An-Najah National University
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AN ASSESSMENT OF THE NITRATE AND CHLORIDE IN THE WEST BANK GROUNDWATER RESOURCES USING GIS

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Dedicated to

My parents

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

AN ASSESSMENT OF THE NITRATE AND CHLORIDE IN THE WEST BANK GROUNDWATER RESOURCES USING GIS

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Abstract

Groundwater is the major source of water to the Palestinians. Efficient management of this resource requires a good understanding of its status. This understanding necessitates a characterization of the utilizable quantities and the corresponding qualities. The research focuses on the long-term degradation of water quality in the West Bank aquifers. A statistical analysis is carried out for the spatial and temporal distributions of the nitrate and chloride concentrations. GIS technology is utilized to facilitate the analysis and to efficiently account for the spatiality inherent in water resources parameters. Results confirm that the nitrate concentration across the West Bank aquifers has an increasing trend after the year 1985. As for chloride, the wells of the Jordan Valley have the highest concentrations. Overall, the recommendations call for an immediate intervention to solve the quality problems in the West Bank aquifers.

CHAPTER ONE

INTRODUCTION

1.1 General Background

Groundwater is the primary source of water for the Palestinians in the West Bank and Gaza Strip (Abed and Wishahi, 1999). Efficient management of this resource requires a well-developed understanding of the groundwater flow systems so that the quantity of a good quality groundwater that can be abstracted on a sustainable basis will be determined. The principal and conventional water resources available to Palestinians include groundwater, surface water, and harvested rainwater (UNEP, 2003). Whereas the non-conventional resources that have limited applications include treated wastewater and desalinated water.

The West Bank lies over the mountain groundwater basin. The mountain basin is divided into the eastern basin, the north-eastern basin, and the western basin (Rofe and Raffety, 1963; Scarpa, 1994). In 2005, the total water use in the West Bank was approximately 145 million cubic meters (mcm) (Almasri, 2005) as shown in Figure 1.

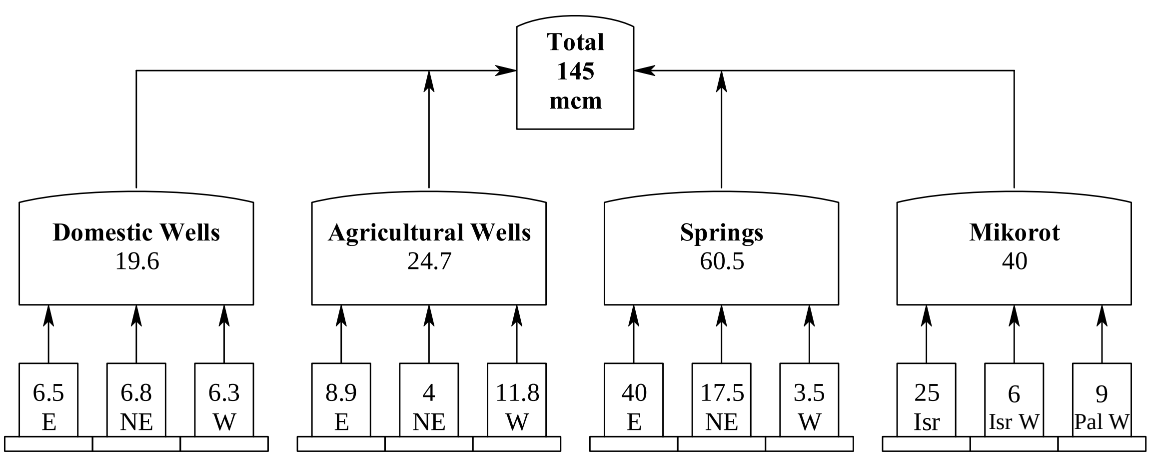


Figure 1: Water use allocation in the West Bank in 2005 (Almasri, 2005) based on the water supply and the corresponding groundwater basins

In 2005, the water supply in the West Bank was distributed as depicted in Figure 2 according to the general use of water. Approximately 2.3 million Palestinians live in the West Bank (PCBS, 1997). This implies that the annual water supply for domestic purposes is 25 m^3 per capita or 68 liter per capita per day. Assuming average network losses of 40%, this leads to an actual consumption rate of 40 liter per capita per day. This is very distant from the international standard of 150 liter per capita per day. Thus, there is a deficit of about100 mcm for domestic use only (Almasri, 2005).

It should be noted that 37% of the local communities in the West Bank are without water distribution networks. These communities obtain their water from household wells used for rainfall harvesting, tankers, low-yield springs, or agricultural wells. Nevertheless, these sources are vulnerable to contamination which limits the utilization of them and/or put the users at risk (Almasri, 2005).

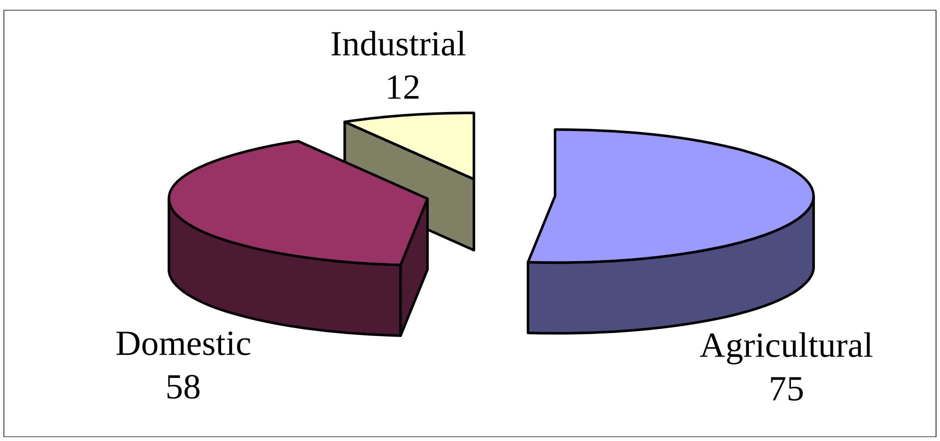


Figure 2: Water supply in the West Bank (in mcm) in 2005 (Almasri, 2005)

The aquifer system in the West Bank is highly permeable due to its geological nature. The limited soil cover over the water recharge zones makes the aquifer highly susceptible to pollution since there is no natural barrier to contaminants that travel down rapidly to the groundwater (Rofe and Raffety, 1965; UNEP, 2003).

Water resources are finite. There are limits to the amounts of water that can be withdrawn from groundwater aquifers. There are also limits to the amounts of potential pollutants that can be discharged into them. Once these limits are exceeded, the concentrations of pollutants in these resources may reduce or even eliminate the benefits that could be obtained from these resources (Almasri, 2005). As such, inclination in the utilization of water resources could be caused by quality deterioration, quantity declination, or both (UNEP, 2003; Zayed et al., 2005). Water resources managers and relevant decision makers have learned how to plan, design, build, and operate the water resources to obtain the maximum benefit.

Israelis exploit approximately 85% of the Palestinian groundwater resources, generated from three aquifer systems located in the West Bank, to meet 40% of its total water needs. The Mountain Aquifer replenishment areas lie almost within the West Bank boundaries but it is totally utilized and exploited by the Israelis (Almasri, 2005).

Water quality refers to the chemical, biological, and physical characteristics of the water. The required water quality is determined by the purpose for which the water to be used (domestic, urban, agricultural, or industrial) (Abdul-Jaber et al., 1999). The evaluation of the water, for any purpose, is based on the characteristics of the water compared to a standard for that use. By “standard” is meant the concentration of constituent which causes to negative effect to the health of the consumer over the life of consumption (WHO, 2006).

However, local requirements, the availability of water resources, the national economy, the political situation, and scientific progress may modify these standards. The water quality short-term deviations from a standard for a specific purpose do not mean that the water is unsuitable for that purpose. Suitability here is judged by the amount and the length of the deviation time as well as by the nature of the constituent involved (Abdul-Jaber et al., 1999).

Groundwater quality is highly influenced by the quality of its source. Drinking water is required to meet stringent microbiological and chemical standards of quality to prevent water borne diseases and health risks from toxic chemicals. Changes in the quantity of water recharging the aquifer or the degradation in the quality of supply water may seriously impair the quality of the groundwater. Leachate from municipal and industrial wastes entering an aquifer is a major source of organic and inorganic pollution. Large-scale organic pollution of groundwater is infrequent. However, significant quantities of organic wastes usually cannot be easily introduced to the subsurface. The problem is quite different with inorganic solutions (e.g. nitrate and chloride), since these move easily through the soil. Nevertheless, once contaminating groundwater it is difficult and costly to treat the groundwater (Viessman and Hammer, 2005).

Groundwater in most areas of the West Bank is generally considered to be of good quality. This is despite the fact that the aquifers are easily contaminated in some regions depending on land use, soil type, and geological characteristics. For instance, the region’s geology is limestone, which has the property of allowing substances to penetrate easily (UNEP, 2003).

The attenuation or removal of nutrients and pollutants in wastewater percolating down to the aquifers is low making aquifers vulnerable to contamination. In some areas, groundwater is unsuitable for drinking because of the salinity. This occurs partly as a result of natural factors, but is expected to worsen over the coming years since over-abstraction of fresh water leads to intrusion of salty water from deeper levels (UNEP, 2003, Wishahi and Awartani, 1999).

The analysis made in this study with regard to the water quality of the groundwater wells in the West Bank was reliant on the PWA database. The water quality has been considered for only two major parameters; nitrate and chloride concentrations. The nitrate concentration mainly indicates pollution of the water due to anthropogenic sources while the chloride concentration specifically indicates salinity (PWA, 2001b).

Groundwater pollution in the West Bank is caused mainly by agricultural practices (notably the use of inorganic fertilizers, pesticides, and herbicides), localized industrial activities (organic pollutants and heavy metals), and inadequate or improper disposal of wastewater and solid waste (including hazardous materials) (Nuseibeh and Nasser Eddin, 1995; Abdul-Jaber et al., 1999; Abed and Wishahi, 1999; Wishahi and Awartani, 1999; PWA, 2001b).

There is no advance treatment of water in the West Bank except for using chlorine to disinfect domestic municipal wells and springs. This is done simply by adding sodium hypochlorite to the water, just prior to its distribution from tanks and reservoirs. In the case of springs and many private wells, disinfecting is not carried out regularly. Even in municipal wells, the efficiency of chlorination is not always up to the required acceptable levels (from 0.1 to 0.5 mg/l). Water that has a high content of organic material, sulphides, ferrous iron, and nitrites require increased chlorine amounts, yet this is not always taken into account (UNEP, 2003).

A GIS-based analysis of the quality and quantity data for the West Bank aquifers is conducted. The analyses furnished in this research do pertain to the quality and quantity issues in the groundwater of the West Bank at different scales and for different explanatory parameters. The analysis in this research will be elucidated according to the following categorization; the inception analysis, the data analysis, and finally the decision analysis. Data were mainly collected from the Palestinian Water Authority (PWA). Publications, reports, and personal communications will be joined to these data in order to well identify the problem. Statistical analysis and data processing will be carried out using the Microsoft Excel and ArcGIS software. Management options will be discussed to draw the conclusions then set up recommendations.

1.2 Research Objectives

The following are the research objectives:

1. To characterize the variability and spatiality of groundwater contamination from nitrate and/or chloride in the groundwater aquifers;

2. To improve our understanding, quantitatively and qualitatively, to the issue of groundwater contamination; and

3. To demonstrate the applicability and practicability of the GIS

applications in water resources system analysis and the corresponding applications in the field of environmental and civil engineering.

1.3 Research Motivations

The following are the research motivations:

1. Groundwater is almost the sole water resource for the Palestinians and thus the assessment of the quality and quantity is vital;

2. No in-depth research was carried out to evaluate the statistical measures pertaining to the groundwater resources in the West Bank;

3. Site-specific characterization is needed to identify areas of high groundwater contamination;

4. Support and enhancement of management and assessment to the water resources;

5. The groundwater contamination problem in the aquifer systems needs to be persuasively and heedfully highlighted to the ordinary public people; and

6. Using GIS technology enables the ease of data processing, visualization, sorting, assessment, computations, and map preparation when compared with traditional technologies.

1.4 Problem Identification

The following are the relevant problems:

1. The extent of groundwater contamination of the West Bank aquifer systems is not properly characterized;

2. The limitations to use and utilize the groundwater resources have to be obviously recognized;

3. The contributing man-made pollution sources to the groundwater contamination problems are badly identified; and

4. The impact of the key and explanatory parameters on the groundwater resources quality and quantity were never scientifically researched and investigated.

1.5 Research Questions

The key purpose of this research is to address, and if possible to answer, the following questions:

1. What are the key and explanatory parameters that dictate the groundwater quality?

2. What is the spatial extent of the pollution occurrences in the groundwater resources of the West Bank in terms of nitrate and chloride?

1.6 Research Outputs

The following are the research outputs:

1. Delineate the key and explanatory parameters' impacts on the groundwater quality;
2. Provide an assessment analyses that can be utilized by decision makers for designing any proposed management options;
3. A map shows the delineated areas of high groundwater contamination;
4. Protection alternative measures to restore the quality of groundwater resources in the West Bank aquifer systems through the minimization of the extent of the pollution sources;
5. A better groundwater quality monitoring program design; and
6. Better plans to direct modeling efforts to hot areas that witness significant contamination.

1.7 Research Methodology

The analyses in this research are elucidated according to the following categorization; the inception analysis, the data analysis, and finally the decision analysis. Figure 3 depicts the research methodology of this research illustrating the different analysis classes.

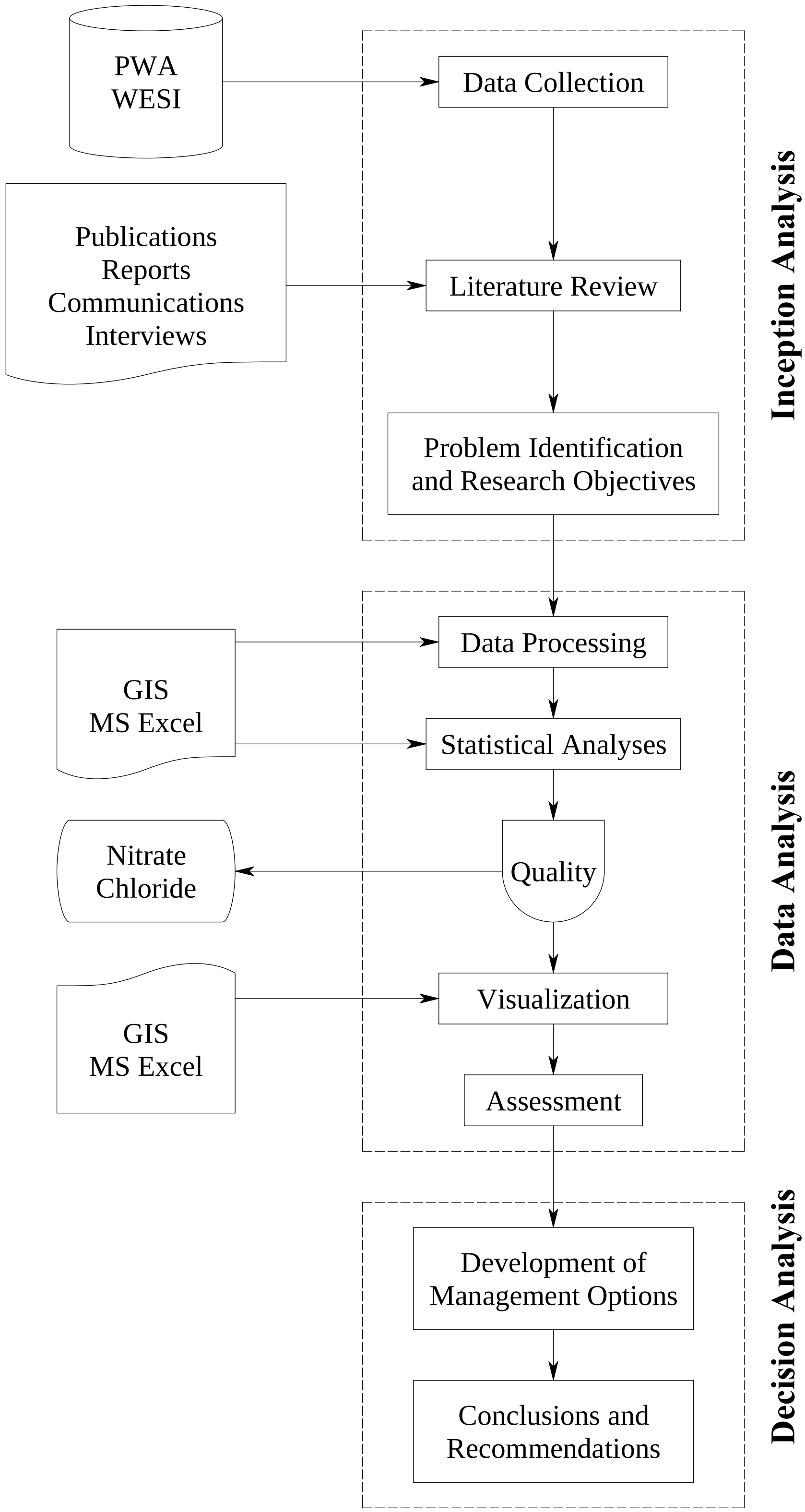


Figure 3: The flowchart of the methodology of the analyses implemented in the research

The first step in the methodology is the inception analysis. The quality and quantity data used in this research were obtained entirely from the Palestinian Water Authority (PWA). The data covers the period from 1965 to 2004. The corresponding well data were aggregated using the database of the Water and Environmental Studies Institute at An-Najah National University. That great deal of all these data is available in a format that is accessible via GIS technology. All available data were assembled into a single composite database to facilitate the analysis.

Many previous studies interested in the quality and quantity disciplines of the groundwater are available. Some of these studies were carried out in the West Bank. This type of studies is extremely useful to recognize the current situation, assess groundwater status in the West Bank, identify major problems and obstacles, and explore research areas that require further study and analysis.

Many collected studies were carried out abroad in different countries. These studies are helpful in providing a general blueprint of how to diagnose problems, conduct analysis, propose solutions, and widen disciplines of study and analysis. A variety of these local and international publications and reports are available in addition to the interviews and personal communications employed in data collection and characterization. As a result of the profound readings carried out before, it was obviously noticed that there is a dire need for a study that utilizes GIS and statistical analyses of the huge and scattered quality and quantity data of the West Bank aquifers in characterization, assessment, and decision making.

The second step in the methodology is the data analysis. It is important to mention hereby that the procedure followed in this research has its distinctive style. The analysis chapters of this research are by large independent from each others. This means that each chapter has its own introduction, data collection, processing methods, data analysis, and conclusions. Nevertheless, this does not mean, in any way, that there is no connection between the different chapters and in different instances the reader is referred to different locations from different chapters.

Data screening, sorting, and processing were conducted for the huge quality data of the groundwater in the West Bank. The quality data includes measurements of a variety of parameters. The database contains the concentration of many constituents in the wells and includes: calcium, chloride, dissolved oxygen, bicarbonate, potassium, magnesium, sodium, nitrate, sulphate, and total dissolved solids. Furthermore, pH, temperature, and electric conductivity of the water samples are also measured. A great deal of the available data covers the nitrate and the chloride concentration for different time spans and locations. Both nitrate and chloride are the most significant parameters, compared to the other parameters, affecting the quality of the groundwater in the West Bank and are as the most widespread contaminants.

That great deal of quality data was made available by the researcher in a format that is accessible via GIS technology. Using the GIS capabilities and techniques provides the ease of data processing, visualization, assessment, analysis, and map preparation. A variety of figures, charts, and box-plots were also developed using MS Excel. At the end of the main research chapters, conclusions are briefly deduced.

Nitrate contamination in the West Bank aquifers is comprehensively studied in chapter five. The analyses furnished in the subsections of chapter five do pertain to the nitrate occurrences in the groundwater of the West Bank at different spatial levels and for different explanatory parameters. Data analyses in these subsections of chapter five cover the topics shown in Figure 4.

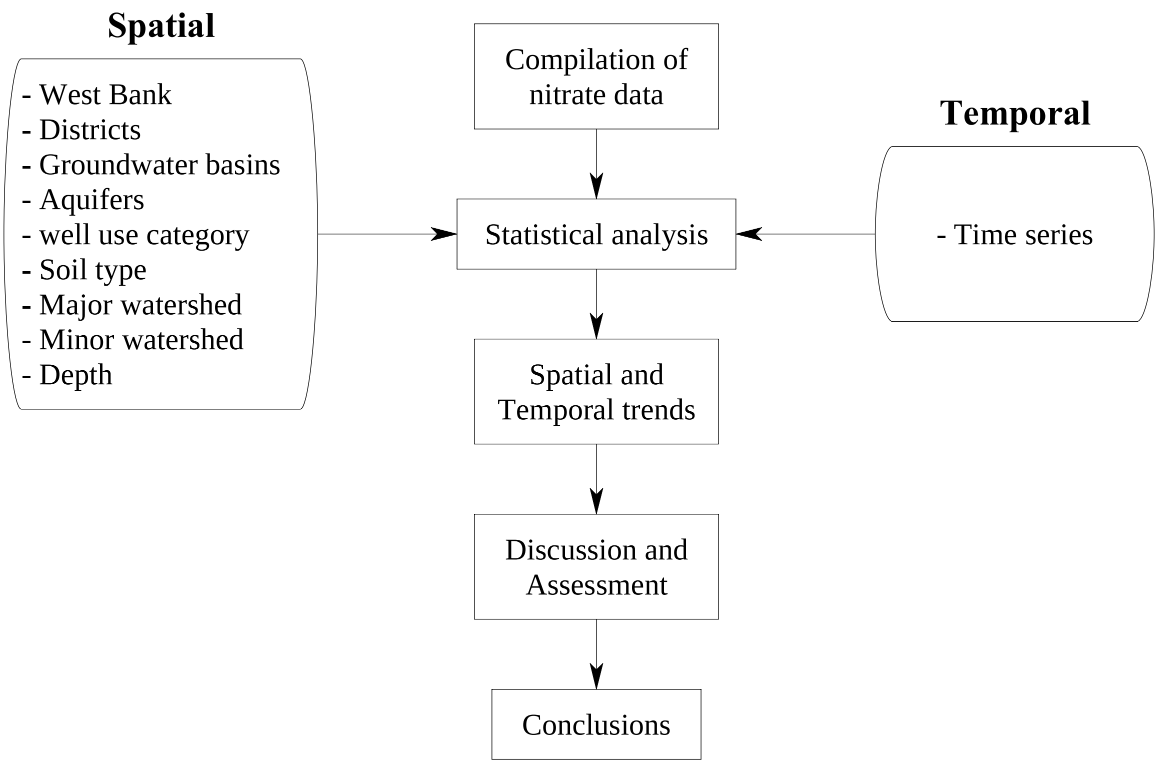


Figure 4: The flowchart of the conceptual methodology used in analyzing nitrate occurrences in the groundwater of the West Bank

Chloride contamination in the West Bank aquifers is thoroughly studied in chapter six. The analyses furnished in the subsections of chapter six do pertain to the chloride occurrences in the groundwater of the West Bank at different scales and for different explanatory parameters. Data analyses in these subsections of chapter six cover the topics shown in Figure 5.

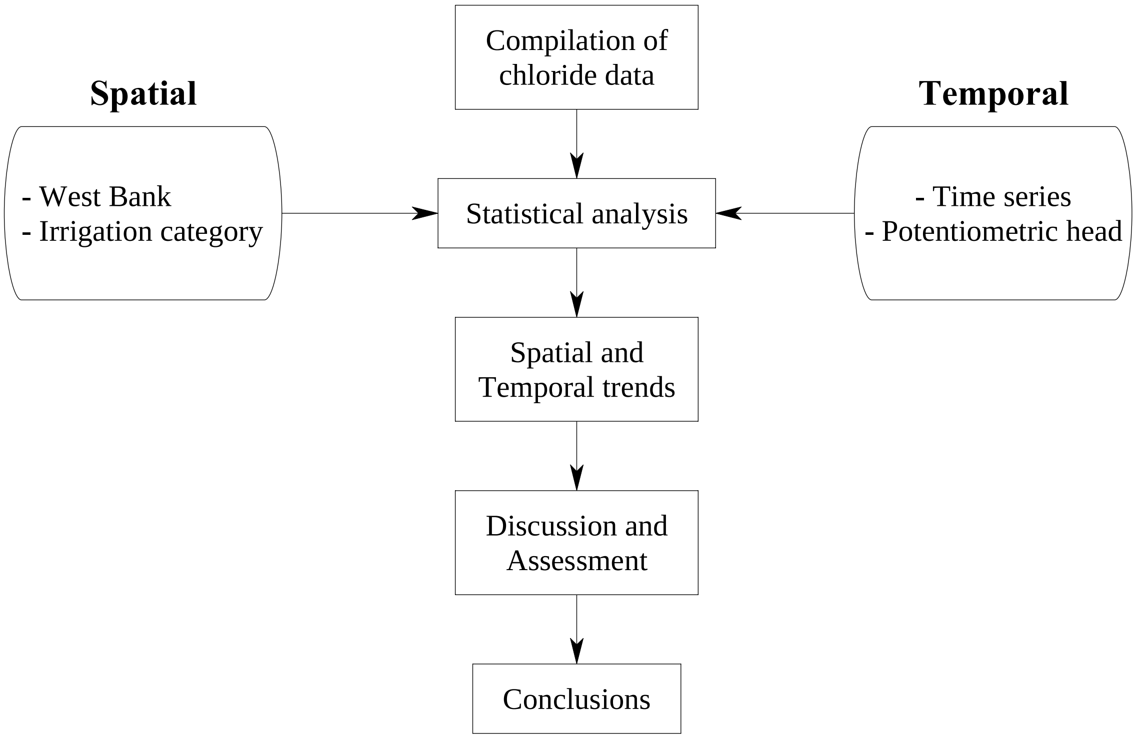


Figure 5: The flowchart of the conceptual methodology used in analyzing chloride occurrences in the groundwater of the West Bank

The third step in the methodology is the decision analysis. In this step, the main conclusions are highlighted. The main conclusions are a brief summary of the detailed conclusions of the main chapters. At the end of the research, the major recommendations for both public and professionals are set up.

CHAPTER TWO

LITERATURE REVIEW

The Middle East is a meeting point of many escalating environmental threats. This is particularly the case in Palestine. Long-term environmental degradation has occurred over recent decades. In an already densely populated area, there are additional problems of scarcity of water resources and land, rapid population growth, a long lasting refugee situation, climate change, desertification, and land degradation.

Several studies and researches were carried out in the West Bank to raise serious concerns regarding the degradation of water quality in many areas, as well as the issue of unsustainable pumping of groundwater from aquifers. In environmental terms, there are many inter-linkages and interactions between water quality and water quantity as shown in Figure 6.

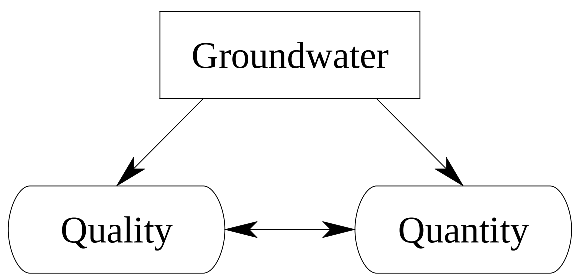


Figure 6: Constraints to utilize groundwater from aquifer systems

The West Bank lies over the mountain groundwater basin. The mountain basin is divided into the eastern basin, the north-eastern basin, and the western basin. The eastern basin and part of the north-eastern basin flow east towards the Jordan River and the Dead Sea (see Figure 7). The western basin and part of the north-eastern basin flow westerly towards the Mediterranean Sea (Scarpa, 1994; Abdul-Jaber et al., 1999; Abed and Wishahi, 1999; PWA, 2001b; UNEP, 2003; Almasri, 2005). It is important to realize that the correct delineation of the boundaries of the different aquifer basins plays a major rule in the determination of their flow patterns. Therefore, many studies were performed to delineate the boundary conditions of aquifer basins (see PWA, 2001a).

