophic

Indicator 9: Stakeholder Engagement (SE)

Source: OECD

Definition: Promote stakeholder engagement for informed and outcome-oriented contributions to water policy design and implementation

Calculation: Qualitative measurement

Severity Scoring System:

Severity Score	proposed Range	Expert proposition
1	In place, functioning and fully implemented.	
2	In place, partially implemented.	
3	In place, not implemented.	
4	Framework under development	
5	Not in place.	

We consider the following scale for the risk likelihood.

1: Rare,
2: Unlikely,
3: Possible,
4: Likely,
5: Almost Certain.

According to this scale and based on literature review and discussion, we have established the following ranges for the risk likelihood.

As expert in the water sector, we are highly interested by your expertise. Could you kindly check our proposal (column 2) and provide any change in the range (column 3)

Likelihood Scoring System

Severity Score	proposed Range	Expert proposition
1	If the indicator values in the study period are within the acceptable range every year	
2	If the indicator values in the study period are within the acceptable range along the last four years	
3	If the indicator values in the study period are within the acceptable range along the last three years	
4	If the indicator values in the study period are within the acceptable range just in one to two years	
5	If the indicator values in the study period are out of the acceptable range every year	

Annex (B)

Calculations of the Indicators (WRA, WL, and CS)

1) Water Resources availability (WRA)

Indicator information

Indicator title: Water Resources availability (%)	
Indicator Code: WRA	
Indicator source: IWA, 2017	
Definition	Percentage of available water that enters the system. It's considered important by the undertakings, but frequently difficult to assess.
Measurement Method	(System input volume during the assessment period x 365 / assessment period)/ (annual yield capacity of own resources + annual imported water allowance) x 100% **WRA = A3 x 365 / H1 / (A1+A2) x 100%** A1 - Annual yield capacity of own resources (m3/year) A2 - Annual imported water allowance (m3/year) A3 - System input volume (m3) H1 - Assessment period (day)

Data collected and Calculations

JENIN					
	2013	**2014**	**2015**	**2016**	**2017**
A1: ground		723,680.00	1,125,090.00	1,041,600.00	1,197,400.00
A2		1,631,718.00	1,563,732.00	1,841,788.00	1,200,580.00
A3		2,355,398.00	2,688,822.00	2,883,388.00	2,397,980.00
WRA		100%	100%	100%	100%

TUBAS					
	2013	**2014**	**2015**	**2016**	**2017**
A1: ground	No Data	No Data	0	0	0
reservoir	No Data	No Data	3,000.00	3,200.00	2,600.00
A2	No Data	No Data	1,293,971.00	1,652,223.00	1,651,680.00
A3	No Data	No Data	1,293,971.00	1,652,223.00	1,651,680.00
WRA	No Data	No Data	99.8%	99.8%	99.8%

TULKARM					
	2013	**2014**	**2015**	**2016**	**2017**
A1: ground	6,851,068.00	6,900,564.00	6,789,670.00	6,820,008.00	7,235,443.00
reservoir	5,130.00	5,160.00	5,160.00	4,000.00	3,950.00
A2	0.00	0.00	0.00	0.00	0.00
A3	6,851,068.00	6,900,564.00	6,789,670.00	6,820,008.00	7,235,443.00
WRA	99.9%	99.9%	99.9%	9.94%	99.9%

QALQILYA

	2013	2014	2015	2016	2017
A1: ground	4,334,207.00	4,419,787.00	4,450,591.00	4,695,302.00	4,454,636.00
reservoir	5,000.00	5,000.00	5,000.00	5,500.00	5,000.00
A2	0.00	0.00	0.00	0.00	0.00
A3	4,334,207.00	4,419,787.00	4,450,591.00	4,695,302.00	4,454,636.00
WRA	99.9%	99.9%	99.9%	99.9%	99.9%

SALFIT

	2013	2014	2015	2016	2017
A1: spring	94,291.00	45,828.00	111,629.00	78,234.00	74,670.00
reservoir	1,500.00	1,500.00	2,100.00	1,500.00	1,500.00
A2	508,030.00	582,460.00	512,402.00	555,640.00	565,030.00
A3	602,321.00	628,288.00	624,031.00	633,874.00	639,700.00
WRA	99.8%	99.8%	99.7%	99.8%	99.8%