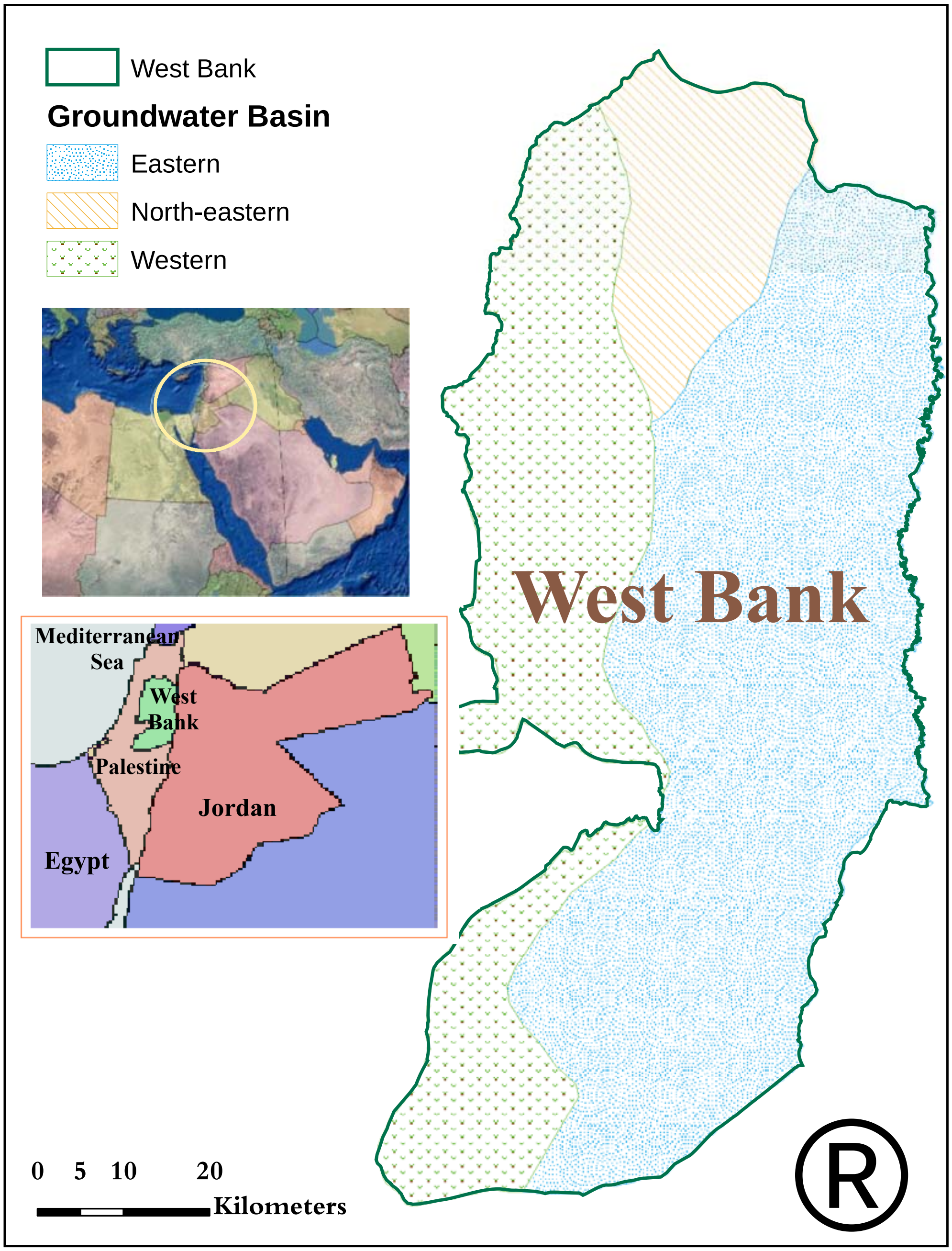


Figure 7: The groundwater basins of the West Bank

2.1 Local Studies of Groundwater Quality

The United Nations Environmental Program (UNEP) carried out a comprehensive desk study in 2003 on the environmental situation in the West Bank and Gaza Strip. This desk study includes an assessment of drinking water quality and quantity, wastewater, solid and hazardous waste as well as conservation and biodiversity. Earnest efforts were performed in this study to outline the state of the environment in Palestine, to identify major areas of environmental damage requiring urgent attention, to address environmental needs in the region, to improve the environmental situation, and to assist in solving urgent environmental concerns. This desk study raises serious concerns on both the degradation of water quality in many areas, as well as the issue of unsustainable pumping of water from aquifers. Groundwater in most areas of the West Bank is considered to be of good quality. However, aquifers are vulnerable to contamination due to disposal of untreated wastewater. In other areas, groundwater is unsuitable for drinking because of its high salinity.

Abed and Wishahi (1999) carried out a comprehensive field study on the geology of Palestine. This field study includes an assessment of water resources, geologic formation of Palestine, groundwater basins, water uses, and many other disciplines. This study also assessed the quality of drinking water in Palestine. Nitrate contamination of groundwater is caused by infiltration of fertilizers and raw sewage, and elevated concentrations are found throughout the West Bank (UNEP, 2003). A detailed study (Marei and Haddad, 1998) found nitrate levels above the WHO standard for drinking water (i.e. > 50 mg/l) in up to one-third of the sampled wells in the Jordan Valley, Nablus, Jenin, and Tulkarm districts.

The water quality for the Palestinian wells in the West Bank was analyzed by PWA (2001b). The water quality has been considered for only two major parameters: chloride and nitrate concentrations. There is chloride data of 363 wells available and nitrate concentration for 365 wells. It was found that 96 wells exceed the WHO standards for drinking water where none of which is domestic. Almost all of these wells are located in the Eastern Basin (Jericho area) and most of them tap the Pleistocene aquifer. As for the nitrate analyses, about 97 wells have concentrations exceeding the WHO standards for drinking water, 13 of which are domestic wells. The maximum nitrate concentration in the domestic wells was measured at 112 mg/l in the Tulkarm area tapping the Cenomanian-Turonian aquifer.

Abdul-Jaber et al. (1997) studied the effect of contamination from wastewater on the shallow perched aquifer systems in the northern West Bank. They concluded that most of the springs and wells within the heavily populated areas were contaminated probably with wastewater through infiltration from septic tanks and the open conduits of raw sewage.

Abed Rabbo et al (1998) introduced the results of a study of the water quality and hydrochemistry of the wells of the Herodion - Beit Fajjar well field. The study showed that this water is biologically and chemically good for drinking and that there are slight variations in the water chemistry which may be controlled by the seasonal rise and fall of the water table in the aquifer.

Qannam (1997) studied, classified, and evaluated the water of the wells in the southern part of the West Bank, south of Jerusalem, for both drinking and irrigation purposes and highlighted the main environmental water-related issues.

The study showed that most of the wells have low sodium, potassium, chloride, sulphate, and nitrate concentrations, and thus are suitable for both drinking and irrigation purposes.

Scarpa et al. (1998) introduced the results of a chemical and biological study of the wells extracting water from the unconfined aquifer system in the northern West Bank. the excessive use of fertilizers, wide distribution of cesspits and uncontrolled disposal of wastewater were considered probable sources of the wide spread biological contamination and the alarming nitrate, chloride, and potassium levels that were found in many of the wells studied.

Chemical and microbiological analyses were carried out for 210 water samples from domestic and agricultural wells throughout the West Bank. The study showed that the water of the West Bank wells is chemically suitable for drinking purposes, although some wells show higher nitrate concentrations than the recommended level by WHO. In addition, most of the West Bank wells are suitable for irrigation, having a low to medium salinity hazard (Abdul-Jaber et al., 1999).

The water quality of the West Bank springs was thoroughly investigated in a study carried out from 1995 to 1997 (Rabbo et al., 1999). About 400 samples were collected and analyzed, taking into account several drinking water parameters. The main contaminants encountered in spring water are nitrate and coliform bacteria from sewage. Some heavy metals are also found, but in nearly all cases these are below the recommended WHO guideline values. However, few samples showed nitrate concentrations above the WHO guideline value of 50 mg/l: two out of four samples in Jenin district, three of 17 in Ramallah, four of 21 in Bethlehem, nine of 42 in Hebron, one of 20 in the Jordan Valley, and none of 18 in Nablus district. Conversely, the majority of the samples for which microbiological analyses were performed were found to be contaminated by infectious sources. It is likely that the contamination is due to the springs being situated close to, and/or downstream from, infectious sources, such as raw sewage from cesspits, sewer leakages, land irrigated with wastewater, or sewage discharged directly to wadis and open ground.

A serious problem in the Jordan valley was documented by Abed and Wishahi, (1999). The chloride concentration of water samples for the wells distributed in the Jordan Valley were measured. Elevated chloride concentrations were mainly encountered in the water samples due to the dissolution phenomenon of the rock in the area.

There have been a number of groundwater studies conducted on the West Bank aquifers. In the northeastern aquifer, Aliewi et al. (1997) made an assessment of the vulnerability of the upper part of this aquifer to wastewater disposal from the City of Nablus. They showed that the magnitude and direction of hydraulic gradient indicate that pollution can be expected, a view backed up by their numerical simulation. They ascribed existing pronounced variations in groundwater quality to pollution that has already occurred.

Pesticide contamination of groundwater is considered to be a major environmental issue in the West Bank, in particular in the Tulkarm area, where greenhouse farming is important (ARIJ, 1998). Microbiological groundwater quality in the West Bank is of major concern, since there are frequent outbreaks of diarrhea among the Palestinian population. Ministry of Health data indicated that 600 of 2,721 samples taken from wells and tanks failed to meet WHO bacteriological standards for drinking water (MOH, 2001). Scarpa et al. (1998) and Abdul-Jaber et al. (1999) showed microbiological pollution to be widespread in all the mountain aquifers. Rather few wells in Bethlehem and Hebron districts were found to be permanently contaminated, though all those tested were subject to at least periodic contamination.

There is relatively little information concerning the impacts of industrial pollution in the West Bank. Though one recent study (SWEMP, 1999) provided some insight and identified pollution ‘hot spots’, including industrial sites such as stone-cutting facilities, olive oil factories, slaughterhouses, and tanneries. While there are no available data concerning the impact of industrial effluent on groundwater quality in the region, it is a fact that almost all industrial wastewater flows directly into municipal wastewater systems without pre-treatment (UNEP, 2003).

The monitoring and assessment of drinking water quality situation in the West Bank are discussed in more detail in the technical papers and studies by Nuseibeh and Nasser Eddin (1995), Abdul-Jaber et al. (1999), ARIJ (2002), MEnA (2001), PWA (2001b), Rabbo et al. (1999), Scarpa et al. (1998), UNEP (2003), Wishahi and Awartani (1999), and Zayed et al. (2005).

2.2 Worldwide Studies of Groundwater Quality

Regional long-term trends and occurrences of nitrate in the groundwater of agricultural watersheds in Whatcom County, Washington State was documented and evaluated by Almasri and Kaluarachchi (2004a). The analysis showed that the areas with nitrate concentrations above the maximum contaminant level are areas characterized by heavy agricultural activities. The analysis also showed that high nitrate presence corresponds to areas with both high groundwater recharge and high on-ground nitrogen loadings. Therefore, Almasri and Kaluarachchi (2005) present an integrated methodology for the optimal management of nitrate contamination of groundwater combining environmental assessment and economic cost evaluation through multi-criteria decision analysis. The results showed the importance of using this integrated approach which predicts the sustainable on-ground nitrogen loadings and provides an insight into the economic consequences due to the satisfying of the environmental constraints.

Saffigna and Keeney (1977) studied nitrate and chloride in groundwater under irrigated agriculture in Central Wisconsin. The results of this study indicate that the nitrate and chloride concentrations in the groundwater are significantly above background, and that the main source is the irrigated agriculture in the region. It was found that nitrate and chloride concentrations varied widely between adjacent wells. Differences in the concentrations of nitrate and chloride between irrigation wells closely reflected the irrigation and fertilizer practices on surrounding fields.

The role of water level data in the investigation of groundwater quality or contamination problems is sometimes underappreciated. To a large degree, predictions about the speed and direction of movement of groundwater contaminants are based on determination of the gradient (slope) of the water table or potentiometric head in the affected aquifer. As an example, pumping by public supply wells completed in the Upper Potomac Raritan Magothy aquifer near the New jersey coastline resulted in a decline in hydraulic heads to more than 40 feet below sea level (Schaefer and Walker, 1981). This resulted in the landward reversal of groundwater flow and migration of saline water. In addition, groundwater in parts of the aquifer became progressively degraded by sharply rising chloride concentrations.

Chloride concentration also can occur in noncoastal areas where the fresh water aquifer is invaded by saline water or brines upwelling from deeply buried sedimentary rocks. Spangler et al. (1996) documented an example of this problem in a study of the quality of water in the Navajo aquifer in southeastern Utah State.

2.3 Local Studies of Groundwater Quantity

The major water resources in the West Bank consist of groundwater and rainwater harvesting. There are 40 municipal wells in the West Bank that are used either wholly or partially by Palestinians. Their annual yield is around 30 mcm (EQA, 2002a).

This is insufficient to meet water demand and the deficit is supplied mainly through springs or through Mekorot (the Israeli Water Company). Many agricultural wells are also used for domestic purposes. There is a total of 300 springs in the West Bank of which more than 100 are considered to have substantial yields. The total average annual yield of the springs is estimated to be around 60 mcm. In the West Bank, springs are a secondary, but important, source of water for drinking and other domestic purposes. They are also used to meet agricultural needs throughout the West Bank. Rainfall cisterns collect around 6.6 mcm per year from rooftops. The average per capita water consumption is around 70 liters per capita per day which is extremely lower than the international standard. Approximately 88 % of the total West Bank population and 55 % of localities (towns and villages) have access to piped water supply systems (EQA, 2002b).

Wishahi and Awartani (1999) initiated a study concerned with the current conditions and rehabilitation prospects of the wells in the Jordan Valley. There are 133 Palestinian wells in the Valley in addition to 35 wells drilled by Mikorot for Israeli settlers. The total quantity of water discharged by Palestinian wells amounted in 1996 to 16.1 mcm, whereas that produced by Israeli wells is estimated at 43 mcm. Water consumption by Palestinians in the Valley is estimated at 64 mcm. Wells contribute around 25 percent of total consumption and the rest is obtained from springs.

Much before September 2000, most of the existing water supply pipes in the West Bank were in urgent need of repair and rehabilitation with leakage losses in the transmission and distribution network of about 30-40 % (PECDAR, 2001). The urgency of lowering these losses is further underlined by the scarcity limited accessibility to the water resources.

PWA (2001b) prepared a working report which is an inventory of the data on the water resources in Israel and West Bank with emphasis on the literature review on modeling studies of the Western Aquifer basin. This report provides briefs on all basins with respect to their boundaries, utilized aquifers, and well and spring stresses. The PWA database on wells and springs of the West Bank was assembled and sorted with regard to the governorates, utilized basin, tapped aquifer, usage, type, and who controls the well or spring.

It was found during the Inception Phase that there is a need to establish a GIS database that can deal with huge numbers of scattered studies, reports, maps of different scales, raw time series data of many hydrological parameters, etc. These materials are well organized within the project database and are ready to be used for the development of the conceptual models for the study areas.

There have been a number of groundwater modeling studies conducted in the West Bank aquifers. In 1995, TAHAL (an Israeli consulting firm) prepared three technical reports to serve as guidelines for use by the PWA in their attempt to meet the Palestinian short-term water supply needs from the eastern aquifer. The reports document the development of MODFLOW-based groundwater flow models of the regional limestone aquifer system that underlies the entire eastern aquifer. The first model (Meir and Guttman, 1984) covers the area of the Wadi Faria catchment only. It is a simple model that does not address the real problems of the eastern aquifer. The second model (Guttman and Zukerman, 1995) covers the Upper aquifer system within the eastern aquifer. The third model (Guttman, 1995) covers the three groundwater flow systems within the eastern aquifer, which are the Upper and Lower aquifers of the regional limestone aquifer system and the unconfined aquifer in the northeastern part of the eastern aquifer in the vicinity of Jericho. TAHAL's models fall well short of simulating the complexity of the eastern aquifer particularly with regard to the interaction between the three sub-systems.

In 1996, USAID contracted an American company; Camp, Dresser, and McKee (CDM), to carry out a major water resources development project in the

West Bank. A major task of this project was to assess the sustainable yield of the eastern basin. CDM found that there is a need to simulate the flow systems of the eastern aquifer in more details. CDM released their modeling reports in 1997 and 1998 outlining the preliminary conceptual model and final model, respectively.

However, only one study that was conducted by Bachmat (1995) deals with the western aquifer. The purpose of this study is to produce an economic model of the western aquifer. It includes a cost estimate of groundwater pumpage. A flow model was introduced for the purpose of the study. Bachmat found that the yield is almost the same as replenishment. However, the exploitation nowadays is more than the replenishment indicating mining of the aquifer basin.

2.4 Worldwide Studies of Groundwater Quantity

Groundwater systems are dynamic and adjust continually to short-term and long-term changes in climate, groundwater withdrawal, and land use. Water level measurements from observation wells are the principal source of information about the hydrologic stresses acting on aquifers and how these stresses affect groundwater recharge, storage, and discharge. Long-term, systematic measurements of water levels provide essential data needed to evaluate changes in the resource over time, to develop groundwater models and forecast trends, and to design, implement, and monitor the effectiveness of groundwater management and protection programs (Taylor and Alley, 2001).

All water level monitoring programs depend on the operation of a network of observation wells. Decisions made about the number and locations of observation wells are crucial to any water level data collection program. Ideally, the wells chosen for an observation well network will provide data representative of various topographic, geologic, climatic, and land use environments. The best observation network requires distributed wells that are unaffected by pumping, irrigation, and land uses that affect groundwater recharge. These and many other technical considerations pertinent to the design of a water level observation network are discussed in more detail in technical papers by Peters (1972), Winter (1972), and Heath (1976).

Statistical evaluation of water level data collected for one or more decades can be used to estimate future high water levels. In popular areas of Rhode Island in the United States, water levels normally change by several feet annually but can change by as much as 20-30 feet (Socolow et al., 1994). Estimates of the maximum (highest) probable groundwater levels are needed to assess the likely chances for basement flooding, damage to building foundations due to increased hydrostatic pressure, and the potential failure of septic tanks and leach fields in unsewered areas. To address this problem, USGS hydrologists developed a technique to estimate the potential maximum groundwater level at a site where only a single measurement of water level may be available (Frimpter, 1980; Frimpter and Fisher, 1983).

CHAPTER THREE

DESCRIPTION OF THE STUDY AREA

The area under consideration in this research is the West Bank. In this chapter, general characteristics and features pertinent to the West Bank are illustrated. These characteristics include the districts, population, geography, ecology, climate, water resources, socio-economic situation, and environment.

3.1 Districts

The West Bank is divided into eleven districts: Bethlehem, Hebron, Jenin, Jericho, Jerusalem, Nablus, Qalqilya, Ramallah and Al-Bireh, Salfit, Tubas, and Tulkarm (see Figure 8). The districts are sub-divided into 89 municipalities. In addition, local councils have been formed to manage all infrastructure and basic services.

3.2 Population

Approximately 2.3 million Palestinians live in the West Bank (PCBS, 1997). Almost 40 percent of Palestinians are refugees since 1948. Around 65 % of the populations live in urban areas (UNFPA, 2001). Annual population growth is estimated at 4.8 % (UNDP, 2002).

3.3 Geography

The West Bank has an area of 5,800 km^2, a 130 km length from north to south and between 40 and 65 km in width from east to west (Abdul-Jaber et al., 1999). The West Bank is mostly composed of limestone hills that are between 700 and 900 m in high. The lowest point of the study area is the Dead Sea at 400 m below the sea level, and the highest the Tall Asur at 1,022 m above sea level (UNEP, 2003). Fertile soils are found in the plains. Soil cover is generally thin and rainfall is erratic. The West Bank formations are comprised of limestone, dolomite, chalk, marl, chert, shale, and clays (PWA, 2001b).

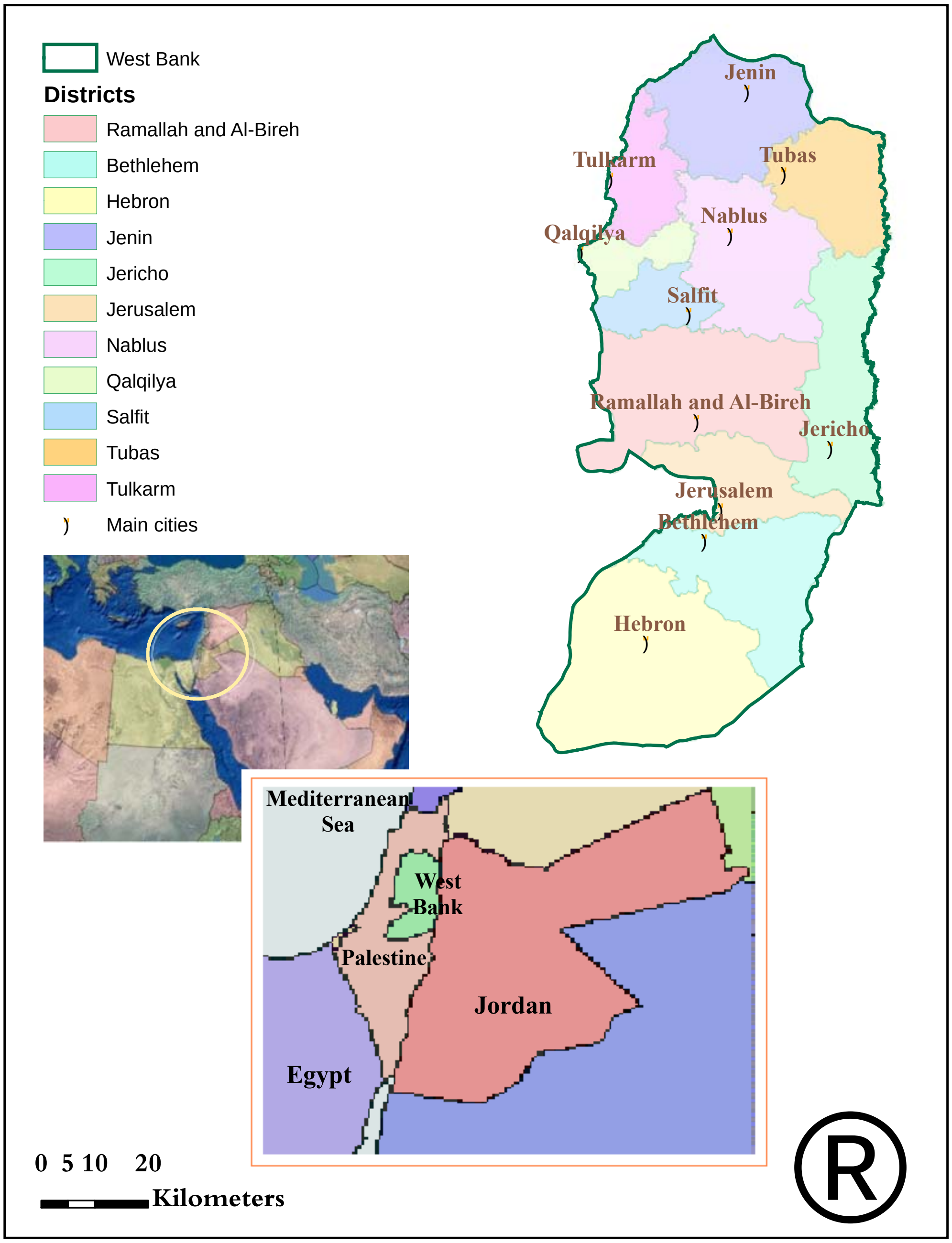


Figure 8: The regional setting of the West Bank, the eleven districts, and the main Cities.

3.4 Ecology

Palestine can be divided into five main ecological sub-regions: the Mediterranean shoreline coastal plain; the upper coastal plain; the central highlands; the semi-arid eastern slope steppes; and the arid semi-tropical Jordan Valley. The dry southern West Bank, eastern slopes and central Jordan Valley are composed of Mediterranean savanna grading into land dominated by steppe brush and spiny dwarf shrubs. The southern Jordan Valley around Jericho and the Dead Sea is also influenced by Sudanian vegetations (UNEP, 2003).

3.5 Climate

The climate in the Mediterranean region has four months of hot dry summer and a short mild winter with rain from November to March. The climate in the West Bank can be characterized as hot and dry during the summer and cool and wet in winter (UNEP, 2003). The climate becomes more arid to the east and south. The central highlands, trending roughly north-south, are part of the South Syrian Arc fold system. These mountains act as a climatic barrier, responsible for the rain-shadow desert to the east, down to the Dead Sea (Abdul-Jaber et al., 1999).

The mean summer temperatures range from 30 °C at Jericho to 22 °C at Hebron which is 850 meters above sea level. The mean ranges in winter from 13 °C at Jericho to 7 °C at Hebron. The annual average relative humidity is about 52 percent at Jericho (UNEP, 2003). Evaporation is high in summer when there is always a water deficit. Annual rainfall on the Central Highlands averages 700 mm and becomes less than 100 mm, at the Dead Sea. However, great variations in rainfall amount and distribution exist. It is common for only half the average to fall in any one year (Abdul-Jaber et al., 1999). The West Bank is composed of four main climatic regions: hyper-arid; arid, semi-arid, and sub-humid. Figure 9 shows the main climatic regions of aridity in the West Bank.

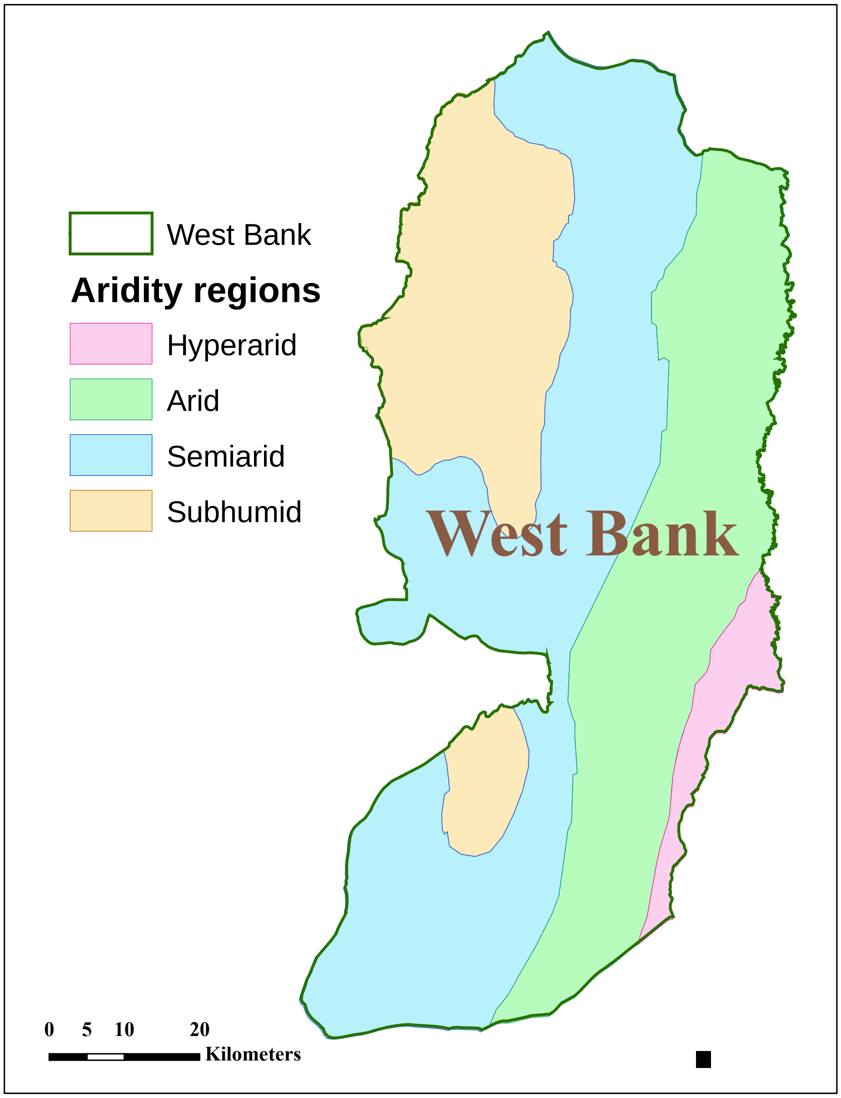


Figure 9: The main climatic regions of aridity in the West Bank

3.6 Water Resources

The principal water resources available to Palestinians include groundwater, springs, and harvested rainwater (UNEP, 2003). There is little surface water and thus groundwater is the principal source of water in the West Bank. Both groundwater and surface water drain either westwards to the Mediterranean or eastwards to the Jordan River and Dead Sea. The lower Jordan River flows southwards at the eastern edge of the West Bank from Lake Tiberias to the Dead Sea (Abdul-Jaber et al., 1999).

The West Bank lies over the Mountain aquifer. The Mountain aquifer is divided into the eastern aquifer, the northeastern aquifer, and the western aquifer as depicted in Figure 7. The eastern aquifer and part of the northeastern aquifer flow east towards the Jordan River. The western aquifer and part of the northeastern aquifer flow westerly towards the Mediterranean Sea (Scarpa, 1994; Abed and Wishahi, 1999; PWA, 2001b; Almasri, 2005).

The quantity of cross boundary fluxes between the groundwater aquifer basins and the inter-aquifer flow within the basins are not well understood, making it difficult to accurately quantify the total groundwater storage and yield in each aquifer system (PWA, 2001b). This uncertainty is reflected by the wide ranges given for each basin, as shown in Table 1.

Table 1: Reported annual recharge rates of the groundwater basins in the West Bank (PWA, 2001b)

Aquifer basin	**Annual recharge rate (mcm)**
Eastern	100 – 172
North-eastern	130 – 200
Western	335 – 380
Total	565 - 752

In a regional context, the Jordan River is about 260 km long and drains a total area of 18,300 km^2 (UNEP, 2003). The river system that composes the Jordan River basin is composed of four tributaries: Banias, Hasbani, Dan, and Yarmouk. Banias, Hasbani, and Dan meet in the north of Palestine to form the Upper Jordan River that flows into Lake Tiberias.

However, Yarmouk River flows in a southwesterly direction into the Lower Jordan River forming the border between Jordan and Syria, and Jordan and Palestine. Yarmouk River has a higher flow during the winter periods which is used to dilute the increasing salinity of the Jordan River (Lonergan and Brooks, 1994).

CHAPTER FOUR

THE QUALITY OF DRINKING WATER: A GENERAL PERSPECTIVE

4.1 General Background

There are limits to the amounts of water that can be withdrawn from surface water bodies and groundwater aquifer systems. There are also limits to the amounts of potential pollutants that can be discharged into them. Once these limits are exceeded, the concentrations of pollutants in these resources may reduce or even eliminate the benefits that could be obtained from these resources (Almasri, 2005). As such, inclination in the utilization of water resources could be caused by quality deterioration, quantity declination, or both.

Many freshwater resources are contaminated due to human activities and man-made effects. More than 20 percent of the world's population do not have access to safe drinking water and a greater proportion still do not have even basic sanitation (Mason, 2002). Every day some 25,000 children die from their every day use of water where 44% of these deaths are simply from diarrhea. It is not only children who suffer. It is estimated that, at any one time, half the inhabitants of developing countries are ill with diseases caused by dirty water and poor sanitation (Mason, 2002). Some 80 percent of all illness and one third of all deaths are due to unwholesome water. In addition, water borne diseases also result in great economic loss. In India, for example, it is estimated that 73 million working days are wasted each year, costing $600 million in lost production and in health care due to water borne diseases. The United Nations 1994 Development Report has estimated that a 12 percent cut in military spending worldwide could provide safe drinking water and primary healthcare for every one. Nevertheless, 18 developing countries were spending more on the military than on both health and education (Mason, 2002).

The quality of drinking water is significantly dependent on the source. Fortunately, the only source of drinking water in the West Bank is groundwater which is clean and reliable. Nevertheless, people in the past looked carefully about contamination in drinking water using simple measures. Those measures were domestically altered either to filter, sediment, boil, or combine among these processes to provide a purified and a safe water source especially for infants. The responsibility for quality assurance of drinking water was transferred to the local authorities developing municipal drinking water networks. The quality of drinking water in the municipal networks is maintained by disinfection. The disinfection is the most powerful and reliable method nowadays to prevent water borne diseases.

Drinking water is required to meet stringent microbiological and chemical standards of quality to prevent water borne diseases and health risks from toxic chemicals. This chapter provides a good understanding to the drinking water standards. Furthermore, the biological and chemical parameters influence the quality of drinking water are discussed. Hence, disinfection of drinking water with chlorine to guarantee compliance with standards is satisfied.

4.2 Guidelines for Drinking Water Quality

Drinking water quality is an issue of concern that entails risks for human health in developing and developed countries world-wide. The risks arise from infectious agents, toxic chemicals and radiological hazards. Experience highlights the value of preventive management approaches spanning from water resource to consumer. The quality of drinking water may be controlled through a combination of protection of water sources, prevention of contamination occurrences, control of treatment processes and management of the distribution and handling of water. Guidelines must be appropriate for regional, national, and local circumstances, which require adaptation to environmental, social, economic and cultural circumstances and priority setting. The World Health Organization (WHO) was one of the key and leading institutions in setting up these guidelines (WHO, 2006).

The primary aim of the WHO Guidelines for Drinking water Quality (GDWQ) is the protection of public health. The Guidelines are intended to be used as a basis for the development of national standards that, if properly implemented, will ensure the safety of drinking water supplies through the elimination, or reduction to a minimum concentration, of constituents in drinking water that are known to be hazardous to health (WHO, 2006). The recommended guidelines are not mandatory limits. They are developed to be used in the preparation of risk management strategies which may include national or regional standards in the context of local or national environmental, social, economic and cultural conditions. In developing national drinking water standards based on the guideline values, it will be necessary to take account of a variety of geographical, socio-economic, dietary and other conditions affecting potential exposure (WHO, 2006).

The United States Environmental Protection Agency (US EPA) is the major agency authorized to set drinking water standards in the US. It is one of the most powerful agencies all over the world. Several countries adopt the guidelines of US EPA to regulate the use of water resources and control the potential areas of contamination.

For instance, the Palestinian Standards Institution (PSI) is the local authority to set the drinking water standards, which assimilates the Jordanian Standards Institution (JSI) (PSI, 2005). Intern, the JSI relies greatly on the WHO and US EPA standards. Nonetheless, water quality issues has been neglected to a certain extent, with most attention focused on measures to solve water quantity and supply problems.

4.3 Categories of Drinking Water Standards

There are two categories of drinking water standards (US EPA, 2006; WHO, 2006):

4.3.1 Primary standards

These standards are legally-enforceable standards that apply to public water systems. Primary standards protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health and are known or anticipated to occur in water. They take the form of Maximum Contaminant Levels (MCLs) (US EPA, 2006). MCL is the highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the Maximum Contaminant Level Goals (MCLGs) as feasible, using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards. MCLG is the level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals (US EPA, 2006).

Table 2: A variety of primary standards of the drinking water quality with necessary information (US EPA, 2006)

Class	**Contaminant**	**MCLG (mg/l)**	**MCL (mg/l)**	**Potential Health Effects from Ingestion of Water**	**Sources of Contaminant in Drinking Water**
1	Cryptosporidium	0.0	0.0	Gastrointestinal illness	Human and fecal animal waste
2	Trihalomethanes (THMs)	none	0.1	Liver, kidney, nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection
3	Chloramines	4	4	Eye/nose irritation; anemia	Additive to control microbes
4	Nitrate	50	50	Shortness of breath for infants and blue-baby syndrome	Runoff from fertilizer use; leaching from septic tanks
5	PCBs	0.0	0.0005	Skin changes; immune deficiencies; increased risk of cancer	Runoff from landfills; discharge of waste chemicals
6	Uranium	0.0	30 ug/L	Increased risk of cancer, kidney toxicity	Erosion of natural deposits

Table 2 lists a number of these contaminants with their MCLs, MCLGs, potential health impacts, and sources of contaminants according to the following classes:

1. Microorganisms; like Cryptosporidium, Giardia, and Total Coliforms

2. Disinfection By products; like Trihalomethanes and Haloacetic acids

3. Disinfectants; like Chlorine and Chloramines 4. Inorganic Chemicals; like Arsenic, Lead, Nitrate, and Nitrite

5. Organic Chemicals; like Benzene and Polychlorinated Biphenyls (PCBs)

6. Radionuclides; like Radium 226 and Uranium

4.3.2 Secondary Standards

These standards are non-enforceable guidelines regarding contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. WHO or US EPA recommends secondary standards to water systems but does not require systems to comply with. However, states may choose to adopt them as enforceable standards (US EPA, 2006). US EPA (2006) summarizes those secondary standards of drinking water as shown in Table 3.

4.4 Biological and Chemical Drinking Water Parameters

Drinking water quality is required to meet stringent microbiological and chemical standards of quality to prevent water borne diseases and health risks from toxic chemicals. However, the chemical quality is required as well as the microbiological quality to prevent body disorders. Therefore, this section is classified into two categories: microbiological quality and chemical quality to emphasize a profound insight for those categories.

Table 3: A variety of secondary standards of the drinking water quality (US EPA, 2006)

Contaminant	Secondary Standard
Aluminum	0.05 to 0.2 mg/l
Chloride	250 mg/l
Color	15 (color units)
Copper	1.0 mg/l
Corrosivity	Non corrosive
Fluoride	2.0 mg/l
Foaming Agents	0.5 mg/l
Iron	0.3 mg/l
Manganese	0.05 mg/l
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/l
Sulfate	250 mg/l
Total Dissolved Solids	500 mg/l
Zinc	5 mg/l

4.4.1 Microbiological quality

The groundwater in the West Bank is certainly influenced by the domestic wastewater leaching from the widespread cesspits and runoff in the rural and urban areas. In addition, the leachate from the solid waste landfills contributes to the ongoing contamination of the groundwater resources. A variety of pathogens are present in domestic wastewater, with the kinds and concentrations depend on the contributing community. Although a reduction of pathogens occurs in conventional wastewater treatment, the effluent still contains persistence pathogens even after chlorination (Viessman and Hammer, 2005). For unrestricted water reuse, filtration after chemical coagulation and chlorination with an extended contact time are necessary to remove all pathogens. Since testing water samples for pathogens is not practical, nonpathogenic fecal coliform bacteria are used as indicators for the presence of pathogens (Viessman and Hammer, 2005).

1. Waterborne diseases: Many human diseases are transmitted by the feces of an infected person getting into the mouth of another person. This travel from anus to mouth, referred to as the fecal-oral route, may be direct from person to person by contaminated fingers or indirect through food or water. In addition, some pathogens may reinfect by inhalation of dust or aerosol droplets, and a few (notably hookworm) can penetrate through the skin. Some of these communicable diseases are endemic in form; that is, they are native to a particular region or country. The four major groups of pathogens are bacteria, viruses, protozoans, and helminthes (worms) (Viessman and Hammer, 2005).

For many bacterial infections, of the intestines, the major symptom is diarrhea. The most serious waterborne diseases are typhoid fever, paratyphoid fever, dysentery, and cholera. While all of these diseases are debilitating and can cause death if untreated, their transmission can be controlled by pasteurization of milk, sanitary disposal of wastewater, and disinfection of water supplies. The most serious viral disease identified as waterborne is infectious hepatitis, resulting in loss of appetite, fatigue, nausea, and pain. The most common protozoal diseases are diarrhea and amoebic dysentery that is severely debilitating to the human host. Hookworms are helminthes live in the soil and, after molting, can infect humans by penetrating their skin resulting in anemia, abdominal pain, and debility.

2. Pathogens: Diseases contracted from water kill annually some 25 million people, most of them children, while millions more are debilitated by water borne diseases. Fecal contamination of water can introduce a variety of pathogens into water ways, including bacteria, viruses, protozoa, and parasitic worms as summarized in Table 4.

Table 4: A variety of water borne diseases and their causative organisms (Mason, 2002)

Pathogens	Causative organisms	Diseases or symptoms
Bacteria	Shigella spp. Esherichia coli Vibrio cholera Micobacterium	Bacterial dysentery Castroenteritis Cholera Tuberculosis
Viruses	Interoviruses	Poliomyelitis & hepatitis
Protozoa	Entamoeba histolytica Giardia lamblia Cryptocporidium spp.	Amoebic dysentery Diarrhea Diarrhea
Helminthes	Schistosoma spp.	Bilharzias

Over 90% of deaths from diarrheal diseases in the developing world today occur in children under five years old as shown in Figure 10. Improved drinking water and sanitation services and better hygiene behavior especially by mothers are crucial in cutting child mortality. Figure 10 shows that infants and young children are the victims of the worldwide failure to make safe drinking water and basic sanitation services available to impoverished people as depicted in Figure 11.

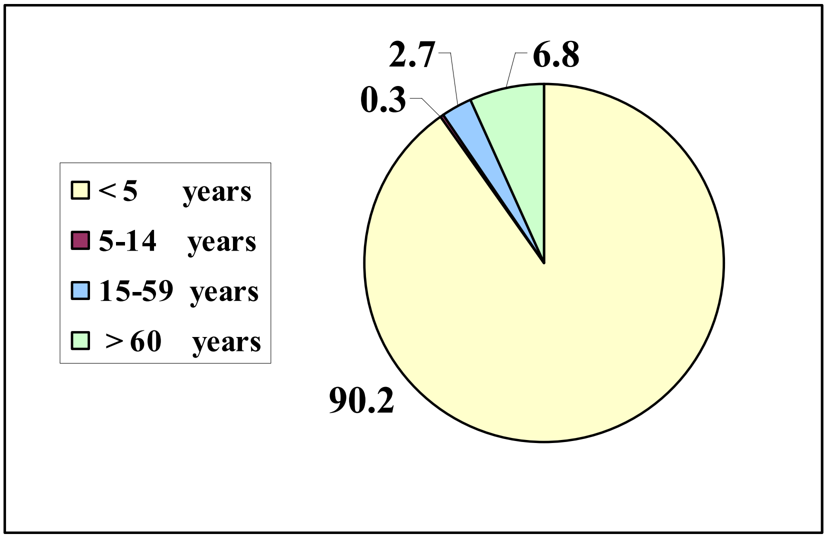


Figure 10: Percentage of deaths by age group in developing regions in 2002 (WHO, 2006)

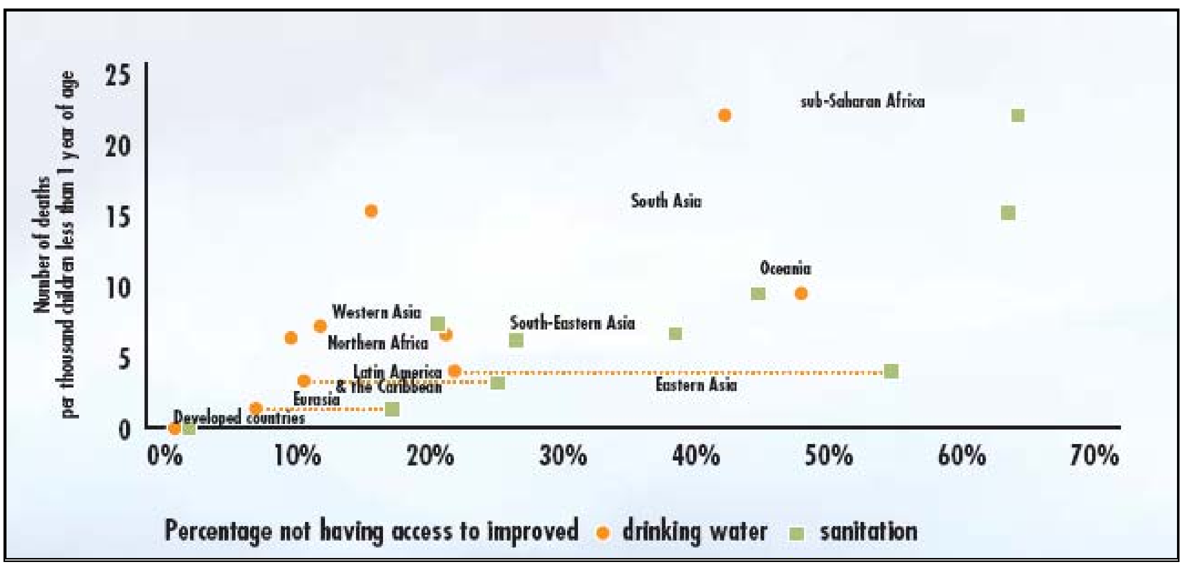


Figure 11: Association between lack of improved sources of drinking water and sanitation facilities, and deaths attributable to diarrheal diseases (WHO, 2006)

Water borne diseases remain a major hazard in many parts of the world. Four classes of water related diseases have been recognized (Cairncross and

Feacham, 1983):

Class 1, the true water borne diseases, are contracted by drinking water that contains pathogenic organisms, usually because of fecal contamination. Examples include cholera, typhoid, and hepatitis A;

Class 2, diseases are indirect infections associated with lack of personal hygiene (e.g. hand washing) which can be reduced by providing adequate amount of water for bathing and washing. Therefore, the role of public awareness is very important in this class. There are sanitary attitudes and customs should be forwarded via consequent generations including simple and cheap habits prevent them from infections. To control such diseases, it is necessary to provide people with sufficient water of reasonable quality; achieving a high bacteriological quality is a secondary consideration (Ellis, 1989). This second class includes all the diseases in class 1, along with other diarrheal diseases, some infections of eyes (e.g. trachoma) and skin (e.g. ringworms) and infections carried by lice and mites;

Class 3, are diseases caused by helminthes which spend part of their life cycle in water; while

Class 4 are diseases that require a water related insect vector (e.g. yellow fever, malaria, river blindness, filariasis), though these are not necessarily associated with polluted waters (Mason, 2002).

3. Communicable diseases in Palestine:

Mortality: In Palestine, 1,045 deaths due to the infectious diseases have been reported in 2004 with a proportion of 10.1% of total deaths, with a rate of 28.7 per 100,000 populations (MOH, 2006). The number of deaths and the mortality rates due to the infectious diseases among the different ages are summarized in Table 5.

Table 5: Number of deaths and mortality rates due to infectious diseases among the different ages in Palestine in 2004 (MOH, 2006)

Age (years)	Number of deaths	Mortality rate
Infants under 5	220	2.1 per 1,000
Children under 5	227	0.4 per 1,000
5-19	58	4.0 per 100,000
20-59	169	12.0 per 100,000
60 and over		335.3 per 100,000

Morbidity: In the last several years, Palestinian health authority has succeeded in preventing and controlling many infectious diseases through the good coverage of vaccination programs, early detection of diseases and health education. No cases of diphtheria has been reported since 1982 and poliomyelitis since 1984. Also no cases of rabies and cholera were reported. Continuous decline in incidence rate of Pulmonary TB and hepatitis B has been achieved. Hepatitis A, B and C are endemic in Palestine as other Middle East countries. No notable change of incidence rate occurred in the last five years. Incidence rate of hepatitis A was 59.3 per 100,000 in the year 2000 increased to 62 per 100,000 in the year 2004. While incidence rate of hepatitis B cases was 2.9 and 2.8 in the year 2000 and 2004, respectively. Incidence rate of hepatitis C cases and carrier decreased from 7.8 per 100,000 in the year 2000 to 5.5 in the year 2004 (MOH, 2006).

In the year 2004 there was an outbreak in mumps especially in the West Bank (incidence rate of 161.2 per 100,000), which needs more investigation. An outbreak of mumps began in the Northern West Bank in December 2003 and was first identified in Askar camp in Nablus district with a virus genotype H. Many of the cases are occurring among vaccinated school aged children (72% of the cases were in children aged 5-14 years) with unusually high number of cases among six years old. The outbreak has continued in 2004 to spread out to other districts and camps in the West Bank such as Qalqilya, Tulkarm and Jenin. At this time, the specific reason for this outbreak remains unknown and appropriate investigations are warranted (MOH, 2006).

Measles is one of the typical viral diseases of childhood. In Palestine, incidence rate has sustained during past few years at rate of 0.1 per 100,000 persons. There was an outbreak of measles in 1999 (incidence rate 5 per 100,000) which dramatically decreased in 2000 to 0.16 and then decreased slightly to 0.08 in 2004 in the West Bank (MOH, 2006). Therefore, continuous strengthening of surveillance system is needed for the success of prevention and control programs of the infectious diseases.

4.4.2 Chemical quality

There are a lot of chemical constituents that exist in the groundwater. These constituents come from a variety of sources. Table 6 summarizes the sources of chemical constituents with corresponding examples.

Table 6: Categorization of sources of chemical constituents (WHO, 2006)

Sources of chemical constituents	**Examples of sources**
Naturally occurring	Rocks, soils and the effects of the geological setting and climate
Industrial sources and human dwellings	Mining (extractive industries), processing and manufacturing industries, wastewater, solid wastes, urban runoff, and fuel leakages
Agricultural activities	Manures, fertilizers, intensive animal practices, and pesticides
Water treatment or materials in contact with drinking water	Coagulants, Disinfection By-Products (DBPs), and piping materials
Pesticides used in water for public health	Larvicides used in the control of insect vectors of disease
Cyanobacteria	Eutrophic lakes

The chemical quality of the drinking water has a great significance in line with the biological quality. The biological deterioration may require chemical remediation to prevent the transmission of the pathogens to the different viable habitats. The best way to prevent pollution of the drinking water systems and networks is by disinfection.

Disinfection of drinking water is a process in which most of the bacteria that would cause the waterborne diseases are killed (Mason, 2002). It can be also defined as the destruction of pathogenic microorganisms in water (Droste, 2003). There must be many reasons to encourage the usage of specific disinfectant among a variety of alternatives. Many ways are used to disinfect water such as chlorination, chlorine dioxide, bromine, iodine, UV light, and ozone (Holden, 1970; James, 1971; Johnson, 1975; Mason, 2002; Droste, 2003; Viessman and hammer, 2005). The efficiency of killing pathogens is not the only criterion in selecting a disinfectant. The characteristics of a good disinfectant are (Droste, 2003; Holden, 1970; Jolley, 1978; Mason, 2002):

1. Effective killing of pathogenic microorganisms;
2. Non toxic to humans or domestic animals;
3. Non toxic to fish and aquatic species;
4. Easy and safe to store, transport, and dispense;
5. Availability;
6. Low cost;
7. Easy and reliable analysis in water; and
8. Provides residual protection in drinking water.

As for chlorination, the first time the chlorine was used as a disinfectant for drinking water was in 1897 (Holden, 1970). Chlorination is a process that involves the addition of chlorine to drinking water in a controlled way. Chlorination can be classified into two main methods; the first is free residual chlorination whilst the second is combined residual chlorination (Holden, 1970; Jolley, 1978; Christman, 1998; Droste, 2003). The most important use of chlorine for sanitary purposes is for the disinfection of potable water. Because of chlorine's oxidizing powers, it was found to serve other useful purposes in water treatment such as taste and odor control; prevention of algae growths in water treatment structures; maintaining clean filter media; removal of iron and manganese; destruction of hydrogen sulfide; color removal by bleaching of certain organic colors; maintenance of distribution system water quality by controlling slime growths; restoration and preservation of pipeline capacity; restoration of well capacity and sterilization of water means and reservoirs (Jolley, 1978).

Although free chlorine is a good disinfectant, the problems of the formation of halogenated organics, particularly chloroform and trihalomethanes, during its use have caused the entire subject of drinking water disinfection to be reviewed (Jolley, 1978; Zuane, 1990; Droste, 2003; Edstrom, 2003). In addition, this method has the disadvantages of chlorinous taste and odor even with small chlorine doses (Holden, 1970; Satterfield, 2006). Treatment of water to remove by-product precursors or treatment to remove formed by-products are possibilities. There is a third possibility to replace the free chlorine by a specific disinfectant or combination of disinfectants but several criteria must be met.

The efficiency of chlorination can be influenced by a variety of factors. All these factors should be taken into consideration to achieve sound and safe chlorination of the drinking water. These factors are: chlorine dosage and contact time; condition of water; temperature; and hydrogen ion concentration (Public Health Bulletin, 1946; Holden, 1970; Jolley, 1978; Droste, 2003; MDWP, 2004; Viessman and hammer, 2005).

At the end, chlorine satisfies the characteristics of a good disinfectant to a large degree. However, experts nowadays are looking forward to solving the disadvantages of chlorine (Droste, 2003). Thus, many detailed studies compare among the different disinfectants (Holden, 1970; James, 1971; Johnson, 1975; Jolley, 1978; Droste, 2003; Viessman and hammer, 2005).

CHAPTER FIVE

NITRATE CONTAMINATION IN WEST BANK AQUIFERS

5.1 Introduction

Changes in the quantity of water recharging the aquifer or the degradation in the quality of supply water may seriously impair the quality of the groundwater. Leachate from municipal and industrial wastes entering an aquifer is a major source of organic and inorganic pollution. Large-scale organic pollution of groundwater is infrequent. However, significant quantities of organic wastes usually cannot be easily introduced to the subsurface. The problem is quite different with inorganic solutions (e.g. nitrate), since these move easily through the soil. Nevertheless, when contaminating groundwater it is difficult and costly to treat the groundwater (Viessman and Hammer, 2005).

It should be noted that the aquifers are easily contaminated in some regions depending on land use, soil type, and geological characteristics. For instance, the region's geology is limestone, which has the property of allowing substances to penetrate easily. The attenuation or removal of nutrients and pollutants in wastewater percolating down to the aquifers is low making aquifers vulnerable to contamination (UNEP, 2003, Wishahi and Awartani, 1999).

Groundwater pollution due to point and nonpoint sources is caused mainly by agricultural practices (noticeable is the use of inorganic fertilizers, pesticides, and herbicides), localized industrial activities (organic pollutants and heavy metals), and inadequate or improper disposal of wastewater and solid waste (including hazardous materials) (Wishahi and Awartani, 1999; UNEP, 2003; Almasri and Kaluarachchi, 2004a).

Nitrate is the most common pollutant found in shallow aquifers due to both point and nonpoint sources (Postma et al., 1991). Elevated nitrate concentrations in drinking water are linked to health problems such as methemoglobinemia in infants and stomach cancer in adults (Addiscott et al., 1992; Lee et al., 1991; Hall et al., 2001; Wolfe and Patz, 2002).

Agricultural activities are the main source of elevated nitrate concentrations. Agricultural practices can result in nonpoint source pollution of groundwater (Hall et al., 2001; Delgado and Shaffer, 2002). With nonpoint sources, groundwater quality may be depleted over time due to the cumulative effects of several years of practice (Addiscott et al., 1992; Schilling and Wolter, 2001). Nonpoint sources of nitrogen from agricultural activities include fertilizers, manure application, and leguminous crops (Hubbard and Sheridan, 1994). Elevated nitrate concentrations in groundwater are common around dairy and poultry operations, barnyards, and feedlots (Hii et al., 1999; Carey, 2002). In addition to agricultural practices, nonpoint sources of nitrogen involve precipitation, irrigation with groundwater containing nitrogen, and dry deposition. Point sources of nitrogen are shown to contribute to nitrate pollution of groundwater (Almasri and Kaluarachchi, 2004a). The major point sources include septic tanks and dairy lagoons.

Many studies have shown high concentrations of nitrate in areas with septic tanks (Cantor and Knox, 1984; Keeny, 1986; Amade, 1999; MacQuarrie et al., 2001). This is of particular concern to rural homeowners who use shallow drinking water wells that can be easily contaminated with septic tank effluent including bacteria and viruses (Almasri and Kaluarachchi, 2004a).

Nitrate contamination of groundwater is caused by infiltration of fertilizers and raw sewage, and elevated concentrations are found throughout the West Bank (UNEP, 2003). A detailed study (Marei and Haddad, 1998) found that nitrate levels above the WHO standard guideline values for drinking water in up to one-third of samples from wells in the Jordan Valley and the districts of Nablus, Jenin, and Tulkarm.

The objectives of this chapter are to identify and document the regional long-term trends of nitrate concentrations in the groundwater of the West Bank; to qualitatively identify the probable sources of elevated nitrate concentration; and to analyze the temporal and spatial variability in nitrate concentrations with key parameters including district, groundwater basin, aquifer system, land use, soil type, watershed, depth, and pumping rate.

The assessment is carried out using the geographic information system (ArcGIS 9) tools (ESRI, 2004). This assessment is intended to provide qualitative recommendations related to future groundwater monitoring, field testing, and aid in the development of a conceptual model for fate and transport of nitrate. Overall, the analyses furnished herein is intended to improve our understanding to the nitrate contamination extent of the groundwater resources in the West Bank. The analysis levels followed in this work are summarized in Table 7 with expected justifications.

Table 7: The analysis levels to study nitrate distribution in the West Bank with brief reasons

No.	Analysis level	Reasons
1	West Bank	Identify and document the regional long-term trends and distribution of nitrate concentrations in the groundwater of the entire West Bank
2	Districts	Demonstrate the spatial variability among the different districts
3	Basins	Provide a qualitative understanding of the general trend of nitrate concentrations in the three basins
4	Aquifers	Detect aquifers of high vulnerability to nitrate contamination
5	Use categories	Substitute the absence of land use map and recognize well use effect
6	Soil types	Aid in the development of management practices that involve agricultural irrigation and the use of non-conventional water resources
7	Major watersheds	Compare the generic trends of nitrate concentration in the major watersheds
8	Minor watersheds	Monitor the minor watersheds susceptible to nitrate contamination with a ranking scheme
9	Depths	Illustrate the vertical nitrate distribution in groundwater
10	Recharge	Link the nitrate concentration and the corresponding rainfall
11	Time series	Show the time series of nitrate concentration for different wells to generate temporal trends
12	Accumulation	Evaluate the nitrate accumulated in the groundwater

5.2 Health Hazards of Nitrate

Nitrate is one of the harmful pollutants when present in groundwater because of its detrimental effect on health. Nitrate may indicate the presence of bacteria, viruses, and protozoa in groundwater if the source of nitrate is animal waste or effluent from septic systems. Likewise, nitrate contamination of surface water is a health and environmental concern (Almasri and Kaluarachchi, 2004b). Transport of nitrate to surface water occurs mainly via discharge of groundwater during baseflow (Hubbard and Sheridan, 1994; Devlin et al., 2000; Schilling and Wolter, 2001; Bachman et al., 2002). Hence, prevention of groundwater contamination protects surface water quality as well.