NABLUS

	2013	2014	2015	2016	2017
A1: ground	7,211,947.00	8,076,636.00	7,868,487.00	8,034,575.00	7,725,698.00
spring	2,208,196.00	1,489,736.00	2,090,660.00	1,777,964.00	1,679,458.00
reservoir	21,022.00	21,022.00	21,022.00	21,022.00	21,022.00
A2	775,040.00	898,027.00	588,924.00	762,926.00	1,162,642.00
A3	10,195,183.00	10,464,399.00	10,548,071.00	10,575,465.00	10,567,798.00
WRA	99.8%	99.8%	99.8%	99.8%	99.8%

RAMALLAH

	2013	2014	2015	2016	2017
A1	No Data	No Data	2,233,694.00	2,041,325.00	1,643,662.00
A2	No Data	No Data	15,094,220.00	15,752,279.00	16,494,994.00
A3	No Data	No Data	17,327,914.00	17,793,604.00	18,138,656.00
WRA	No Data	No Data	100%	100%	100%

JERICHO

	2013	2014	2015	2016	2017
A1	3,110,300.00	3,110,300.00	3,064,280.00	2,897,271.00	2,924,705.00
A2	0.00	0.00	0.00	0.00	0.00
A3	3,106,300.00	3,106,300.00	3,060,280.00	2,897,271.00	2,924,705.00
WRA	99.8%	99.8%	99.8%	100%	100%

BETHLEHEM

	2013	2014	2015	2016	2017
A1	0.00	0.00	0.00	0.00	0.00

A2	4,697,285.00	4,500,263.00	5,447,282.00	4,993,583.00	5,390,536.00
A3	4,697,285.00	4,500,263.00	5,447,282.00	4,993,583.00	5,390,536.00
WRA	100%	100%	100%	100%	100%

HEBRON					
	2013	2014	2015	2016	2017
A1	236,319.00	215,000.00	0	120,000.00	0
A2	5,355,056.00	5,972,736.00	6,909,200.00	7,231,186.00	7,800,000.00
A3	5,591,375.00	6,187,736.00	6,909,200.00	7,351,186.00	7,800,000.00
WRA	100%	100%	100%	100%	100%

2) *Water losses*

Indicator information

Indicator title: Water losses per system input volume (%)	
Indicator Code: WL	
Indicator source: IWA, 2017	
Definition	Water losses during the assessment period
Measurement Method	(Water losses / system input volume) x 100% **WL = (B2 / A3) x 100%** B2 - Water losses (m^3) A3 - System input volume (m^3)

Data Collected and Calculations

JENIN					
	2013	**2014**	**2015**	**2016**	**2017**
B2			1,319,633.00	1,421,697.00	1,056,493.00
A3			2,688,822.00	2,883,388.00	2,397,980.00
WL (%)			49.1%	49.3%	44%
TUBAS					
	2013	**2014**	**2015**	**2016**	**2017**
B2			329,937.00	479,548.00	458,830.00
A3			1,293,971.00	1,652,223.00	1,651,680.00
WL (%)			25.5%	29%	27.8%
TULKARM					
	2013	**2014**	**2015**	**2016**	**2017**
B2			2,563,106.00	2,624,153.00	2,874,577.00
A3	6,851,068.00	6,900,564.00	6,789,670.00	6,820,008.00	7,235,443.00
WL (%)			37.8%	38.5%	39.7%
QALQILYA					
	2013	**2014**	**2015**	**2016**	**2017**
B2			1,074,600.00	1,155,293.00	1,155,909.00
A3	4,334,207.00	4,419,787.00	4,450,591.00	4,695,302.00	4,454,636.00
WL (%)			24%	24.6%	26%
SALFIT					
	2013	**2014**	**2015**	**2016**	**2017**
B2			97,040.00	90,539.00	91,644.00
A3	602,321.00	628,288.00	624,031.00	633,874.00	639,700.00
WL (%)			15.6%	14.3%	14.3%
NABLUS					
	2013	**2014**	**2015**	**2016**	**2017**
B2			3,604,887.00	3,615,073.0	3,154,146.0