Nitrate is the common form of inorganic nitrogen found in water solution. In agricultural regions, heavy fertilizer application results in unused nitrate migrating down into the groundwater. As a result, groundwater withdrawn by private and public wells is likely to have measurable concentrations of nitrate, and in the same regions well water in many rural communities can exceed the MCL of 50 mg/l of nitrate (Viessman and Hammer, 2005).

The health hazard of ingesting excessive nitrate in water is the infant methemoglobinemia. In the intestine of an infant, nitrate can be reduced to nitrite that is absorbed into the blood, oxidizing the iron of hemoglobin. This interferes with oxygen transfer, resulting in cyanosis and giving the baby a blue color. During the first three months of age, infants are particularly susceptible (Viessman and Hammer, 2005). Other studies have shown that nitrate may be one of the reasons causing stomach cancer in adults (Addiscott et al., 1992; Lee et al., 1991; Hall et al., 2001; Wolfe and Patz, 2002).

5.3 Methods and Data Analysis

5.3.1 Data Collection

The nitrate concentration data used in this study were obtained entirely from the Palestinian Water Authority (PWA). The corresponding well data were aggregated using the database of the Water and Environmental Studies Institute at An-Najah National University. All available data were assembled into a single composite database to facilitate the analysis. The total number of wells in the West Bank is 623 while the total number of wells in the database is 479. However, there are only 430 wells with 4,372 measurements of nitrate concentration in the database covering the period from 1981 to 2004 (except one reading were taken in 1971 which was ignored). The database includes well ID, well coordinates, concentration, measurement year, locality, district, aquifer, basin, well use, soil type, minor watershed, major watershed, average long-term pumping rate, and sampling depth.

That great deal of data is available in a format that is accessible via GIS technology. Using the dynamic GIS tools, techniques, and capabilities provides the ease of data processing, visualization, computations, analysis, and map preparation. Many problems were found in the original database. First, some of the parameters hadn't been precisely determined like district and basin. A GIS polygon shapefile for the districts of the West Bank was spatially joined to well original database, and so was a GIS polygon shapefile for the basins of the West Bank. Second, a lot of important parameters are missing in the database. A GIS polygon shapefile for the major watersheds of the West Bank was also spatially joined with well original database, and so was a GIS polygon shapefile for the minor watersheds of the West Bank. The land use GIS shapefile is unavailable, the reason stimulated to apply intersection geoprocess with the original database providing plentiful database for each well. A GIS point shapefile of well spatial locations and the corresponding data was developed and used in the analysis.

It was noticed that the variability in number of readings of nitrate concentration sampled from each well for the period from 1981 to 2004 was too large. Further analysis shows that the frequencies of readings of nitrate concentration for each well vary between 1 to 22 as depicted in Figure 12 with an average value that exceeds 10 readings. The following analyses furnished in the following subsections do pertain to the nitrate occurrences in the groundwater of the West Bank at different scales and for different explanatory parameters.

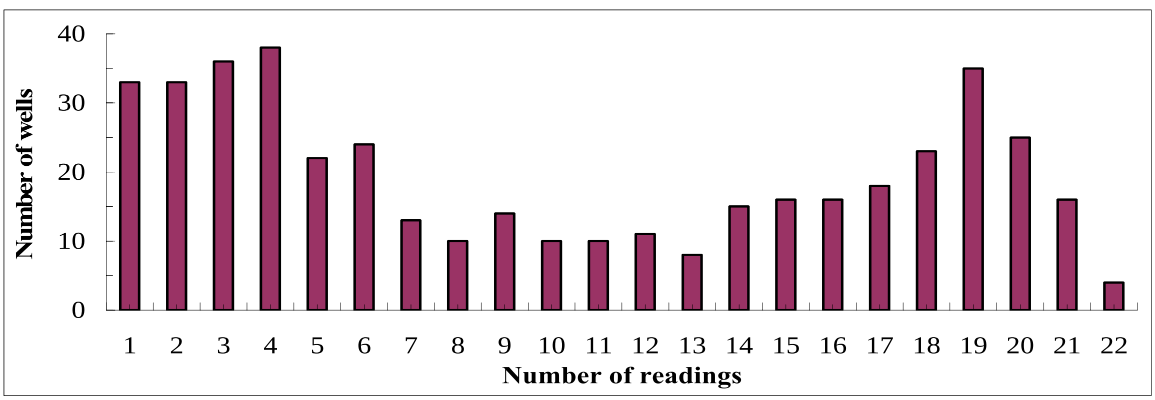


Figure 12: Frequency distribution of nitrate concentration readings for the period from 1981 to 2004 and the corresponding number of wells

5.3.2 Nitrate Distribution Across the West Bank

Since the objective of the analysis is to study the overall trend of nitrate concentration in the groundwater of the West Bank, no attempt was made to remove wells of short time series that do not represent the complete period from

1981 to 2004. This approach is common in many studies especially studies conducted for regional-scale assessment for the development of best management practices (Nolan and Stoner, 1995; Parliman, 2002; Almasri and Kaluarachchi, 2004a).

Figure 13 illustrates the frequency of annual nitrate concentration readings distributed over the period from 1981 to 2004. That Figure is drawn using the capability of "summarizing tables" provided by the GIS. The average number of annual readings is approximately 182, which means that about 42% out of the 430 wells were sampled for nitrate.

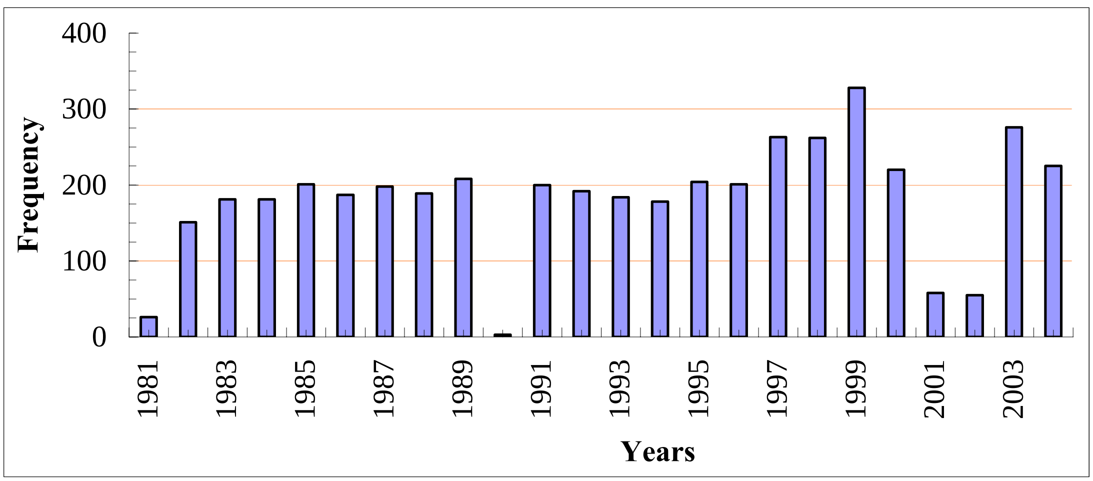


Figure 13: Frequency of annual nitrate concentration readings for the period from 1981 to 2004 for the entire West Bank

It is obvious from Figure 13 that the maximum number of samples is 328 in 1999, while the minimum number of samples is 3 in 1990. These observations could refer to political or technical constraints. Anyhow, the frequency of nitrate concentration readings should be increased including all the sampling wells. Annual nitrate concentration statistics from 1981 to 2004 are shown in Figure 14. The distribution of nitrate concentrations in 1981 and 1990 were as excepted and as shown in Figure 13. This expectation is because of the low number of readings in those two years.

The results show that the median is always below the MCL, indicating that at least 50% of the nitrate concentrations are below the MCL from 1981 to 2004. It is noticeable that the average is always higher than the median and two more closer to the MCL. As can be concluded from Figure 14, the 75% percentile (3rd quartile) is generally closer to the MCL. Also, the MCL was exceeded in five years solely.

The annual maximum nitrate concentration exhibits an overall increasing trend. The annual maximum concentrations are always above the MCL. A value of 285 mg/l is observed in 2004. In the eighties, the average concentrations decreased to its minimum value in 1985 then these concentrations increased. After that time period, the average concentrations still constant with an increasing trend in the last few years. The same trends are noticed for the median concentrations.

The spatial distribution of nitrate concentrations across the West Bank for the year 2004 was developed using the inverse distance weighting (IDW) interpolation method as supported by GIS and shown in Figure 15. To assess the possible anthropogenic effects on groundwater quality, nitrate concentrations were classified into four groups based on the work of Madison and Brunett (1984) and Cox and Kahle (1999).

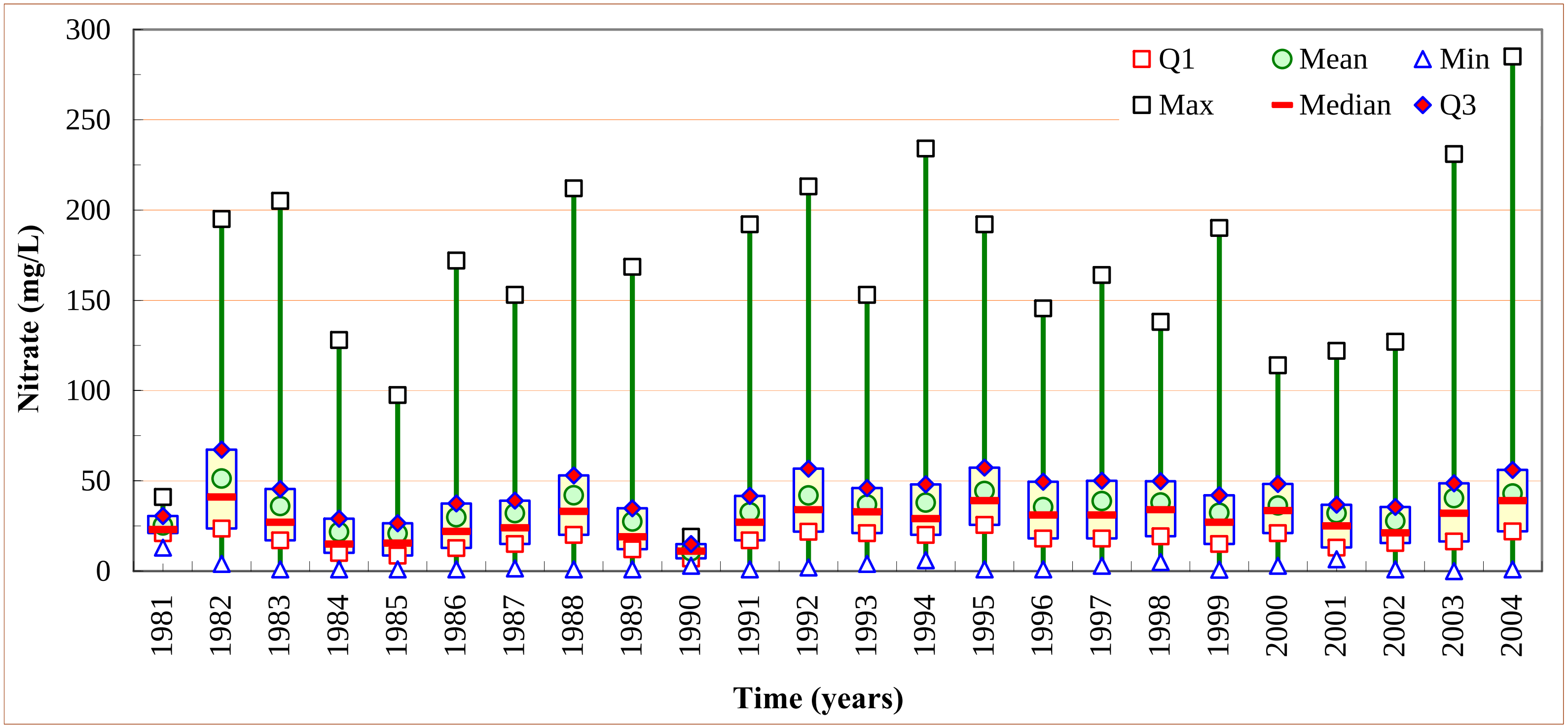


Figure 14: Annual nitrate concentration statistics in the entire West Bank in the period from 1981 to 2004

The four concentration ranges were approximated as shown in the legend of Figure 15 and those are: 0-5 mg/l to indicate the most likely background concentration; 5-15 mg/l to indicate a possible human influence; 15-50 mg/l to indicate pollution due to human influence; and greater than 50 mg/l to indicate that the MCL was exceeded as a result of excessive human activities.

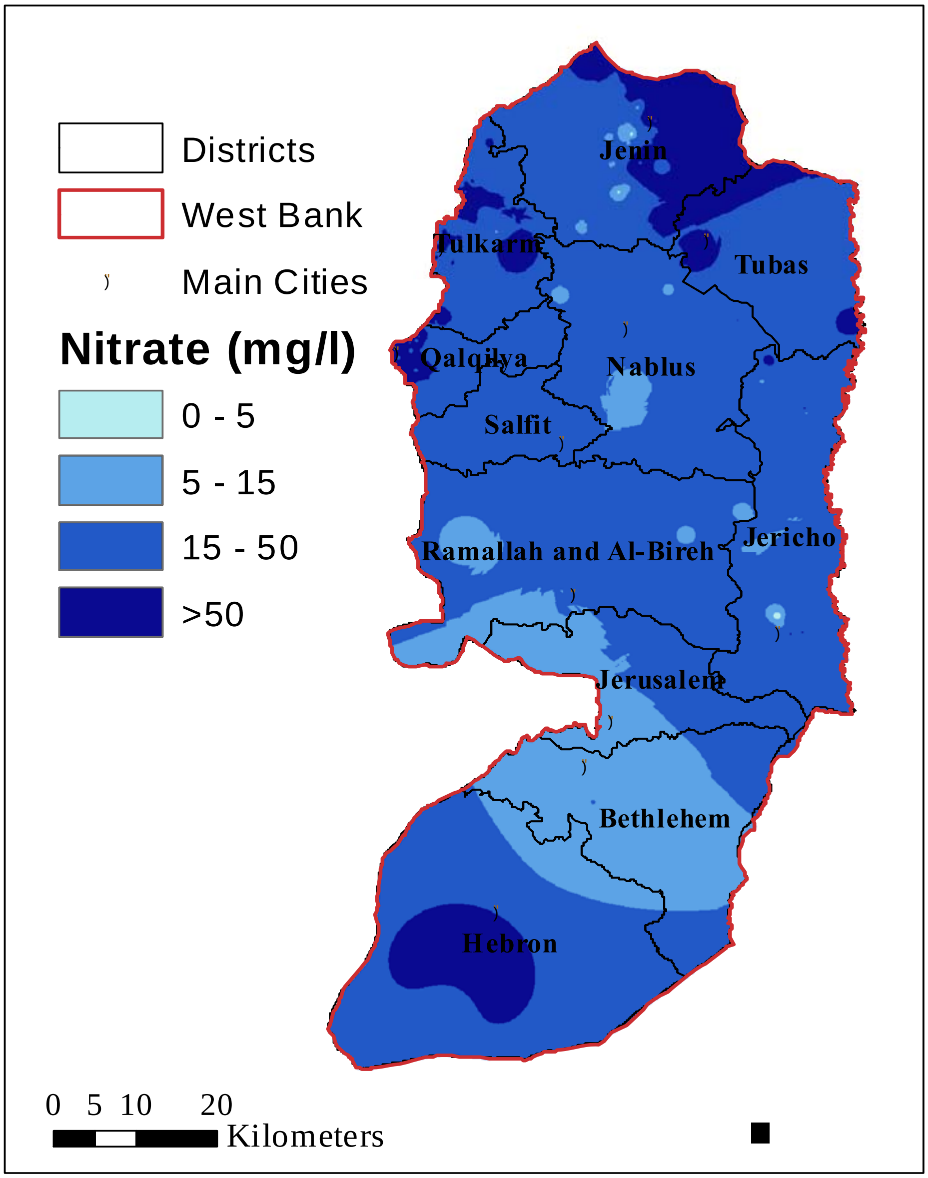


Figure 15: The distribution of nitrate concentration across the West Bank for the year 2004 as interpolated using the IDW method

It can be deduced from this Figure that the highest nitrate concentrations are mainly encountered in the north specifically in Jenin and Tubas districts as well as in the south in Hebron district. In addition, some areas in Tulkarm and Qalqilya districts encounter such high concentrations. Those nitrate concentrations exceed the MCL of 50 mg/l. These observations can be attributed to the agricultural activities that are associated with the elevated on-ground nitrogen loadings due to the use of nitrogen-based fertilizers.

To better comprehend and assess the distribution of nitrate concentrations in the groundwater of the West Bank, the on-ground nitrogen loadings ought to be computed. This will enable the correlation (spatially) between the on-ground nitrogen loadings and the corresponding nitrate concentrations in groundwater. In order to compute the nitrogen loadings, the land use distribution in the West Bank should be available in a processable format which is not the case here in. The land use map enables the spatial allocation of the nitrogen loadings according to the land use class.

The nitrogen sources in the study area may include (but not limited to) manure, inorganic fertilizers, atmospheric deposition, irrigation with nitrogen-contaminated groundwater, cesspits, and nitrogen fixed by legumes (Abed and Wishahi, 1999; Wishahi and Awartani, 1999; Abdul-Jaber et al., 1999; UNEP, 2003).

5.3.3 Nitrate Distribution Across the West Bank Districts

The West Bank is administratively divided into eleven districts and these are Bethlehem, Hebron, Jenin, Jericho, Jerusalem, Nablus, Qalqilya, Ramallah and

Al-Bireh, Salfit, Tubas, and Tulkarm as shown in Figure 15. The districts are sub-divided into 89 municipalities, in addition to local councils that have been formed to manage the basic services (UNEP, 2003).

It is obvious that the political boundaries do not dictate the transport of contaminants in groundwater. Nevertheless, a lot of studies consider the political boundaries in the analysis to evaluate the effect of each proponent on the sharing resource. The GIS shapefile of the spatial distribution of the West Bank districts is used to spatially join the nitrate sampling well locations (and hence the concentrations) to the district polygons similar to the technique used in Figure 15. The ranges of nitrate concentrations in the West Bank districts are shown in Figure 16.

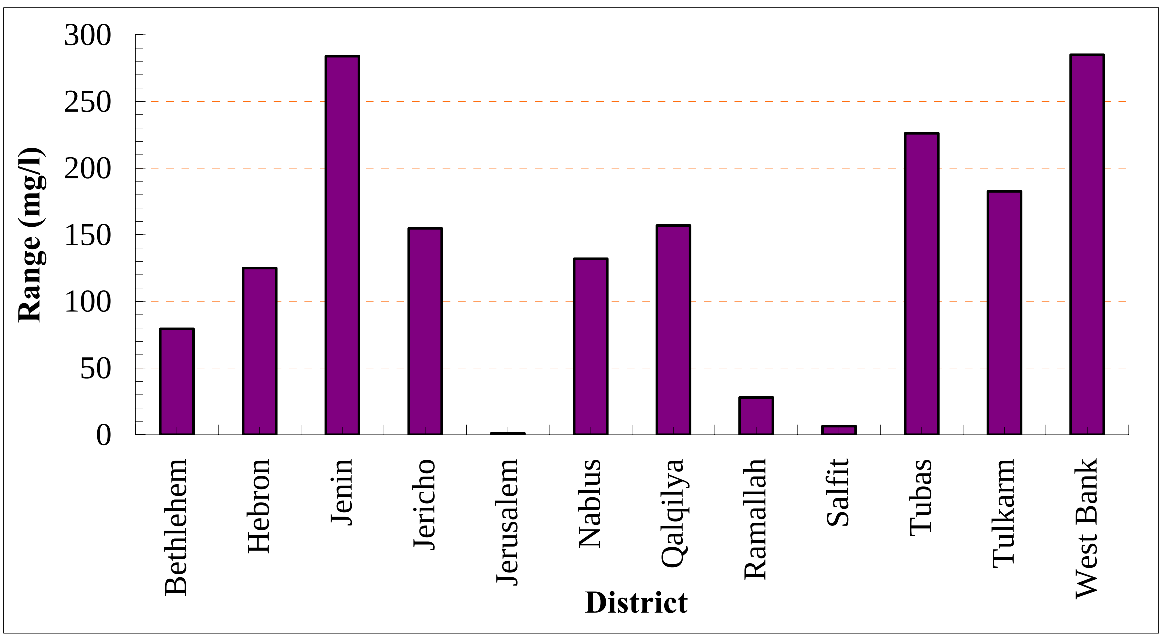


Figure 16: Ranges of nitrate concentrations in the West Bank districts for the period from 1981 to 2004

The ranges represent the difference between the maximum and minimum nitrate concentrations during the period from 1981 to 2004. A value of 284 mg/l is the maximum range in the West Bank which was observed in *Jenin* district where a whole lot of agriculture-dominated areas are located within. *Tubas* district, a next-door neighbor of Jenin District, has the second rank with a range of 226 mg/l. Both districts have similar land use practices.

Tulkarm district has the third rank of about 182 mg/l. *Jerusalem* and *Salfit* districts were ignored due to the little available data reported in those districts. In general, all the districts except *Ramallah*, have nitrate concentrations that severely violate the MCL. This trend reflects the intense of agricultural activities as well as the existence of other possible sources including the cesspits and the disposal of untreated wastewater.

It is important to keep in mind that the sources might be at a remote distance from the detection wells due to the possible fate and transport processes that may act on the nitrate once in the groundwater.

5.3.4 Nitrate Distribution in the West Bank Groundwater Basins

The Mountain Aquifer system underlying the West Bank is by far the most important source of water. The aquifer system is highly permeable due to its geological nature. The limited soil cover over the water recharge zones makes the aquifer highly susceptible to pollution since there is no natural barrier to contaminants that travel down rapidly to the water table (UNEP, 2003).

Groundwater in the Mountain Aquifer system flows in three main directions, according to which three main groundwater basins had been identified, namely the *Western*, *North-eastern*, and *Eastern* Aquifer Basins (UNEP, 2003; Abed and Wishahi, 1999). The three main groundwater basins distributed across the

West Bank are shown in Figure 17. The Figure also depicts the direction of the groundwater in the three basins and the location of the nitrate wells.

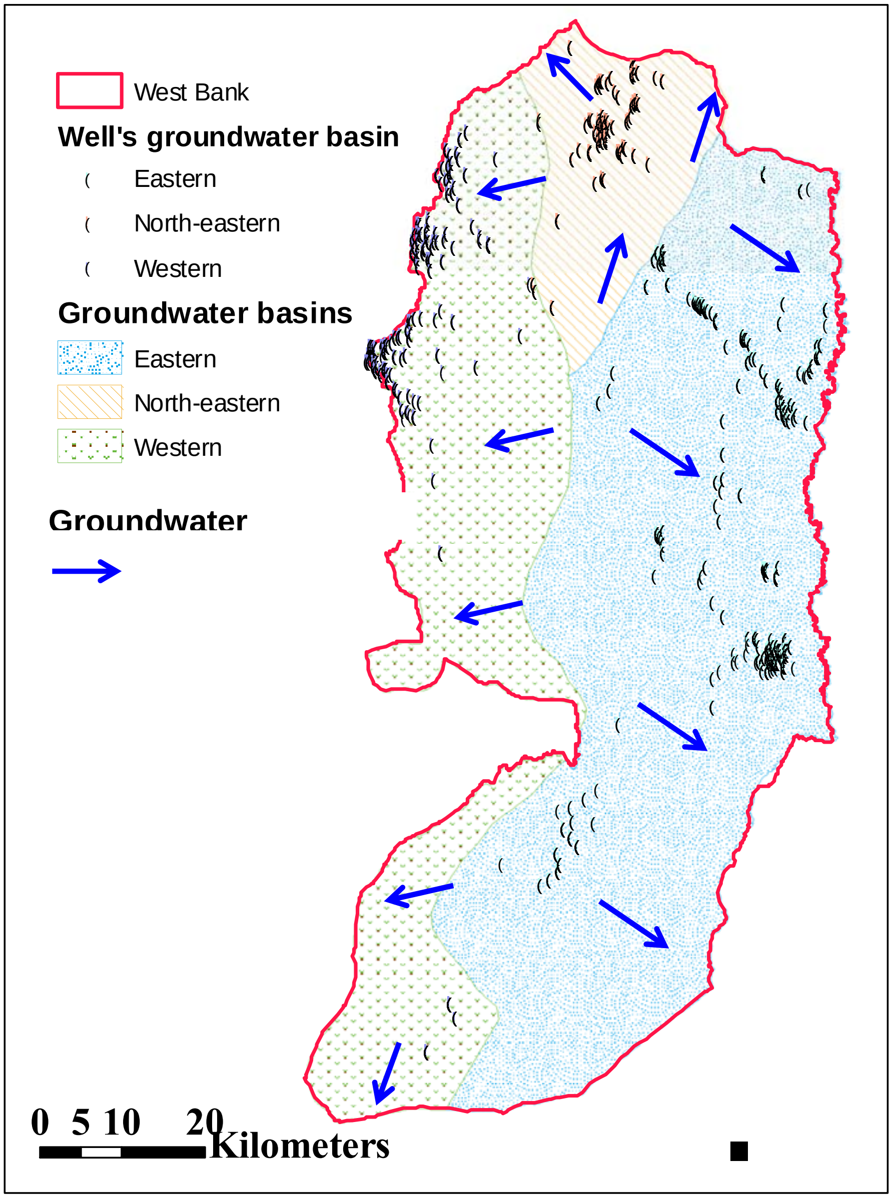


Figure 17: The spatial distribution of the nitrate sampling wells in the West Bank groundwater basins and the direction of the groundwater

The *Eastern* groundwater basin covers the eastern part of the West Bank. It is divided hydrogeologically into seven sub-basins; Alluvium, Alluvium and

Eocene, Eocene, Lower Cenomanian, Lower and Upper Cenomanian, Upper Cenomanian, and Neogene. Its area is about 2,705 km2. The Cities of Jerusalem, Hebron, Bethlehem, and Ramallah are located within that basin (Abed and Wishahi, 1999).

The *North-eastern* groundwater basin covers the northern part of the West Bank. It is divided hydrogeologically into three sub-basins; Eocene, Lower Cenomanian, and Upper Cenomanian. Its area is about 1,050 km2. The Cities of Jenin and Nablus are located within that basin (Abed and Wishahi, 1999).

The *Western* groundwater basin covers the western side of the West Bank. It is divided hydrogeologically into three sub-basins; Eocene, Lower Cenomanian, and Upper Cenomanian. Its area is about 1,795 km2. The Cities of Tulkarm and Qalqilya are located within that basin (Abed and Wishahi, 1999).

The surface area is an important parameter affecting the vulnerability of groundwater to contamination. However, there are many other parameters that have a significant influence. One of them is the recharge rate. The annual recharge volumes for the *Eastern*, *North-eastern*, and *Western* basins are 172, 145, and 362 mcm, respectively. This adds up to a total of 679 mcm per year for the entire West Bank as recognized in Article 40 under the Oslo II Accord. It should be noted, however, that other references (e.g. Guttman, 2000) provide quite different estimates of the recharge figures (UNEP, 2003; Abed and Wishahi, 1999). Although the area of the *Western* basin is two thirds of that of the *Eastern* basin, yet the average annual recharge volume for the *Western* basin exceeds two times that for the *Eastern* basin. These facts may imply a higher vulnerability to contamination of the *Western* basin.

Nitrate concentration data for the West Bank groundwater basins were analyzed to obtain the trends of nitrate concentrations in groundwater per each basin. The GIS shapefile of the spatial locations of the West Bank groundwater basins was used to spatially join the nitrate sampling well locations to the basin outlines. The results of the analysis show mean values of 29.8, 35.4, and 45.0 mg/l for the *Eastern*, *North-eastern*, and *Western* basins, respectively, for the period from 1981 to 2004. Since the three basins are the main source of drinking water and recharge many springs, the mean annual nitrate concentrations from 1981 to 2004 were computed and depicted in Figure 18, Figure 19, and Figure 20 for the *Eastern*, *North-eastern*, and *Western* basins, respectively.

These figures provide a qualitative understanding of the general trend of nitrate concentrations in the three basins. Figure 18 confirms that the nitrate concentration in the *Eastern* basin has a decreasing trend till 1990 after which the oscillations in concentrations diminish with time. Figure 19 shows that the nitrate concentration in the *North-eastern* basin has an upward behavior with an increasing trend in the last few years. In the *Western* basin, the nitrate concentration behaves in a different manner. Figure 20 confirms that the nitrate concentration in the *Western* basin has an increasing trend over the entire period from 1981 to 2004. For instance, the mean annual nitrate concentration in the *Western* basin increased drastically after 1984 and the highest value occurred in 1995. Out of the 1,301 samples from the *Western* basin, a total of 423 samples (33%) exceeded the MCL.

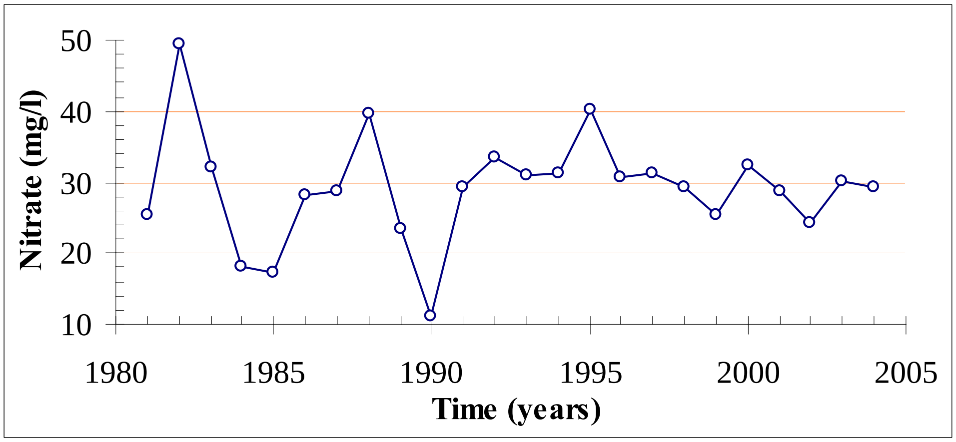


Figure 18: Time series of mean annual nitrate concentration in the Eastern basin for the period from 1981 to 2004

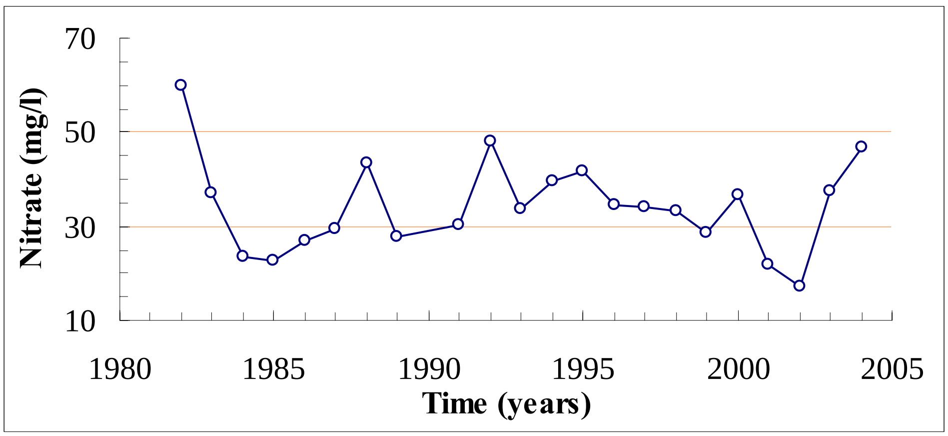


Figure 19: Time series of mean annual nitrate concentration in the North-eastern basin for the period from 1981 to 2004

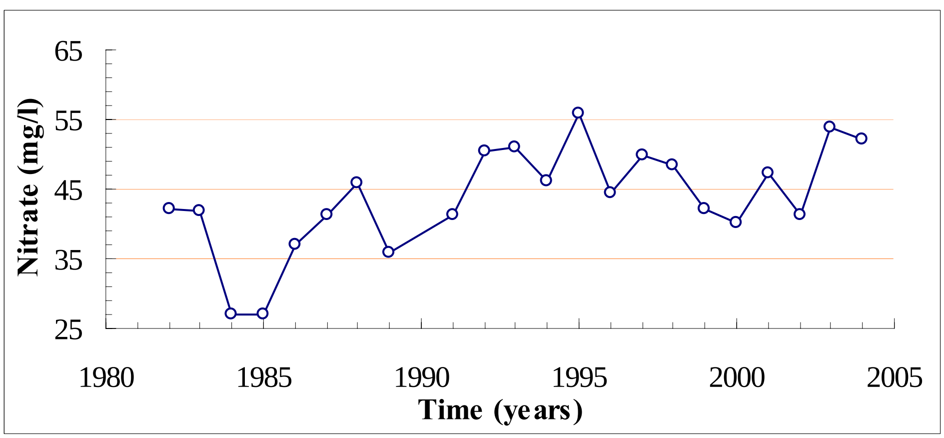


Figure 20: Time series of mean annual nitrate concentration in the Western basin for the period from 1981 to 2004

Using the spatial analysis capability of GIS, the occurrence of these 423 samples were analyzed and it was found that 200 samples are located within Qalqilya district, 199 samples are located within Tulkarm district, and 24 samples are located in Hebron district.

From the analysis shown above, it can be concluded that the most vulnerable groundwater basin to contamination is the *Western* basin. That result can be attributed to the agricultural activities in the next-door neighboring areas. That result necessitates the problem of transboundary basins which should be solved by cooperative measures and organized management options to prevent the quality of the groundwater from contamination. In general, the average sampling depth of the data exceeding the MCL is about 113 m. Hence, the vulnerability to nitrate contamination of a basin is demonstrated regardless its farness to land surface.

5.3.5 Nitrate Distribution Across the West Bank Aquifers

Each of the three basins mentioned above covers a large area with a wide range of different climatic, water use, topographic, geological, and hydrogeological features (PWA, 2001b). Each basin can be divided into seven aquifer systems based on the geologic formations. These aquifers are: *Alluvium*, *Alluvium and Eocene*, *Eocene*, *Lower Cenomanian*, *Lower and Upper Cenomanian*, *Neogene*, and *Upper Cenomanian*. The aquifer system of each sampling well was determined by the Palestinian Water Authority except for 6 samples. Figure 21 shows the distribution of the sampling wells in the West Bank based on the corresponding aquifer system. The statistics of annual nitrate concentrations of the different aquifer systems from 1981 to 2004 were computed and are depicted in Figure 22.

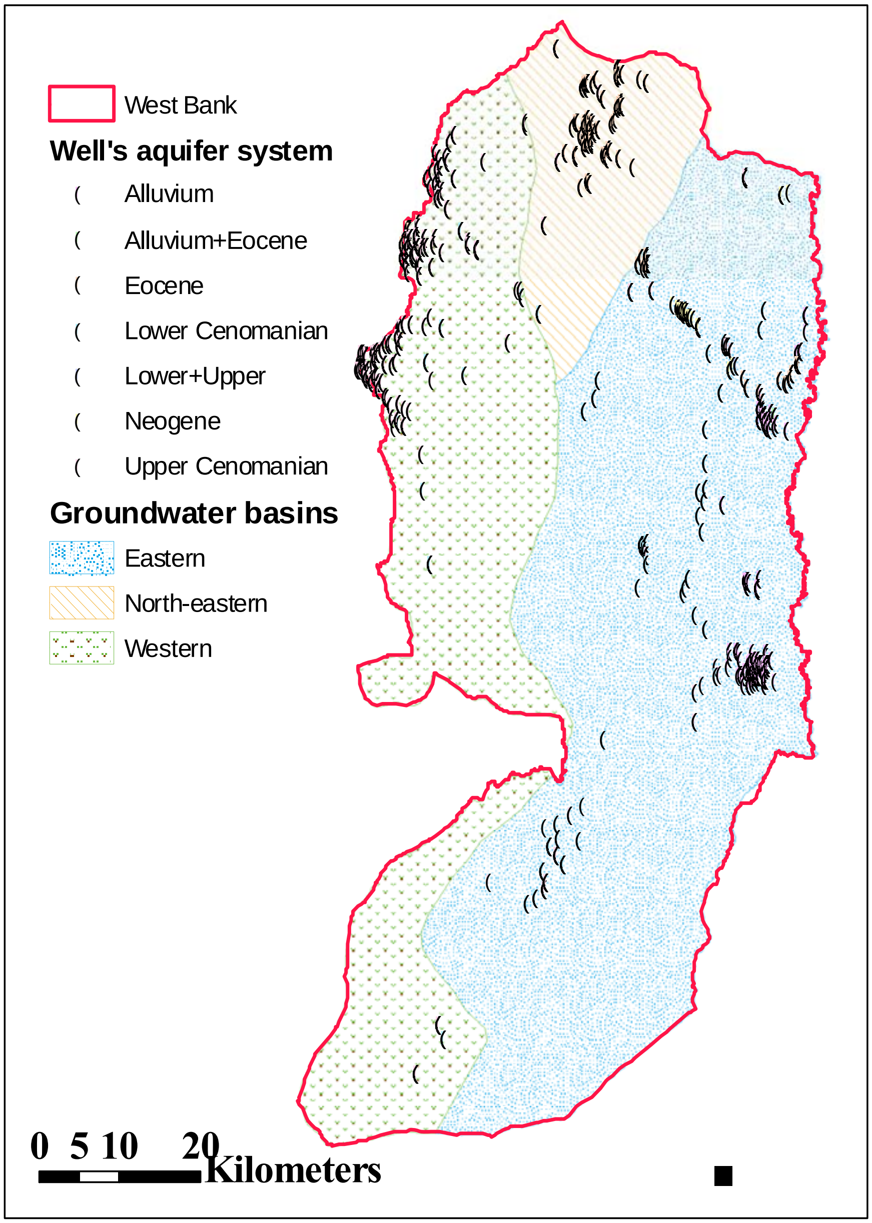


Figure 21: The distribution of the sampling wells in the West Bank based on the different aquifer systems

The *Lower and Upper Cenomanian* aquifer has four samples and thus they were dropped out of the analysis. Almost all the maximum nitrate concentrations are above the MCL of 50 mg/l for the aquifer systems. A value of 285 mg/l was observed in the groundwater of the *Eocene* aquifer. The 75th percentile is above the MCL in the *Upper Cenomanian* aquifer only, therefore, further analysis should take place for this aquifer since it represents about 34% of the samples. The 75th percentile is close to the MCL in the *Eocene* aquifer. The *Alluvium* aquifer is ranked as the third in terms of the vulnerability to nitrate contamination. In terms of the frequency of nitrate sampling, those three aquifer systems are the most representative because they have almost 90% of the nitrate samples.

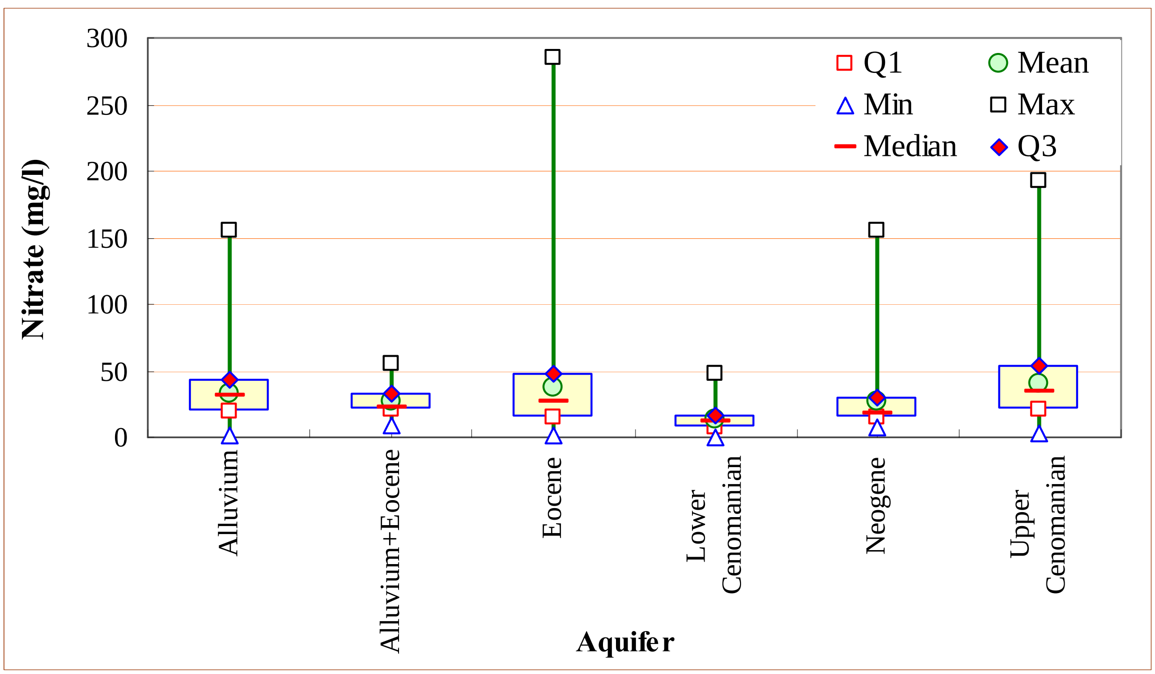


Figure 22: Statistics of annual nitrate concentration for the aquifer systems for the period from 1981 to 2004

In those aquifer systems, the majorities of the land surface is occupied by agriculture-dominated areas and condense populated localities. The remaining 460 nitrate samples out of the 4,372 are distributed across the middle part of the West Bank. The result that supports the claim of transboundary problem and suspected activities applied in the next-door neighbor areas.

Despite the fact that the mean nitrate concentrations are always higher than the median concentrations, nevertheless both are lower than the MCL for all the aquifers throughout the period from 1981 to 2004. It is noted that all the aquifer systems, except the *Lower Cenomanian*, have mean and median nitrate concentrations close to the MCL, typically in the range of 15-50 mg/l. nitrate concentrations in this range are the result of anthropogenic and man-made effects. The highest mean and median nitrate concentrations are encountered in the *Upper Cenomanian* aquifer.

5.3.6 Nitrate Distribution According to the Well Use Categories

The use categories of most sampling wells are determined by the PWA. The 90th percentile of the annual nitrate concentrations for the different categories of well use for the period from 1981 to 2004 are depicted in Figure 23.

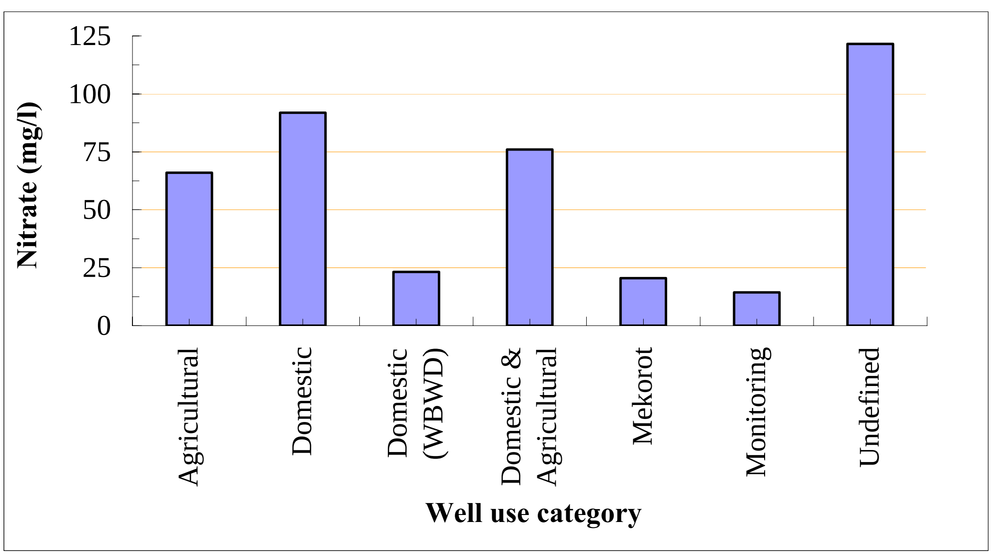


Figure 23: The 90th percentile of annual nitrate concentrations according to well use category

The results show that the 90th percentile concentrations are lower than the MCL in only *Domestic (WBWD)*, *Mekorot*, and *Monitoring* wells. The records of these wells represent about 7% of the total number of records, i.e. the 90th percentile of annual concentrations is higher than the MCL for 93% of the samples. The 90th percentile of annual concentrations of the *Agricultural* wells is lower than the MCL of 150 mg/l adopted by FAO (1985). The agricultural wells exceed 77% of the samples. Nevertheless, the 90th percentile of annual concentrations of the *Domestic & Agricultural* wells is higher than the MCL of 50 mg/l. The 90th percentile concentration of the *Domestic* wells is much higher than the MCL and their records approach 9% of the total number of records. The maximum 90th percentile concentration recorded is found in the *Undefined* well use category with a value of 121.6 mg/l, which is extremely higher than the MCL of 50 mg/l. It reflects the susceptibility to nitrate contamination of the *Domestic*, *Domestic & Agricultural*, and *Undefined* wells. The statistics of annual nitrate concentrations of the different well use categories from 1981 to 2004 are depicted in Table 8.

It is found that none of the well use category has mean or median nitrate concentration above the MCL during the study period. Except *Domestic (WBWD)* and *Monitoring* wells, all the maximum concentrations exceed the MCL. Surprisingly, the nitrate concentrations are not the highest in the *Agricultural* use category wells. It may be justified by the spatial interference of the different well use categories, but maybe it isn't the main reason for that observation. The main reason could be referred to the transport of nitrate in the groundwater due to advection, dispersion, or reaction processes.

Table 8: Statistics of annual nitrate concentrations of the different well use categories in the period from 1981 to 2004

Parameter	Agricultural	Domestic	Domestic (WBWD)	Domestic & Agricultural	Mekorot	Monitoring	Undefined
Count	3386	382	167	162	127	5	143
Mean	36.0	43.8	13.6	43.3	15.8	7.5	41.8
Min	0.8	0.0	1.0	5.0	5.0	1.0	3.0
10th Perc.	10.5	9.0	5.0	12.0	10.0	2.2	8.7
25th Perc.	18.0	14.0	7.5	26.0	12.0	4.0	15.0
Median	30.0	38.0	13.0	37.0	14.5	4.7	22.5
75th Perc.	46.2	65.4	16.0	59.4	17.5	12.0	47.3
90th Perc.	66.0	91.9	23.2	76.0	20.5	14.4	121.6
Max	285.0	148.0	46.0	144.5	80.5	16.0	213.0
Range	284.3	148.0	45.0	139.5	75.5	15.0	210.0
Mode	20.0	12.0	7.0	26.0	12.0	-	27.0
St. Dev.	27.0	33.1	8.3	25.5	7.9	6.2	45.9
Variance	730.9	1095.5	68.7	647.8	61.8	38.8	2102.7
Skewness	2.2	0.8	1.4	1.0	5.1	0.6	2.0
Kurtosis	8.6	-0.1	2.4	1.5	37.4	-1.7	3.5

The use category for 294 records of 47 sampling wells are unknown where only 143 of these samples have reported nitrate concentrations. The highest mode nitrate concentration is noticed in the *Undefined* wells. The nitrate concentrations in the wells of *Undefined* use category are very dispersed because they have the maximum standard deviation. These sampling wells need to be further studied and their use categories should be identified.

In general, the well use category is interrelated to the land use type corresponding to each well. Therefore, having the land use map will assist to profoundly interpret the nitrate distribution across the entire West Bank and thus justify the variability of nitrate concentrations.

5.3.7 Nitrate Distribution According to the Soil Types

Soil is the main resource for agricultural production since it contains the nutrients that sustain the proper plant growth. The soil also works as the main support and fixing agent for the plants body. A good understanding of the soil characteristics aids in the development of management practices that involve agricultural irrigation and the use of non-conventional water resources. This later point is of great importance when considering the reuse of treated wastewater in agriculture discerning that the soil dictates largely the migration and transport of pollutants down to groundwater in addition to the build up of chemical elements that may alter soil suitability for specific practices (Almasri et al, 2006).

The Applied Research Institute – Jerusalem (ARIJ, 2002) developed a soil map to identify the major soil associations in the West Bank. Almasri and others (2006) classified them and summarized the main properties of the West Bank soil types. It is important to mention here that a new and modified soil type map was used in the analysis of this section.

A polygon GIS shapefile of the spatial distribution of the soil types for the entire West Bank was utilized in the analysis described in this section. The spatial distribution of nitrate concentration in groundwater was spatially joined with the corresponding distribution of soil type classes as shown in Figure 24.

Table 9 summarizes the mean, median, and maximum nitrate concentrations in groundwater for the different soil type classes across the West Bank for the period from 1981 to 2004.

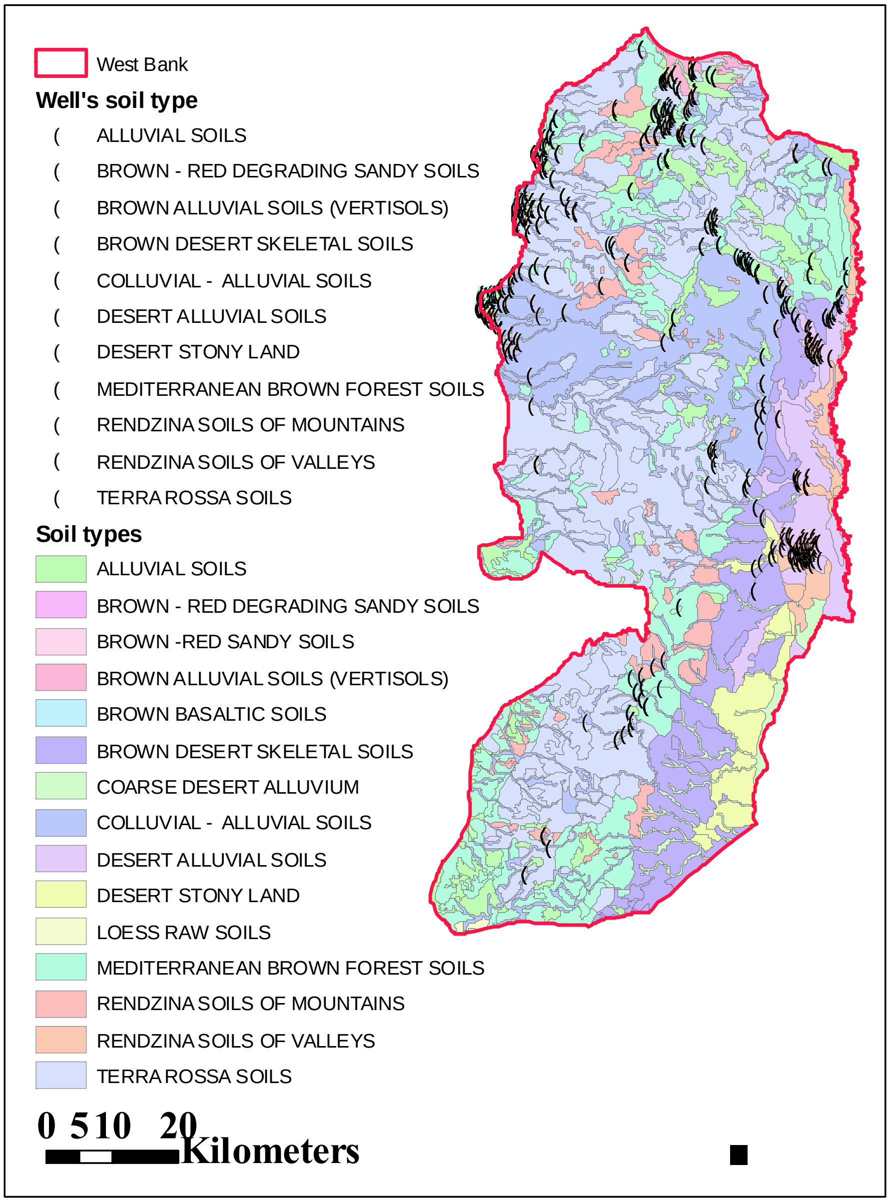


Figure 24: The distribution of the nitrate sampling wells in the West Bank based on the different soil type classes

The results indicate that areas with *Brown-red degrading sandy* soils have a high mean nitrate concentration exceeding the MCL followed by *Vertisols* soils and *Renzina soils of valleys*. The same ranking is approximately applicable for the median nitrate concentrations. These results do not imply the highest vulnerability to nitrate contamination for the *Brown-red degrading sandy* soils.

This is because a small number of wells are within this soil type class, signifying a possible bias in the results.

Table 9: Mean, median, and maximum nitrate concentrations (mg/l) for the different soil type classes for the period from 1981 to 2004

Soil types	**Number of samples**	**Mean**	**Median**	**Maximum**
Alluvial Soils	1265	35.1	27.0	192.5
Brown-Red Degrading Sandy Soils	11	104.3	93.5	164.0
Brown Alluvial Soils (Vertisols)	189	46.6	43.0	153.0
Brown Desert Skeletal Soils	153	25.0	22.0	70.0
Colluvial-Alluvial Soils	958	40.7	31.0	285.0
Desert Alluvial Soils	1050	32.7	30.3	155.5
Desert Stony Land	8	11.4	12.0	15.0
Mediterranean Brown Forest Soils	172	23.0	16.0	130.0
Rendzina Soils of Mountains	45	34.2	17.0	97.0
Rendzina Soils of Valleys	3	46.1	45.0	49.0
Terra Rossa Soils	518	36.3	25.0	231.0

Except for *Desert stony land* and *Rendzina soils of valleys* soil type classes, all the maximum nitrate concentrations are higher than the MCL. The overall maximum nitrate concentration is reported for *Colluvial-Alluvial* soils with a value of 285 mg/l, and so are the maximum standard deviation and variance of data. The *Vertisols* soil areas have the maximum skewness and kurtosis.

Almost 75% of the samples that are located within areas of *Alluvial*, *Desert Alluvial*, and *Colluvial-Alluvial* soil classes, do not have a mean nitrate concentration greater than 41 mg/l or a median nitrate concentration greater than 31 mg/l. Although these values are less than the MCL, however, these values are close to the MCL signifying possible man-made pollution sources.

5.3.8 Nitrate Distribution According to the Major Watersheds

The West Bank area is divided into several watersheds depending upon the drainage destination of the surface runoff running on a specific catchment. There are a lot of factors affecting the runoff; mainly rainfall intensity and duration, soil type category, rock formation, land use, and topology. There is no doubt that the most important factor is the topography followed by rainfall intensity and duration (Abed and Wishahi, 1999).

The runoff in south of the West Bank takes place whether the daily rainfall exceeds 50 mm or the cumulative rainfall in two consequent days exceeds 70 mm (Alkhatib, 1985). The runoff in south of the West Bank is higher than that in north because of the elevated topography (Shahab, 1997; Gvirtzman, 1994; Rofe and Raffety, 1963).

Due to the diversity of the factors affecting the runoff, the runoff ratio will vary across the West Bank. According to Rofe and Raffety (1965) report, the average of the runoff ratio for the entire West Bank is 2% of the rainfall. Whilst GTZ (1996) report estimated that average is about 3.2%. Based on the topography of the West Bank, the runoff is directed either eastward to the *Jordan River* and the *Dead Sea*, or westward to the *Mediterranean Sea* (Abed and Wishahi, 1999). Thus, the West Bank overlays three major watersheds; *Dead Sea*, *Jordan River*, and *Mediterranean Sea*. Each of them contains several minor watersheds.

A polygon GIS shapefile of the spatial distribution of the major watersheds for the entire West Bank was utilized in the analysis described in this section. The spatial distribution of nitrate concentrations in groundwater was spatially joined with the corresponding major and minor watersheds as shown in Figure 25. The mean nitrate concentrations were evaluated using the GIS tools in a separate sheet in Excel format. The data was joined to the attribute table of the nitrate concentration shapefile to get the mean nitrate concentration for each well.