A3	10,195,183.0	10,464,399.0	10,548,071.0	10,575,465	10,567,798
WL (%)			34.2%	34.2%	29.8%
RAMALLAH					
	2013	**2014**	**2015**	**2016**	**2017**
B2			4,813,062.00	4,398,320.00	4,195,886.43
A3			17,327,914.0	17,793,604.0	18,138,656.0
WL (%)			27.8%	24.7%	23%
JERICHO					
	2013	**2014**	**2015**	**2016**	**2017**
B2			819,400.00	555,329.00	373,696.00
A3	3,106,300.00	3,106,300.00	3,060,280.00	2,897,271.0	2,924,705.0
WL (%)			26.8	19.2	12.8
BETHLEHEM					
	2013	**2014**	**2015**	**2016**	**2017**
B2			1,865,721.00	1,871,796.0	1,580,634.0
A3	4,697,285.0	4,500,263.00	5,447,282.00	4,993,583.0	5,390,536.0
WL (%)			34.25	37.48	29.32
Hebron					
	2013	**2014**	**2015**	**2016**	**2017**
	No Data	No Data	29.9	29.8	29.98
Calculation Example	WL-5 = 2,338,419.00 / 7,800,000.00 X 100% = 29.98 %				

3) Continuity of Water Supply

Indicator information

Indicator title: Continuity of Water Supply (%)	
Indicator Code: WS	
Indicator source: IWA, 2017	
Definition	Percentage of hours when the (intermittent supply) system is pressurized. It refers to intermittent supply systems and aims to assess the portion of the day or of the week the population has access to piped water.
Measure	Number of hours when the system is pressurized during the assessment period/ 24 / assessment period x 100% **WI-2 = H2 / 24 / H1 x 100%** H1 - Assessment period (day) H2 - Time system is pressurized (hour)

Data Collected and Calculations

JENIN					
	2013	**2014**	**2015**	**2016**	**2017**
H2 (Hour/day)	No Data	No Data	No Data	No Data	4
CS (%)	No Data	No Data	No Data	No Data	17%
Note:					
TUBAS					
	2013	**2014**	**2015**	**2016**	**2017**
H2 (Hour/day)	No Data	No Data	No Data	No Data	24
CS (%)	No Data	No Data	No Data	No Data	100%
Note:					
TULKARM					
	2013	**2014**	**2015**	**2016**	**2017**
H2 (Hour/day)	No Data	No Data	No Data	No Data	24
CS (%)	No Data	No Data	No Data	No Data	100%
Note:					
QALQILYA					
	2013	**2014**	**2015**	**2016**	**2017**
H2 (Hour/day)	No Data	No Data	No Data	No Data	24
CS (%)	No Data	No Data	No Data	No Data	100%
Note:					
SALFIT					
	2013	**2014**	**2015**	**2016**	**2017**
H2 (Hour/day)					17
CS (%)	No Data	No Data	No Data	No Data	70.8%

Note:					
NABLUS					
	2013	2014	2015	2016	2017
H2 (Hour/day)	No Data	No Data	No Data	No Data	7.5
CS (%)	No Data	No Data	No Data	No Data	31.3%
Note:					
RAMALLAH					
	2013	**2014**	**2015**	**2016**	**2017**
H2 (Hour/day)	No Data	No Data	No Data	No Data	13
CS (%)	No Data	No Data	No Data	No Data	54%
Note:					
JERICHO					
	2013	2014	2015	2016	2017
H2 (Hour/day)	No Data	No Data	No Data	No Data	15
CS (%)	No Data	No Data	No Data	No Data	62.5%
Note:					
BETHLEHEM					
	2013	**2014**	**2015**	**2016**	**2017**
H2 (Hour/day)					11
CS (%)	No Data	No Data	No Data	No Data	45.8%
Note:					
HEBRON					
	2013	**2014**	**2015**	**2016**	**2017**
H2 (Hour/day)	No Data	No Data	No Data	No Data	0.8
CS (%)	No Data	No Data	No Data	No Data	3.3%
Note:					