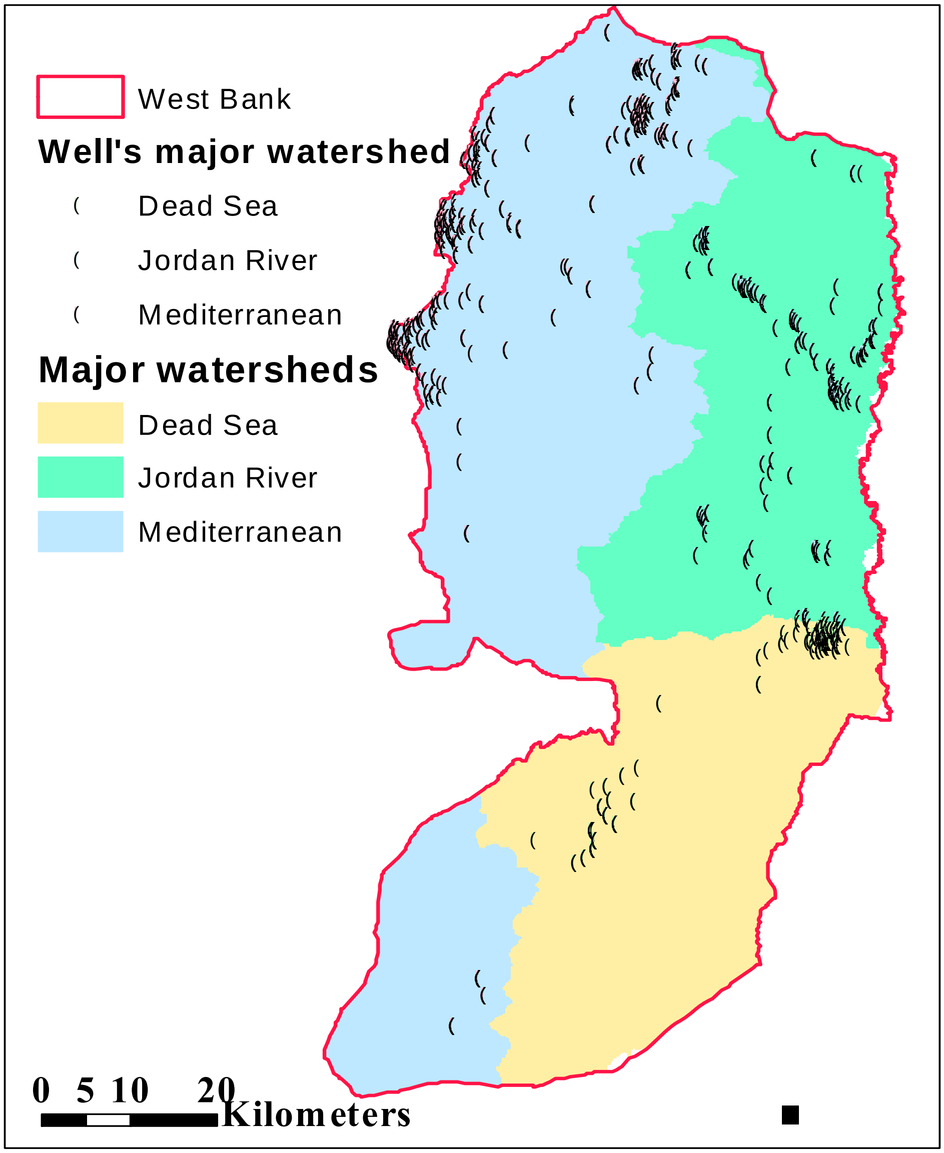


Figure 25: The distribution of the nitrate sampling wells in the West Bank based on the different major watersheds

Figure 26 shows the mean nitrate concentrations across the West Bank for the period from 1981 to 2004 with the well corresponding watersheds. In Figure 26, the minor watersheds are labeled on the map, so that the boundary of each minor watershed is delineated. The background of each minor watershed is shaded to characterize the pertaining major watershed of each one.

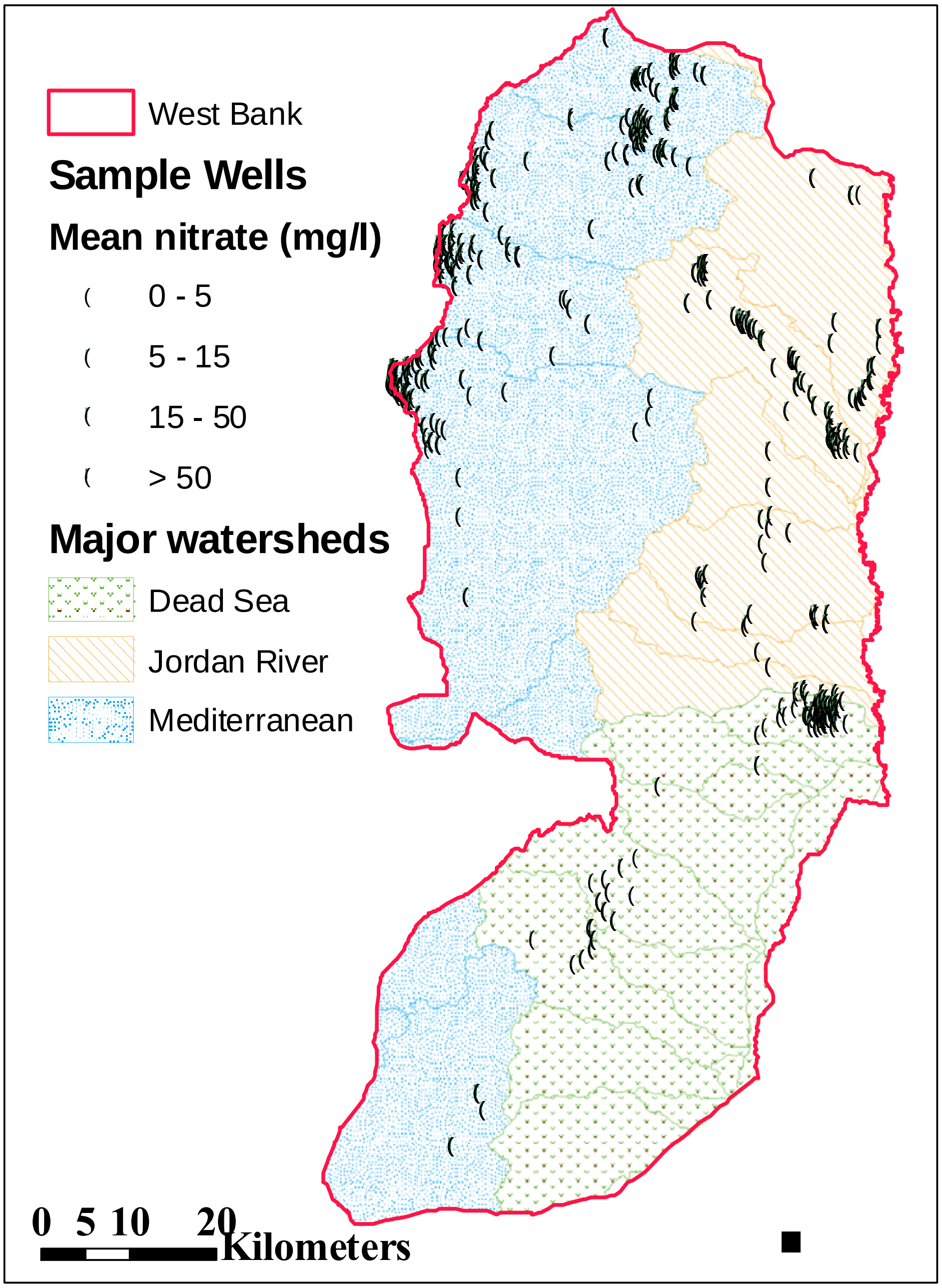


Figure 26: Mean nitrate concentrations across the West Bank from 1981 to 2004 with the corresponding major and minor watersheds for each well

Using the capabilities of GIS in summarizing results, the annual maximum and mean nitrate concentrations for each major watershed from 1981 to 2004 are summarized in Table 10 and Table 11, respectively. The annual mean nitrate concentrations of the different major watersheds are shown in Figure 27.

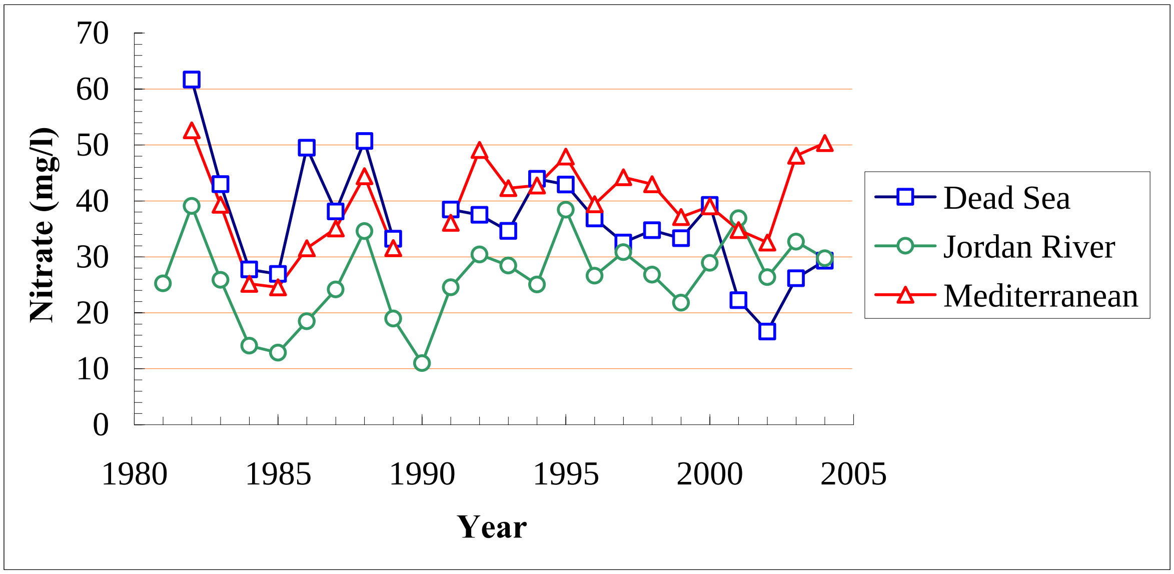


Figure 27: Annual mean nitrate concentrations of the major watersheds in the period from 1981 to 2004

The annual mean in the *Mediterranean* major watershed exhibits a general increasing trend and exceeds the MCL in 2004. The opposite takes place in the *Dead Sea* major watershed. The annual mean in the *Jordan River* major watershed is almost constant especially in the period after 1990.

The annual mean nitrate concentrations in the *Jordan River* major watershed were always the lowest except in the last five years. More analysis will be profoundly done using the annual maximum nitrate concentrations. The annual maximum nitrate concentrations of the different major watersheds are shown in Figure 28.

Table 10: Annual maximum nitrate concentrations (mg/l) according to the major watershed from 1981 to 2004

YEAR	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**
Dead Sea		127.5	104.0	73.0	82.0	155.5	101.0	124.5	87.0		94.0	91.0
Jordan River	41.0	111.5	136.5	70.0	78.5	61.5	109.5	141.5	83.5	19.0	104.5	97.5
Mediterranean		195.0	205.0	128.0	97.5	172.0	153.0	212.0	168.5		192.0	213.0

YEAR	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Dead Sea	77.0	72.0	97.0	73.0	64.0	67.0	80.5	85.0	61.0	34.3	79.9	54.0
Jordan River	106.0	77.0	154.5	93.5	150.5	92.0	107.0	114.0	90.0	73.5	231.0	143.0
Mediterranean	153.0	234.0	192.0	145.5	164.0	138.0	190.0	110.0	122.0	127.0	192.5	285.0

Table 11: Annual mean nitrate concentrations (mg/l) according to the major watershed from 1981 to 2004

YEAR	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**
Dead Sea		61.7	43.0	27.8	26.9	49.5	38.1	50.7	33.2		38.5	37.5
Jordan River	25.3	39.1	25.9	14.1	12.9	18.5	24.2	34.6	19.0	11.0	24.6	30.4
Mediterranean		52.6	39.3	25.2	24.6	31.5	35.1	44.4	31.6		36.1	49.1

YEAR	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Dead Sea	34.6	44.0	42.9	36.9	32.5	34.8	33.3	39.3	22.3	16.7	26.2	29.3
Jordan River	28.5	25.1	38.4	26.6	30.8	26.8	21.8	28.9	36.9	26.4	32.7	29.8
Mediterranean	42.3	42.8	47.9	39.4	44.2	43.0	37.1	39.0	34.8	32.5	48.1	50.4

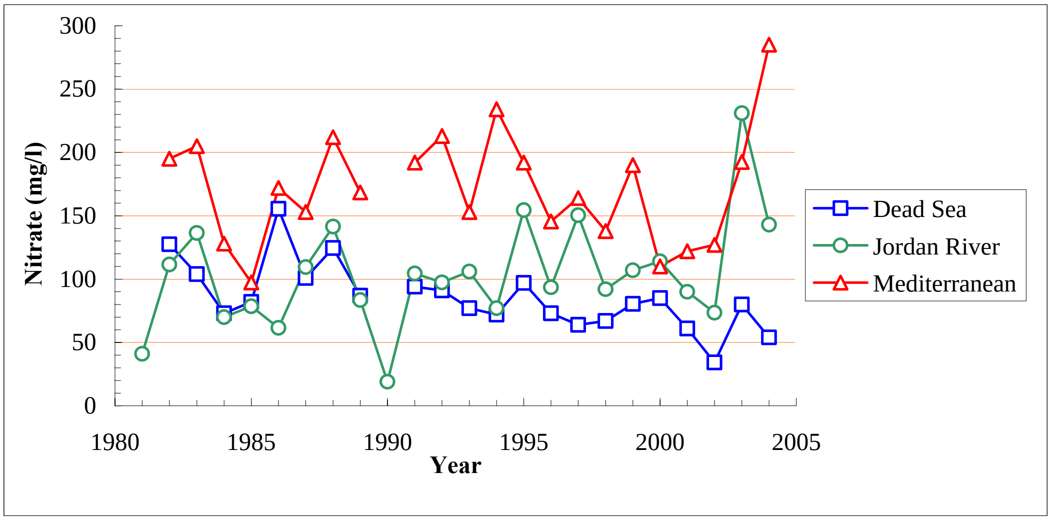


Figure 28: Annual maximum nitrate concentrations of the major watersheds in the period from 1981 to 2004

The annual maximum nitrate concentrations in the *Mediterranean Sea* watershed are always above the MCL in the range of 97.5 to 285 mg/l with an overall peak in 2004. The *Mediterranean Sea* watershed almost has the highest reported maximum nitrate concentrations. Figure 28 shows that the annual maximum exhibits a general increasing trend from the year 2000. The mean nitrate concentration exceeds the MCL in two years; 1982 and 2004 as depicted in Figure 27.

The annual mean concentration is somehow close to the MCL in the remaining years in the range of 15-50 mg/l. Nitrate concentrations in this range are the result of anthropogenic effects due to intensive agricultural activities. The annual median nitrate concentration also exhibits a general increasing trend from 1984 except for the year 2002 due to missed data. The annual median nitrate concentrations are always in the range of 15-50 mg/l. The maximum nitrate concentration recorded is from the same watershed. A possible reason for this observation is the high nitrogen application rates due to agricultural activities in this watershed. It may be also due to the recharge rate, soil type, etc.

The annual maximum nitrate concentrations in the *Jordan River* watershed (except for the years 1981 and 1990) are always above the MCL and range from 61 to 231 mg/l with the peak in 2003. The results show that the annual maximum exhibits a general increasing trend from about 1991. None of the mean nitrate concentration exceeds the MCL. Except for the years 1984, 1985, and 1990; the annual mean concentration is in the range of 15-50 mg/l.

The annual maximum nitrate concentrations in the *Dead Sea* watershed (with the exception of the year 2002) are always above the MCL and range from 54 to 155 mg/l with the peak in 1986. The results show that the annual maximum exhibits a general decreasing trend from the year 1982. The mean nitrate concentration also exceeds the MCL in 1982 and 1988. The annual mean concentration is always in the range of 15-50 mg/l. A certain reason for this observation is the high nitrogen rates due to heavy agricultural activities in that watershed, in addition to the disposal of untreated wastewater.

Many of the wells in the abovementioned watersheds show high nitrate concentrations over time. More than 28% and 22% of the samples in the *Mediterranean Sea* and *Dead Sea* watersheds have nitrate concentrations above the MCL, respectively. This percentage drops to almost 9% for the *Jordan River* watershed.

It is found that none of the watersheds has annual maximum nitrate concentrations below the MCL during the period from 1981 to 2004. Three observed maximum values with a limited number of data; in 1981, 1999, and 2002, stand out because of the low maximum nitrate concentrations. There were fluctuations in the maximum nitrate concentrations in the individual watersheds, but in general, there is increasing trends in the *Mediterranean Sea* and *Jordan River* watersheds associated with a decreasing trend in the *Dead Sea* watershed. The *Mediterranean Sea* watershed has the highest maximum nitrate concentrations during the study period.

5.3.9 Nitrate Distribution in the Minor Watersheds

As mentioned earlier, the three major watersheds in the West Bank are the *Dead Sea*, *Jordan River*, and *Mediterranean Sea*. Each of them contains several minor watersheds. A polygon GIS shapefile delineating the outlines of the minor watersheds for the entire West Bank is depicted in Figure 29.

The spatial distribution of nitrate sampling wells is spatially joined with the corresponding minor watersheds, so that each well will be attributed to the minor watershed in which the well is located.

In the following subsection, the minors of each major watershed will be independently studied and analyzed. In the end, all the minor watersheds will be gathered together to evaluate the general situation.

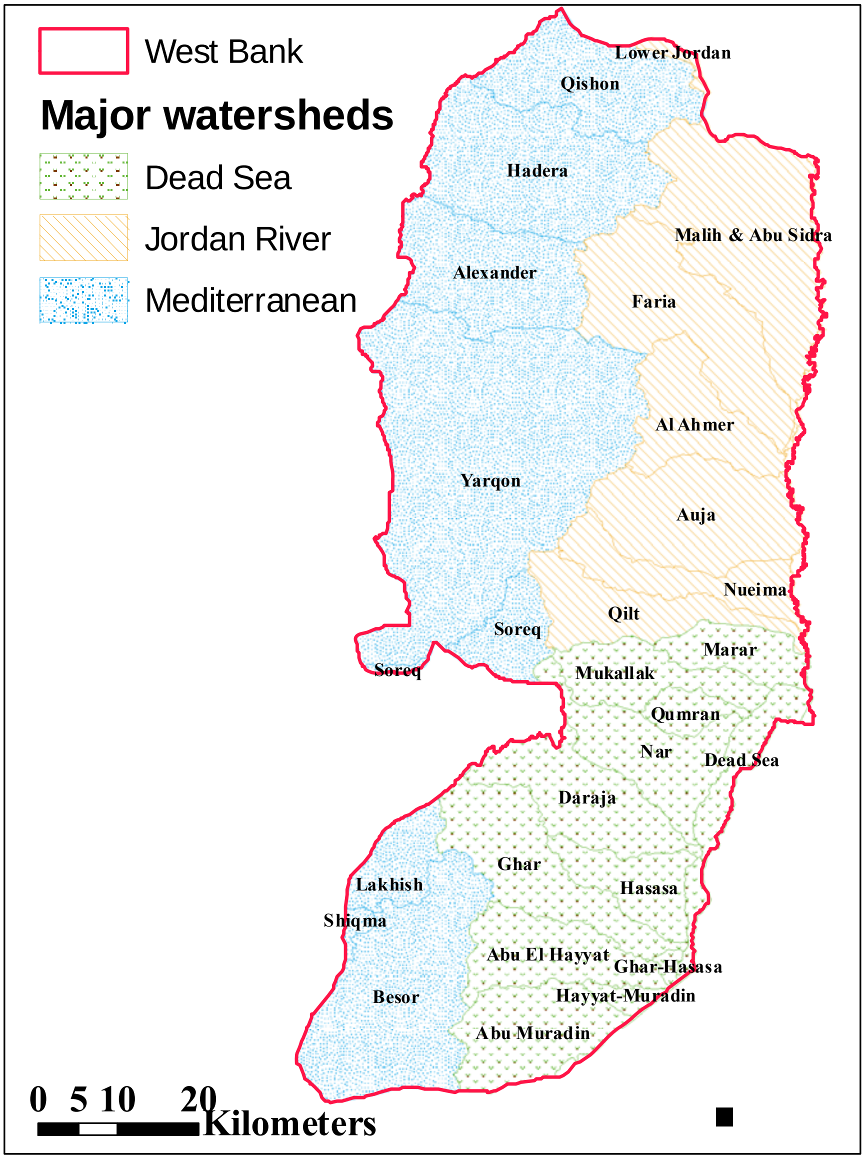


Figure 29: The spatial distribution of the minor watersheds for the entire West Bank and the corresponding major watershed

Dead Sea Minor Watersheds

The statistics of the annual nitrate concentrations for the Dead Sea minor watersheds are depicted in Figure 30. The results show that the third quartile (75th percentile) is above the MCL in *Marar* minor watershed only. *Marar* is the most powerful minor watershed because more than 82% of the samples in the Dead Sea are located within it.

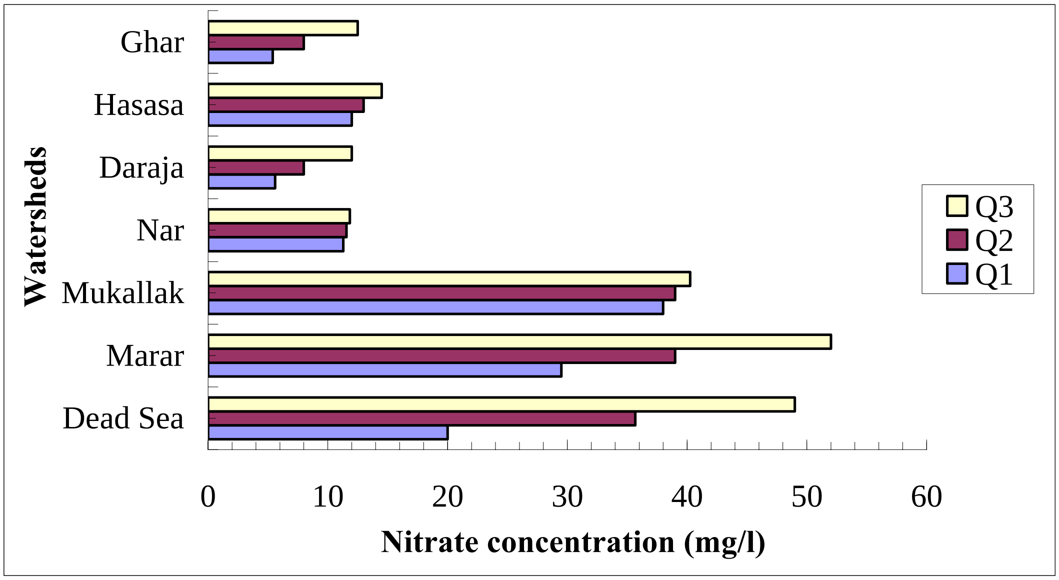


Figure 30: The 1st, 2nd, and 3rd quartiles of nitrate concentrations in the Dead Sea minor watersheds for the period from 1981 to 2004

The second quartile (median) of the *Marar* watershed is in the range of 15-50 mg/l. *Mukallak* watershed has three records only while the other watersheds have low nitrate concentrations. Nevertheless, *Mukallak* watershed has the highest 1st and 2nd quartiles. This makes the *Marar* watershed the most significant one in terms of the reliability in the analysis. In few watersheds, the 2nd and 3rd quartiles are almost identical as a result of the limited data.

It is noticeable that the 1st quartile of the *Hasasa* watershed is greater than the 2nd quartile of the *Nar*, *Daraja*, and *Ghar* watersheds. It is also greater than the 3rd quartile of the *Nar* watershed and equals the 3rd quartile of the *Daraja* watershed.

Jordan River Minor Watersheds

The statistics of the annual nitrate concentrations for the Jordan River minor watersheds are depicted in Figure 31.

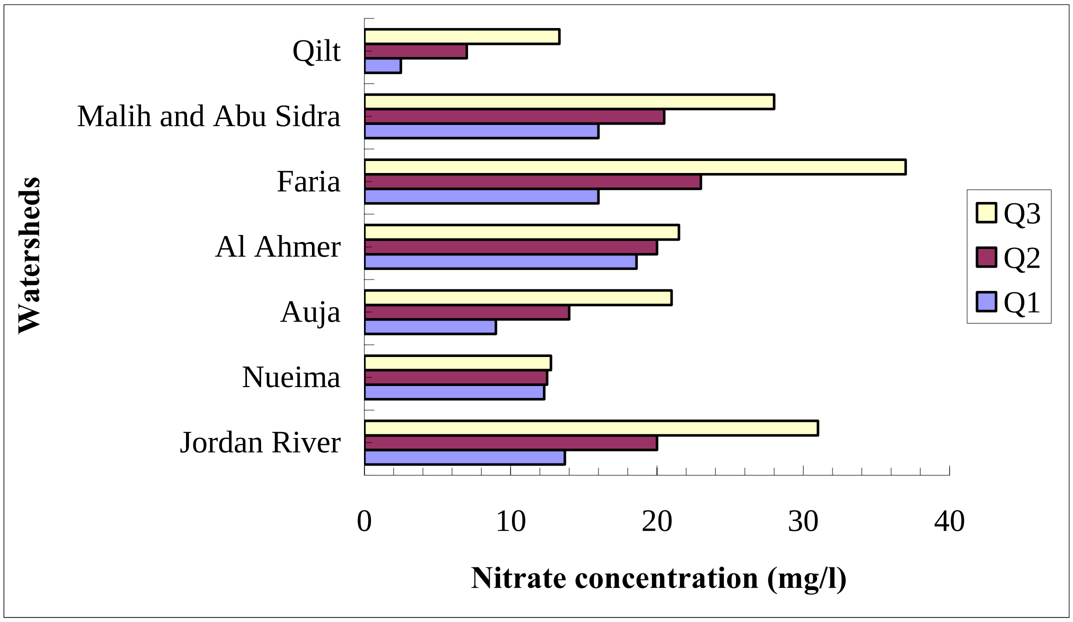


Figure 31: The 1st, 2nd, and 3rd quartiles of nitrate concentrations in the Jordan River minor watersheds for the period from 1981 to 2004

The results show that none of the third quartiles is above the MCL. The 3rd quartile of nitrate concentrations for the *Faria* watershed is the maximum among the other watersheds with a value of 37 mg/l and so is the 2nd quartile. More than 61% of the samples in the Jordan River watershed are located within the *Faria* watershed where 116 of its 810 samples have nitrate concentrations above the MCL. A certain reason for this observation is the high nitrogen application rates due to the dense agricultural activities in this specific watershed. The neighboring watersheds to *Faria*, namely *Al Ahmar* and the *Malih and Abu Sidra*, come after it in terms of nitrate contamination though encounter similar practices. It is observed that 1st, 2nd, and 3rd quartiles for the three watersheds are all in the range of 15-50 mg/l. It is noticeable that *Al Ahmar* watershed has the highest 1st quartile followed by both *Faria* and *Malih and Abu Sidra* watersheds. While the lowest 1st quartile is reported in *Qilt* watershed.

Mediterranean Sea Minor Watersheds

The statistics of the annual nitrate concentrations for the Mediterranean Sea minor watersheds are depicted in Figure 32.

The results show that the third quartile of nitrate concentrations is always above the MCL, except that for the *Hadera* watershed. This does not mean that the *Hadera* watershed is safe because more than 15% of its samples (85th percentile) have nitrate concentrations above the MCL. The median nitrate concentration in the *Besor* watershed is above the MCL. For the remaining watersheds, nitrate concentration ranges from 22 to 46 mg/l. These results verify the alarming situation in the Mediterranean watershed, mainly in the *Besor* and *Yarqon* minor watersheds that together represent about 23% of the samples in that major watershed and more than 42% of their samples have nitrate concentrations above the MCL.

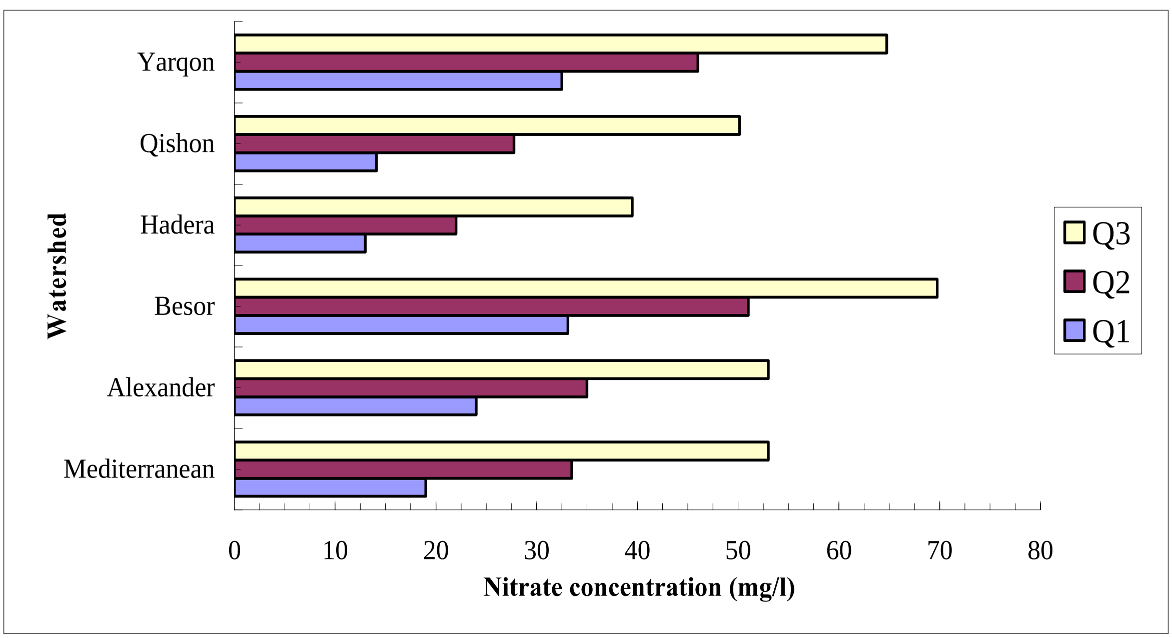


Figure 32: The 1st, 2nd, and 3rd quartiles of nitrate concentrations in the Mediterranean Sea minor watersheds for the period from 1981 to 2004

The Mediterranean Sea major watershed is the most vulnerable watershed to nitrate contamination because of its elevated nitrate concentrations compared with the other two major watersheds. The 1st quartile in the *Besor* watershed is the highest followed by the *Yarqon* watershed. It is noticeable that the 1st, 2nd, and 3rd quartiles for both watersheds are all in the range 15-50 mg/l. *Alexander* watershed is ranked as the third in vulnerability to nitrate contamination in the Mediterranean major watershed.

West Bank Minor Watersheds

In order to compare among the various minor watersheds regardless of their classification according to the major watershed, the minor watersheds from the different major watersheds were analyzed together. It is important to do this in order to get a general overview regarding of the nitrate concentration occurrences in the different watersheds across the West Bank.

The statistics of the annual nitrate concentrations for the entire West Bank minor watersheds are depicted in Figure 33. The Figure verifies the alarming situation in all the Mediterranean minor watersheds, extremely in the *Besor* and *Yarqon* watersheds. Moreover, the maximum nitrate concentration in the West Bank for the period from 1981 to 2004 was reported in the *Hadera* minor watershed. All these results necessitate the vulnerability to nitrate contamination for the Mediterranean major watershed.

Although the nitrate concentration range in *Faria* minor watershed is higher than that of the *Marar* minor watershed, but the *Marar* watershed is more vulnerable to nitrate contamination. The reason refers to the fact that the central measures, like mean and median, of the *Marar* watershed are more elevated than those of the *Faria* watershed.

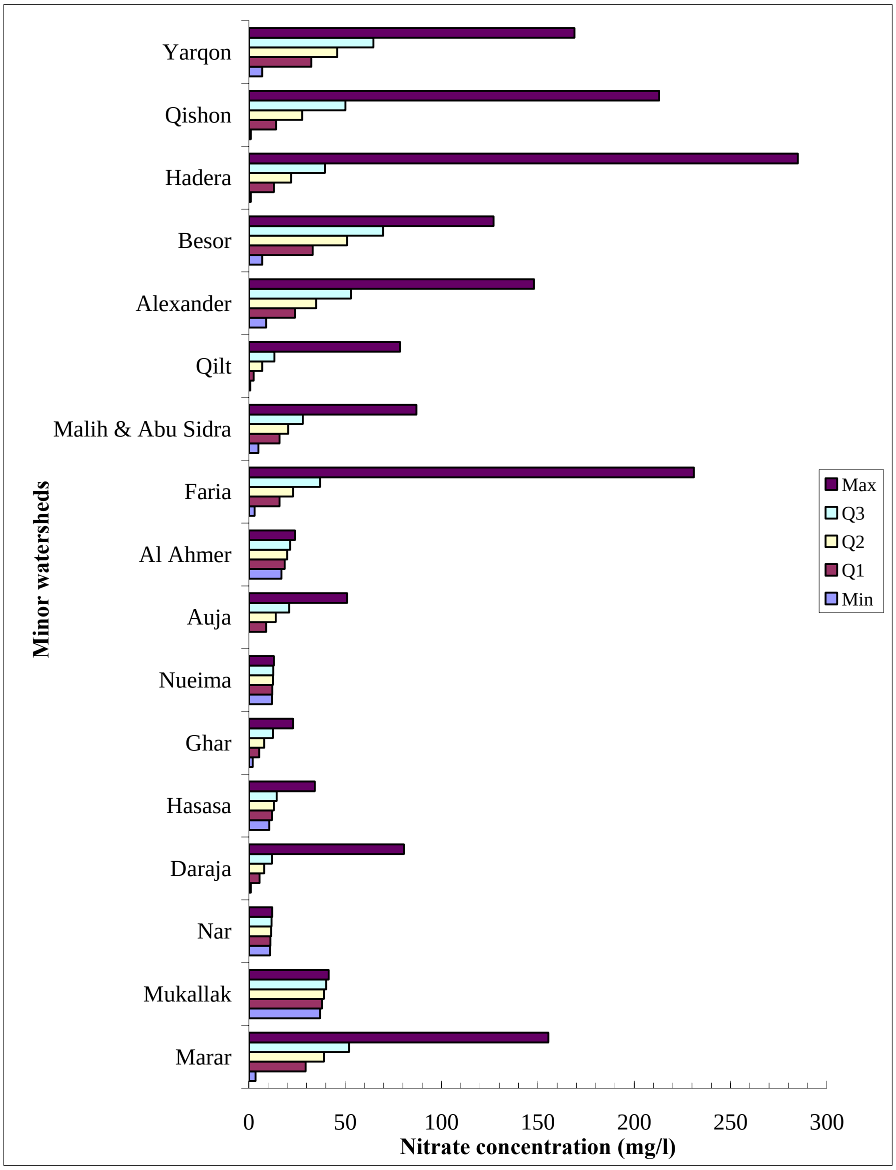


Figure 33: Statistics of nitrate concentrations for the different minor watersheds in the West Bank for the period from 1981 to 2004

To have a better visualization of the results, a ranking table can be drawn to summarize those results. In Table 12, all the minor watersheds in the entire West Bank are ranked starting from the higher to the lower in terms of the mean, median, and maximum nitrate concentrations for the period from 1981 to 2004.

Table 12: The descending ranking of the minor watersheds in the entire West Bank according to the mean, median, and maximum nitrate concentrations for the period from 1981 to 2004

Rank	Minor watersheds		
	Mean	**Median**	**Max**
1	Yarqon	Besor	Hadera
2	Besor	Yarqon	Faria
3	Marar	Marar	Qishon
4	Alexander	Mukallak	Yarqon
5	Mukallak	Alexander	Marar
6	Qishon	Qishon	Alexander
7	Hadera	Faria	Besor
8	Faria	Hadera	Malih & Abu Sidra
9	Malih & Abu Sidra	Malih & Abu Sidra	Daraja
10	Al Ahmer	Al Ahmer	Qilt
11	Auja	Auja	Auja
12	Hasasa	Hasasa	Mukallak
13	Nueima	Nueima	Hasasa
14	Nar	Nar	Al Ahmer
15	Qilt	Daraja	Ghar
16	Daraja	Ghar	Nueima
17	Ghar	Qilt	Nar

It is noted that the first ranks in the mean, median, and maximum concentrations are specified to the Mediterranean minor watersheds. Although Besor and Yarqon watersheds have the first ranks in the mean and median concentrations, but many other watersheds exceed them in the maximum concentration. Auja is the only watershed that has the same (11^{th}) rank in the mean, median, and maximum concentrations.

5.3.10 Vertical Nitrate Distribution in Groundwater

In general, the nitrate concentration in groundwater decreases with increasing sampling depth (Hallberg and Keeney, 1993; Tesoriero and Voss, 1997). This phenomenon takes place due to several reasons. One of the main reasons is the nitrogen deposition resulting from the on-ground nitrogen loadings on the land surface. The frequencies of nitrate sampling based on the depth of the sampling well were significantly varying. Therefore, the nitrate samples were classified based on several depth intervals as depicted in Figure 34.

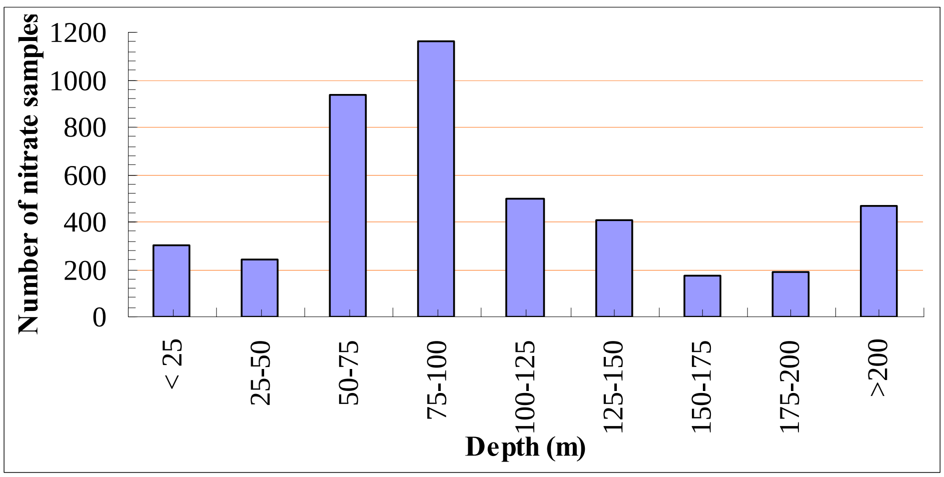


Figure 34: Frequencies of nitrate samples based on the depth of the sampling well for the West bank in the period from 1981 to 2004

According to Figure 34, the number of nitrate samples ranges from 172 to 1,160 for the depths 75-100 and 150-175 meters, respectively. It is noted that almost half of the nitrate samples fall within the depth interval 50-100. Needless to mention that the depth interval from 0-50 is the most important since it represents the nitrate concentration immediately after leaching.

For all the nitrate samples, the nitrate concentrations were associated with the corresponding depth of the sampling wells to investigate the relationship between these two parameters. Figure 35 depicts this scattered relationship for the West Bank for the years from 1981 to 2004.

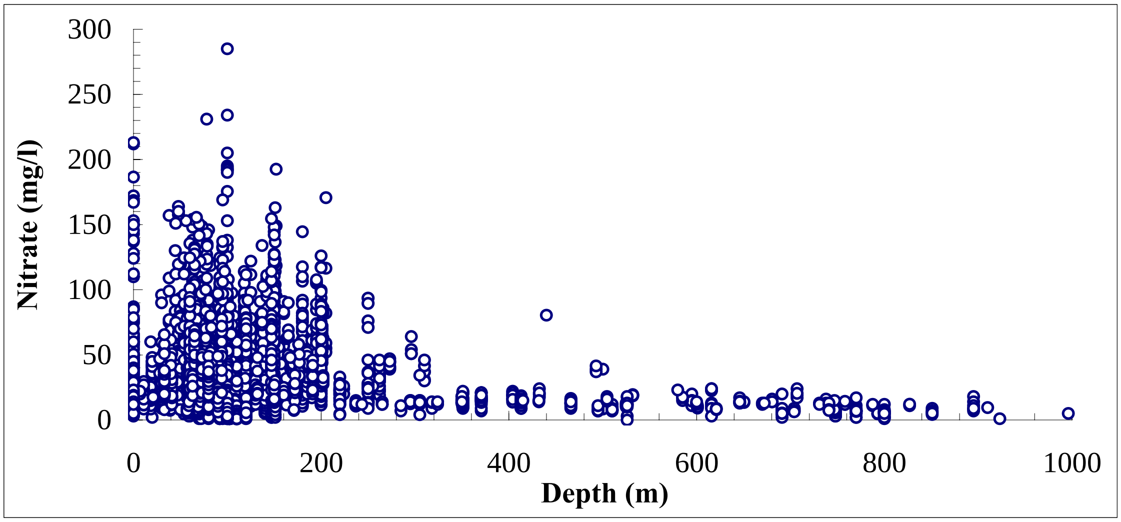


Figure 35: Variability of nitrate concentration with sampling depth for the West Bank for the period from 1981 to 2004

Many observations can be drawn out from Figure 35. First, the results compare well with the general trend of nitrate concentration variability with the sampling depth as reported in many studies (Nolan and Stoner, 1995; Parliman, 2002; Hanson, 2002). No explicit justifications and conclusions can be made with respect to the vertical nitrate profile in groundwater. Nevertheless, this phenomenon can be attributed mainly due to three factors; denitrification in groundwater, vertical groundwater movement and the associated nitrate transport, and mixing (Almasri and Kaluarachchi, 2004a).

Denitrification of nitrate is an anaerobic process by which bacteria converts nitrate to N_2 and N_2O gases. The importance of denitrification as a major pathway of nitrate removal from aquifers has been reported in many studies (Frind et al., 1990; Postma et al., 1991; Korom, 1992; Tesoriero and Voss, 1997; Tesoriero et al., 2000). The common requirements for denitrification are

(Korom, 1992): the presence of an electron acceptor which in this case is nitrate; presence of a microbial population that possess the metabolic capacity; presence of suitable electron donors; and the presence of anaerobic conditions or restricted oxygen availability. The main limiting factor for these four requirements is the presence of dissolved oxygen, which is preferred over nitrate due to the high redox potential.

Dissolved oxygen diffuses about 10,000 times more slowly through water than through air (Addiscott, 1992). As such, it is common to observe higher dissolved oxygen content in shallow depths than at deeper depths (Almasri and Kaluarachchi, 2004a). This conclusion is further demonstrated in Figure 36 from the dissolved oxygen concentration data obtained for the West Bank from 1981 to 2004. However, this conclusion is not well matching with an exception that there are few high dissolved oxygen concentrations found in some deep wells. This happens because the sampling wells are not observing wells and some of those wells have excessive pumping rates. As a result of this, the samples may be drawn out from lower depths giving higher nitrate concentrations.

For the data in field, there is no noticeable variability in the dissolved oxygen concentration across the different depths of sampling wells. The site-specific reason for these observations is not known at the present time. In general, nitrate is most likely to be denitrified at deep depths due to lack of oxygen (DeSimone and Howes, 1996; 1998).

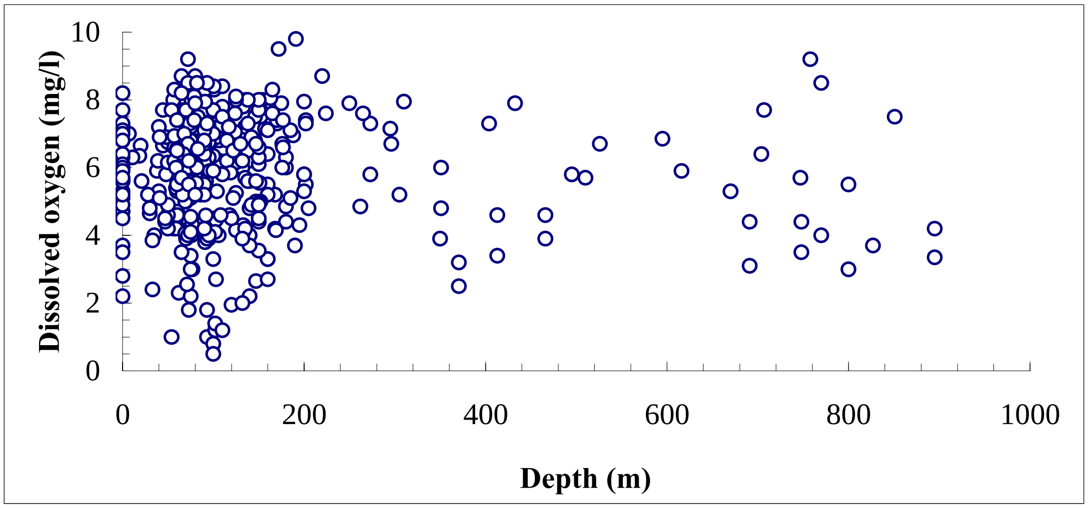


Figure 36: Variability of dissolved oxygen concentration with sampling depth for the West Bank for the period from 1981 to 2004

Figure 37 depicts the relationship between the nitrate concentration and the dissolved oxygen concentration.

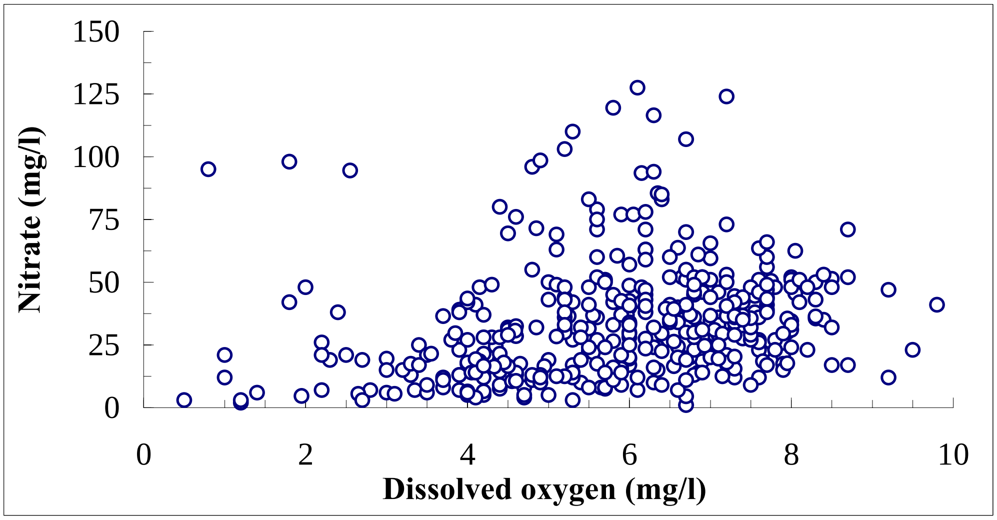


Figure 37: Variability of nitrate concentration with dissolved oxygen for the West Bank for the period from 1981 to 2004

Although no obvious relationship can be inferred, however, Figure 37 shows that at high dissolved oxygen concentrations, clustered high nitrate concentrations are noticed and vice versa. This observation implies that when there is adequate dissolved oxygen, there is no active decay (denitrification) of nitrate. It should be kept in mind that it is difficult to attribute the variability of nitrate concentration with depth exclusively to denitrification.

The second factor affecting the nitrate variability with depth is the vertical groundwater movement, which is influenced mainly by water pumping from the deeper aquifers. The deepest wells are in Nablus district followed by Bethlehem and Ramallah and Al-Bireh districts. Therefore, these wells can easily cause nitrate transport into deeper aquifers. The pumping of water from deep depths causes a downward hydraulic gradient, therefore, nitrate will be transported downward into such depths. The majority of the wells in the West Bank extract water from the shallow aquifers. The depths of more than 60% of the wells do not exceed 100 meters.

The third possible factor that can affect the nitrate variability with depth is the mixing of water with high nitrate concentrations when it enters deep groundwater. It can be concluded that high nitrate concentrations are within the upper 100 m of groundwater in the West Bank. After this depth, nitrate concentration decreases with depth.

The statistics of the nitrate concentrations based on the depth of the sampling well for the entire West Bank for the period from 1981 to 2004 are shown in Figure 38. This Figure provides a better visualization of the variability of nitrate concentration with the depth. Figure 38 shows that all maximum nitrate concentrations exceed the MCL. The maximum nitrate concentration is encountered at within the depth interval 75-100 meters. The figure also shows that the 3rd quartile exceeds the MCL at the following depth intervals 25-50, 50-75, 100-125, and 175-200 meters. Surprisingly, the 3rd quartile in the surface wells is below the MCL. Moreover, the highest mean and median nitrate concentrations were within the depth interval 175-200 meters. This observation may be justified by the high groundwater recharge rate or heavy on-ground nitrogen loadings. This observation is in concordant with the fact that 83% of the samples are located in Qalqilya and Tulkarm districts where agricultural activities are intensive. In addition, pumping rates of these wells are relatively high which enhance the vertical downward transport of nitrate.

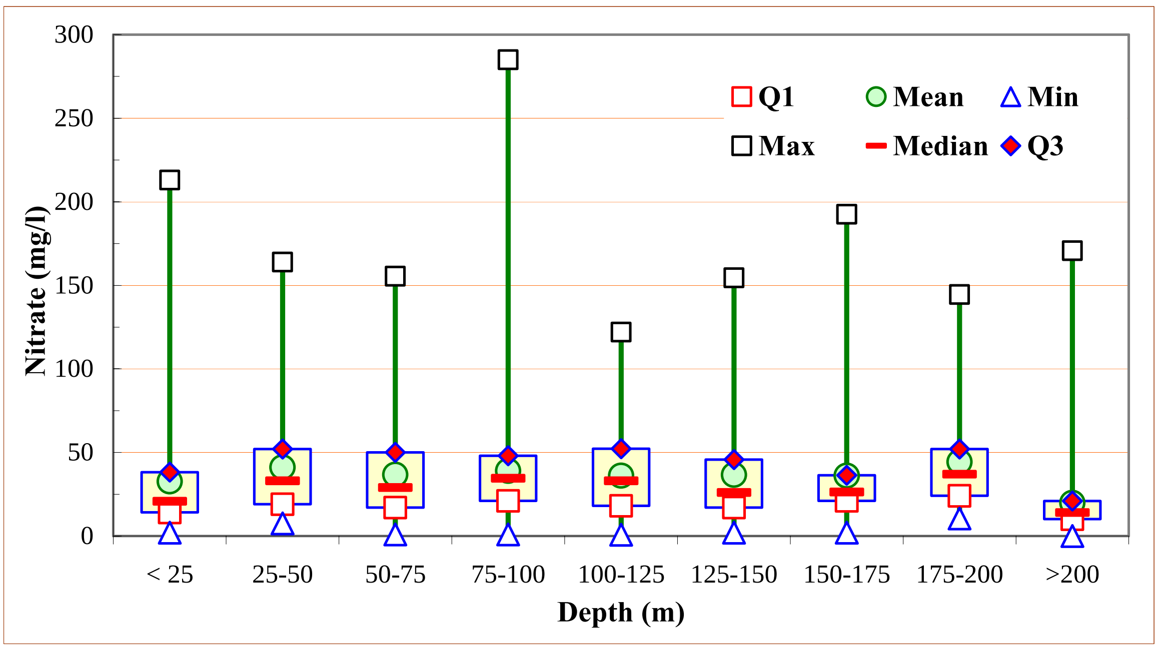


Figure 38: Statistics of nitrate concentrations based on depth of the sampling well for the entire West Bank for the period from 1981 to 2004

5.3.11 Vertical Nitrate Distribution in Nested Wells

In the last section, the variability of nitrate concentration with sampling depth for the West Bank for the period from 1981 to 2004 was demonstrated. This gives the nitrate distribution for the entire study area but in an inclusive view. Further analysis is needed to provide the vertical distribution of nitrate in close nested wells.

Three groups of nested wells were carefully selected at the highest well- density zones in the West Bank: Zone A located in Jericho district, Zone B located in Jenin district, and Zone C located in Qalqilya district. The selected zones of nested wells are shown in Figure 39.

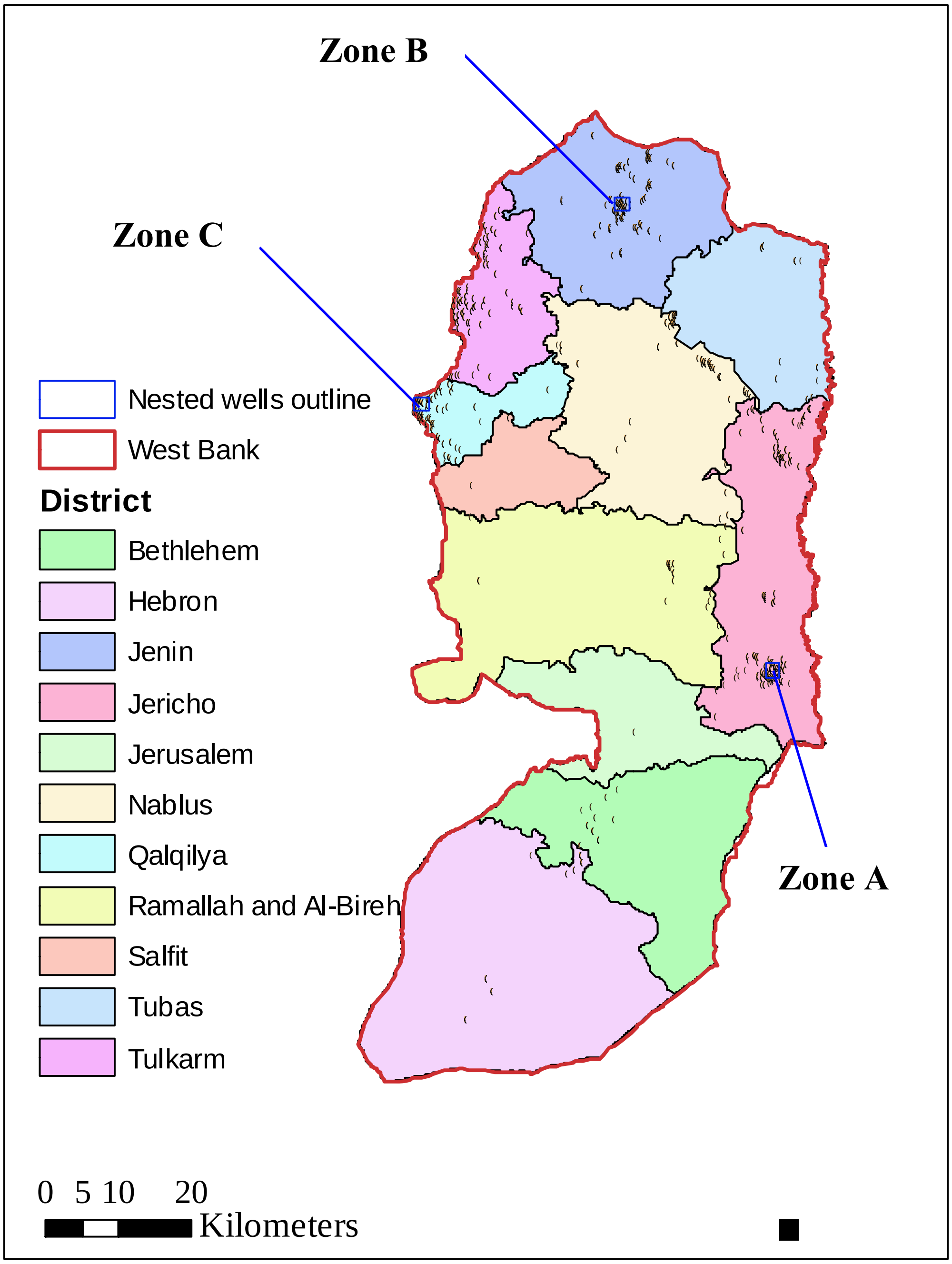


Figure 39: The location of the selected zones of nested wells

The same procedure followed in the last section for the entire West Bank was repeated but for the three groups of nested wells. The variability of nitrate concentration with sampling depth for the period from 1981 to 2004 for Zone A, Zone B, and Zone C are depicted in Figure 40, Figure 41, and Figure 42, respectively.

Zone A contains 28 wells of 342 samples, Zone B contains 21 wells of 247 samples, and Zone C contains 18 wells of 112 samples. The area of the zone selected is 2.0 km × 2.0 km. The vast majority of samples were taken from depths not more than 150 m.

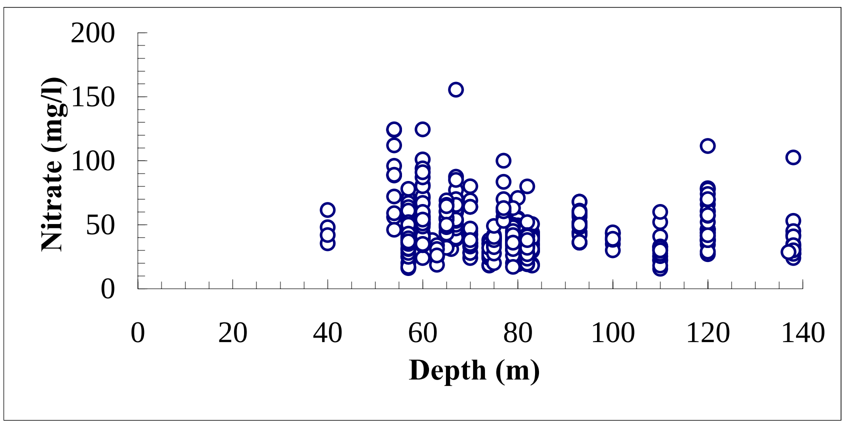


Figure 40: Vertical nitrate distribution of nested wells in Zone A

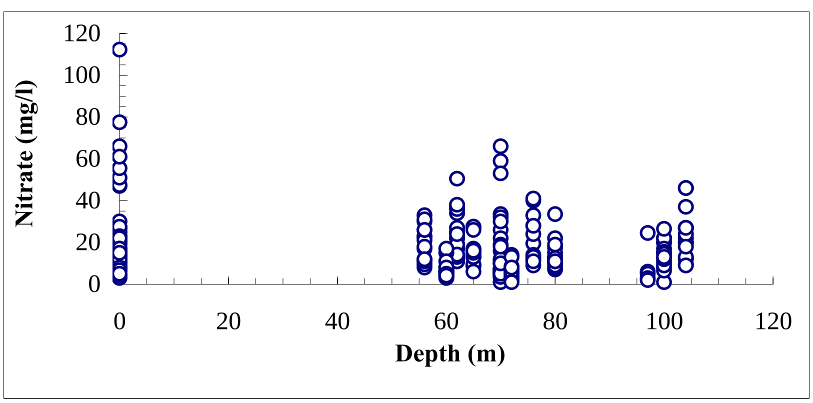


Figure 41: Vertical nitrate distribution of nested wells in Zone B

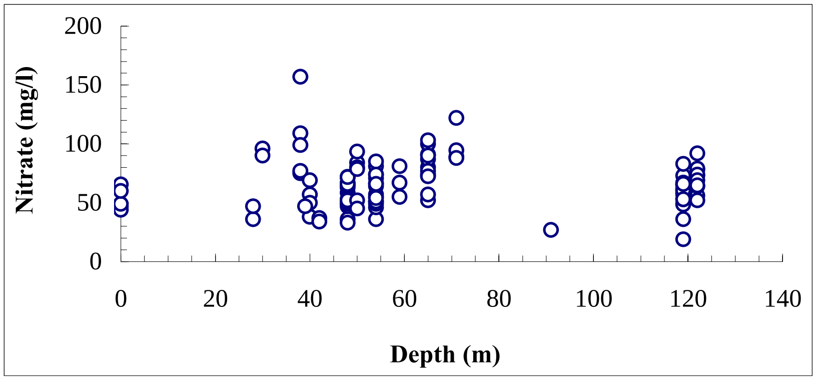


Figure 42: Vertical nitrate distribution of nested wells in Zone C

In the last section, it was concluded that high nitrate concentrations are within the upper 100 m of groundwater in the West Bank. After this depth, nitrate concentration decreases with depth. However, the figures above demonstrate an opposite trend. The lowest nitrate concentration is reported at depth 100 m. This trend is very clear in Figure 40 because depth of samples were evenly distributed providing a representive relationship. Figure 41 shows the same trend to a limited range, while Figure 42 shows a generic decay in nitrate concentration with depth.

5.3.12 Nitrate Distribution with Groundwater Recharge

Leaching of nitrate from the soil zone increases with groundwater recharge due to the high mobility of nitrate (Shaffer et al., 1991; Meisinger and Delgado, 2002; Almasri and Kaluarachchi, 2004a). Many studies showed that nitrate concentration in the groundwater of shallow aquifers increases with increasing groundwater recharge (Saffigna and Keeney, 1977; Spalding et al., 2001; Hanson, 2002).

Groundwater recharge is the main vehicle to transport nitrate downward. Groundwater recharge is a function of many factors including soil type, antecedent soil water content, precipitation, and land cover. Therefore, multiple mathematical equations are used to estimate the groundwater recharge from the rainfall. Generally, there are linear relationships between groundwater recharge and rainfall. Therefore, rainfall is used instead of recharge for simplicity of analysis. Mapping the relationship between nitrate concentration and the rainfall provides a preliminary understanding of these factors. This relationship can also help in designating the areas of high risk of nitrate pollution of groundwater and thus providing a priority for future management actions.

In this section, a GIS point shapefile of the long-term average annual rainfall distribution for the West Bank was obtained. This point shapefile of the distribution of the rain stations was utilized in the development of a shapefile for the Thiessen polygons of the rainfall (see Figure 43) using a special GIS extension.

In order to find out the overall rainfall rate of each watershed, GIS spatial capabilities wee utilized in intersecting between the Thiessen polygon shapefile and the shapefile of the watersheds. The overall rainfall value for each minor watershed was calculated using the area weighted method of the rainfall for the intersected polygons in the specific minor watershed.

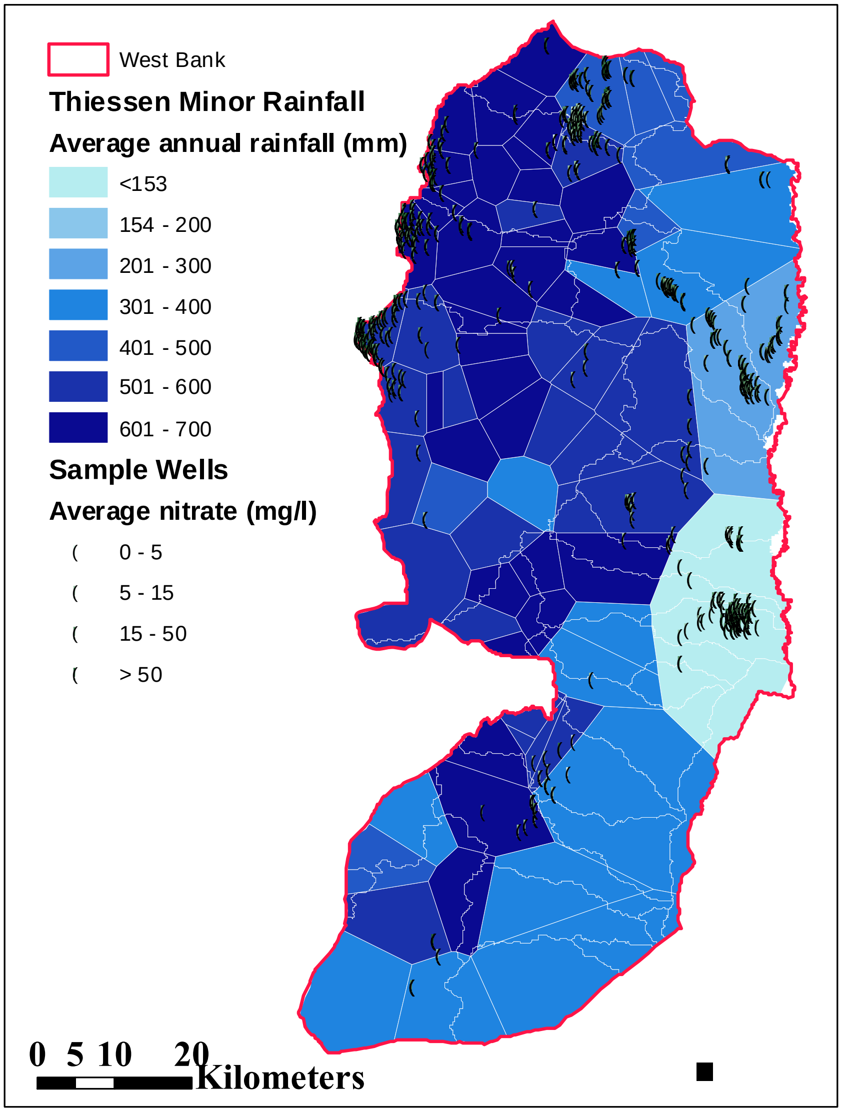


Figure 43: Thiessen polygons of long-term average annual rainfall values for the entire West Bank

Using the GIS tools, a table is developed to link the mean nitrate concentration of each minor watershed and the corresponding rainfall value for each minor watershed. Figure 44 shows the relationship between mean nitrate concentration of each minor watershed and the corresponding rainfall. As can be seen from Figure 44, the rainfall varies between 157 and 625 mm. Figure 44 shows a trend with many outliers. The possible reasons for the presence of these outliers are that these data points may correspond to rainfall polygons receiving high on-ground nitrogen loading due to the existing land use classes which is unavailable to the study area.

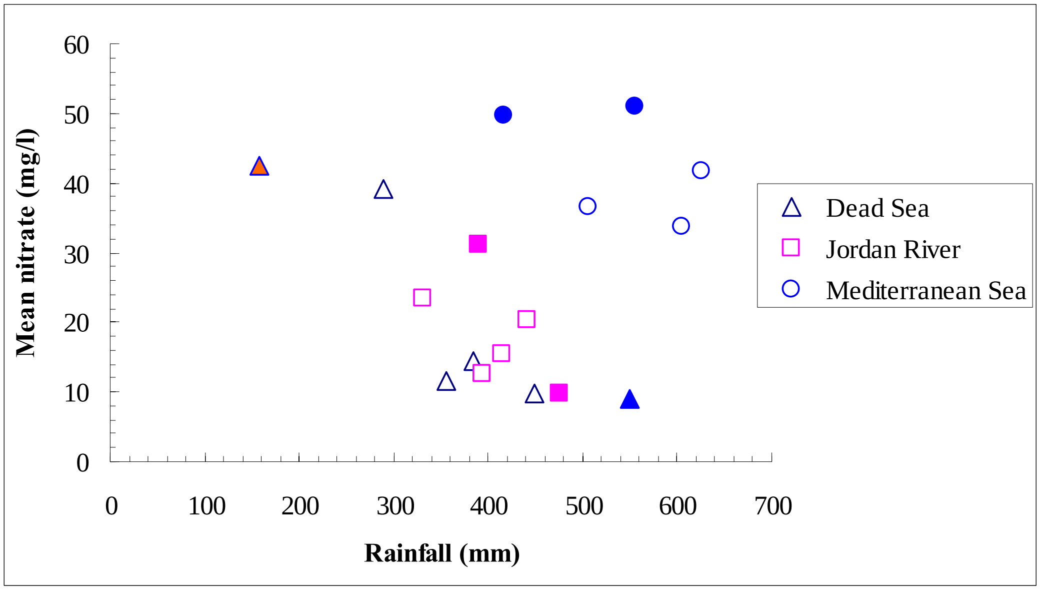


Figure 44: The relationship between the mean nitrate concentration of each minor watershed and the corresponding rainfall

For example, the orange-colored triangular data point with a rainfall of 157 mm represents the Marar minor watershed. However, 548 out of the 562 samples in this watershed were taken from agricultural wells and thus high on-ground nitrogen loading is expected in that area which is adjacent to Jericho city where the main profession of residents is agriculture.

Similarly, the blue-colored triangular data point with a rainfall of 550 mm and mean nitrate concentration of 9 mg/l is in the Ghar minor watershed. However, 31 out of the 34 samples in this watershed were taken from domestic wells. Thus, although the rainfall is high, the availability of soil nitrogen is limited and insufficient to produce a high rate of nitrate leaching to groundwater. It is noticeable that both minors, Marar and Ghar, are located within the Dead Sea major watershed.

In the Mediterranean Sea major watershed, the two blue-colored circular data points with rainfalls of 555 mm and 416 mm represent the *Yarqon* and *Besor* minor watersheds, respectively. Those two data points are biased so that the linear relationship could not been attained. This result was expected since both watersheds have the first ranks in nitrate concentrations among the watersheds in the entire West Bank as shown in Table 12.

In the Jordan River major watershed, the pink-colored square data point with a rainfall of 391 mm represents the *Faria* minor watershed. In this watershed, 735 out of its 810 samples were taken from agricultural wells and thus high on-ground nitrogen loading is expected in that area where the main profession of residents is agriculture. On the other hand, the other pink-colored square data point with a rainfall of 476 mm has a low average nitrate concentration. This data point represents the *Qilt* minor watershed where 80 out of its 85 samples were taken from agricultural wells. There are other parameters that may significantly influence the nitrate concentration and hence should be taken into consideration. Therefore, more analysis is required in order to justify such conflicts observed in Figure 44.

5.3.13 Time Series of Nitrate Concentration for Selected Wells

In this chapter, the nitrate distribution in groundwater was analyzed according to different parameters such as district, soil type, well use, sampling depth, and watersheds. These categories implied different nitrate distribution following dissimilar trends. Many of the wells as analyzed according to the abovementioned categories showed high nitrate concentrations over time. The wells with the lowest nitrate concentrations were mostly in areas of deep aquifers.

Figure 45 shows the time series of nitrate concentration for different wells with high frequent samples and well distributed in the West Bank. These figures provide a qualitative understanding of the general temporal trends of nitrate concentrations in the groundwater of the West Bank. In general, Figure 45 shows that nitrate concentration has an increasing trend after the year 1985. For Jerusalem and Salfit districts, few wells within these districts have significant data, therefore, they were not considered in this analysis. The spatial locations of these wells are demonstrated in Figure 45.

Let us consider the agricultural *well 14-17/025* that is located in Qalqilya district and taps the Upper Cenomanian aquifer of the Western basin. In this well, 14 samples out of 19 exceeded the MCL throughout the period from 1982 to 2004.

Jenin district is adjacent to Tubas district and both are similar in nature and conditions. *Well 17/20-051A* located in Jenin district and *well 19/19-010* located in Tubas district are both having the same nitrate concentration trends with almost identical rates. *Well 17/20-051A* taps a very deep depth with a much higher average annual rainfall value compared to *well 19/19-010*.

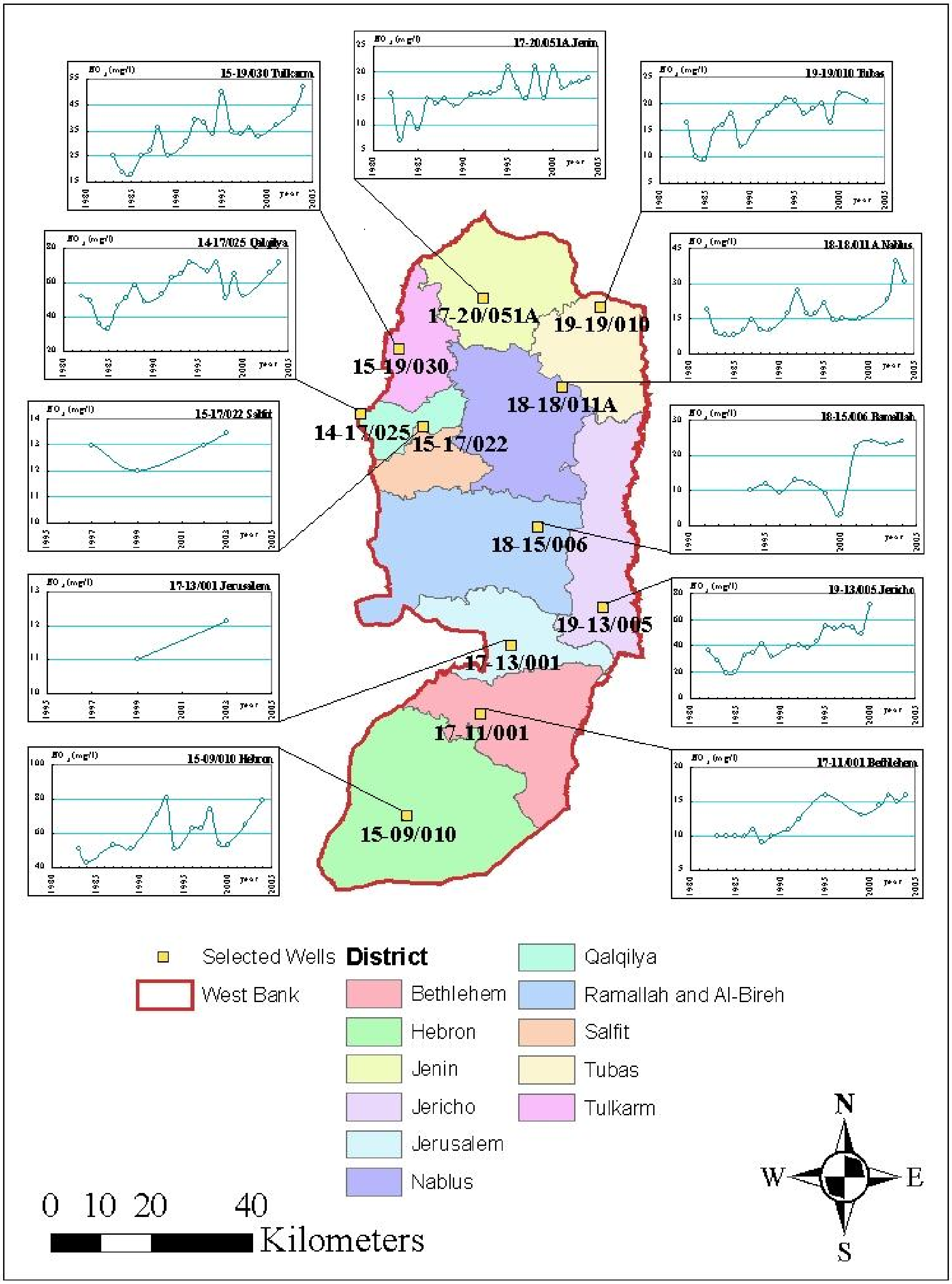


Figure 45: Time series of nitrate concentrations for selected wells in the West Bank for the period from 1981 to 2004

Although Bethlehem district is adjacent to Hebron district with considerable similarity in man-made activities, yet nitrate concentrations of *well 15-09/010* located in Hebron district has a big difference than those of *well 17/11-001* located in Bethlehem district. Both of these wells tap the same aquifer system with similar soil type and well use. The depth of *well 17/11-001* is three times more the depth of *well 15/09-010*. This considerably affects the nitrate concentration as illustrated in the previous section. The nitrate concentrations in both wells have an increasing trend but with a drastic increase in *well 15/09-010*. Furthermore, 13 out of 14 samples for that well exceed the MCL while none of the samples in *well 17/11-001* is close to the MCL. Nevertheless, the average annual rainfall for the areas containing *wells 15/09-010* and *17/11-001* are 513 and 385 mm, respectively. Hence, many factors ought to be considered when looking into time series.

Qalqilya and Tulkarm are both considered as agricultural districts. *Well 14/17-025* located in Qalqilya district is more vulnerable to nitrate contamination compared to *well 15/19-030* located in Tulkarm district. In *well 14/17-025*, 15 out of the 20 samples exceed the MCL while the nitrate concentration exceeds the MCL in *well 15/19-030* just in year 2004. *Well 14/17-025* is closer to the Israeli borders where very intensive agricultural activities and irrigation by treated wastewater are taking place. The density of wells around *well 14/17-025* is higher than that around *well 15/19-030*. Moreover, the depth of *well 14/17-025* is less than one third of the depth of *well 15/19-030*.

Well 19/13-005 located in Jericho district is a shallow well used in agriculture. There is an increasing trend in nitrate concentrations at a noticeable rate. Hence, the nitrate concentration in that well went up from 40 to 71 mg/l during the period from 1999 to 2000. The area surrounding *well 19/13-005* is utilized for agricultural activities that connote high on-ground nitrogen loadings. However, the average annual rainfall is 153 mm which reflects the arid conditions in the area encompassing this well.

Well 18/18-011A located in Nablus district is a shallow well used in agriculture. There is an increasing trend in nitrate concentrations at a moderate rate. None of the nitrate concentrations in that well exceed the MCL. The surprising issue here is that the area surrounding *well 18/18-011A* witnesses intensive agricultural activities and thus high nitrate concentrations were expected. However, the depth of that well is 68 meters whilst the average annual rainfall is 314 mm. This reflects the arid conditions prevailing the area encompassing that well. Further studies ought to be considered to interpret the abnormal behavior of nitrate concentrations in this specific well.

5.3.14 Nitrate Accumulation in Groundwater

As mentioned earlier, the nitrate concentration in groundwater has an increasing trend over the year 1985 for the entire West Bank. This section just provides a qualitative understanding of the general temporal trend of nitrate concentrations in the West Bank districts. The rate of increment varies among the different districts depending on the interrelated factors, especially the on-ground nitrogen loading and land use. Regional assessment of groundwater quality is complicated by the fact that nitrogen sources are spatially distributed (Tesoriero and Voss, 1997). However, related information to this is not available for the West Bank and the same applies for the land use map. The identification of areas that receive heavy nitrogen loadings from point and nonpoint sources is important for land use planners and environmental regulators. In such areas, management alternatives can be considered to minimize the risk of nitrate leaching to groundwater (Lee et al., 1991; Tesoriero and Voss, 1997).

Accurate quantification of nitrate leaching is difficult. Nitrate leaching from the soil zone is a complex interaction of land use, on-ground nitrogen loading, groundwater recharge, soil nitrogen cycle, soil characteristics, and the depth of soil (Almasri and Kaluarachchi, 2004a).

In order to cope with the problem of quantification, the nitrate accumulated in the groundwater will be evaluated instead for the period between 1981 and 2004. It was found that the number of nitrate concentration samples before 1985 was low. The spatial distribution of nitrate concentration maps across the West Bank for the years 1985 and 2004 were developed using the inverse distance weighting interpolation method supported by the GIS. The spatial distribution raster of nitrate for 1985 was subtracted from that for 2004. The resulting raster represents the difference of nitrate concentrations between these two years as depicted in Figure 46.

In Figure 46, it can be seen that the map of the differences in the nitrate concentrations has elevated values at the boundaries of the northern districts of the West Bank. This indicates high nitrate accumulation due to man-made activities. It is surprising that the highest nitrate differences are in Hebron district denoting the existence of activities and causes that need to be further studied and analyzed.

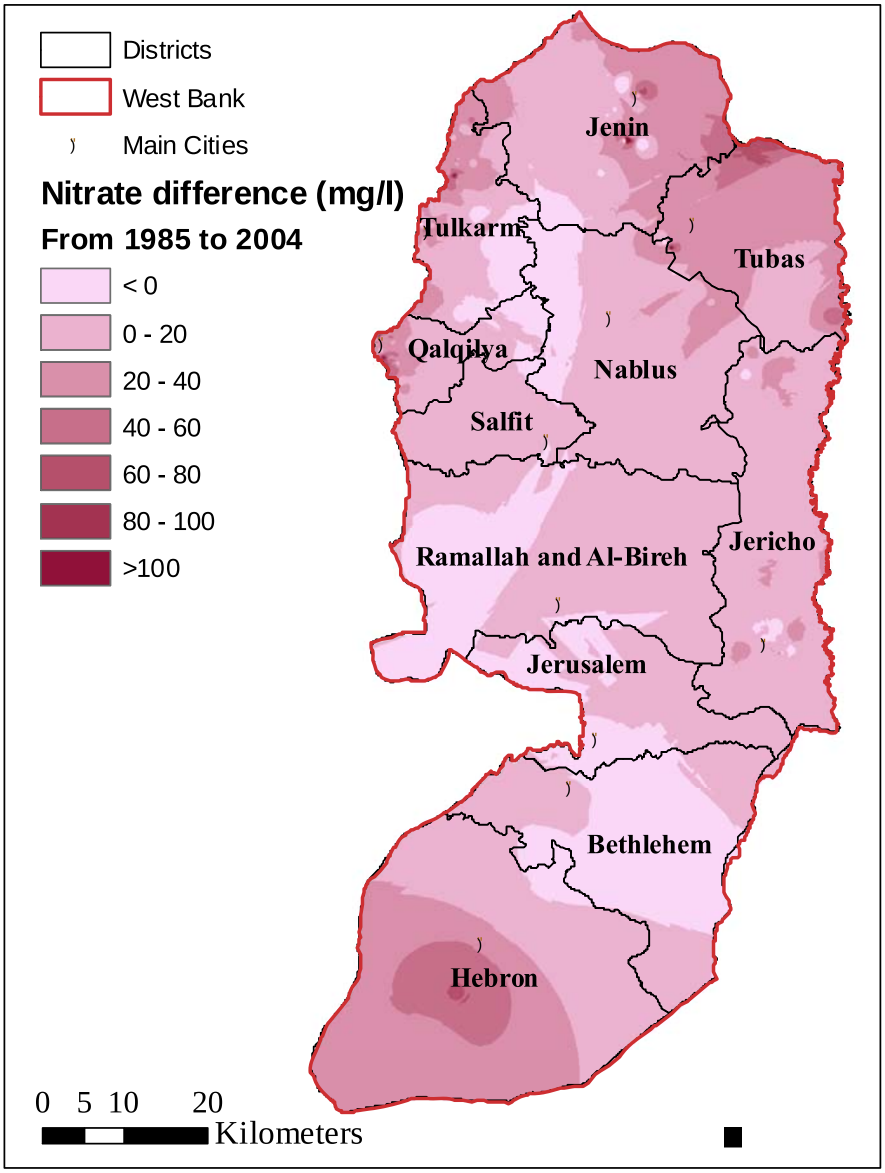


Figure 46: A map of nitrate differences for the entire West Bank for the years 1985 and 2004

5.3.15 Management of Nitrate Contamination

Managing nitrate concentration of groundwater is a challenge. This is because management plans to lessen nitrate pollution should address strategies that account for soil properties, hydrology, hydrogeology, agricultural practices, and crop-tillage systems for a specific site. Many studies show that a high groundwater recharge increases the potential for high nitrate leaching providing that there is an adequate soil nitrogen mass available from on-ground nitrogen loadings (Meisinger and Delgado, 2002; Almasri and Kaluarachchi, 2004a). Areas with high groundwater recharge may not necessarily produce high nitrate leaching as long as the on-ground nitrogen loading is low. In essence, the leaching potential is a function of both groundwater recharge and the availability of soil nitrogen from the on-ground nitrogen loading.

It can be concluded that the on-ground nitrogen loading should be controlled in areas of high groundwater recharge to minimize nitrate available for leaching, thus reducing the risk of groundwater contamination. Nevertheless, it should be kept in mind that nitrate leaching from soil is a function of different factors including but not limited to soil type, soil organic matter content, nitrate residues in the soil, soil physical and chemical properties, method of irrigation, nitrogen dynamics in the soil such as denitrification and mineralization, types and amounts of fertilizers and manures applied, and crop type. In addition, site-specific hydrological parameters are critically important (Almasri and Kaluarachchi, 2004a).

Since almost all the maximum annual nitrate concentrations exceeding the MCL in the groundwater of the three major watersheds, corrective management alternatives are needed to minimize future pollution and to preserve the groundwater quality. The management alternatives should focus on areas of high potential for nitrate leaching and areas of elevated nitrate concentrations.

In order to apply the management options, specific actions should be carried out. The management actions may include fertilizer and manure reduction, increasing the cost of nitrogen-based fertilizers and manures, manure exporting, adoption of feeding strategies, use of surrogate fertilizers, accounting for nitrogen in the irrigation water and soil, control of on-ground nitrogen loadings, irrigation scheduling, the use of deep root crops that are able to retrieve nitrate from deep locations in the soil, adding crops that fully utilize the soil-water resources, waste dumping management, prohibiting direct discharge of raw sewage to wadis and soil, and cesspits maintenance and management (Meisinger and Delgado, 2002; Almasri and Kaluarachchi, 2004a; UNEP, 2003). For an inclusive illustration and discussion of these management actions, the interested reader may refer to Delgado (1999, 2001, 2002), Delgado et al. (1999), Hall et al. (2001), Follett and Delgado (2002), Delgado and Shaffer (2002), Meisinger and Delgado (2002), and Almasri and Kaluarachchi (2004a).

In the West Bank, management options could be introduced at areas characterized by high on-ground nitrogen loadings, increasing trend of nitrate concentrations, elevated recharge values, and shallow water table elevations. Hebron, Jenin, and Tubas districts have large areas of nitrate-contaminated groundwater which need additional studying and frequent monitoring. Wells tapping the Western basin have a significant increasing trend of nitrate concentrations, therefore, more attention should be paid herein.

According to the well use category, there are undefined wells recognized with high nitrate concentrations. On the other hand, wells with Brown-Red Degrading Sandy Soils witness high vulnerability to nitrate contamination and thus require more attention. While wells located within the Mediterranean major watershed also require frequent monitoring and surveillance. Furthermore, additional monitoring wells should be installed within the depth of 100 meters to interpret the abnormal increment of nitrate concentrations there. Such options may also be required for wells within the depths from 175 to 200 meters. in addition to selected wells on long time series of nitrate concentrations indicating possible susceptibility to contamination.

5.4 Conclusions

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

Almost all the annual maximum nitrate concentrations in the entire West Bank are above the MCL. However, the annual maximum exhibits a general slight increasing trend. The analysis confirms that the nitrate concentration in the Western groundwater basin has an increasing trend over the period from 1985 to 2004. Out of the 1,301 samples from the Western basin, a total of 423 samples or 33% exceeded the MCL. For the aquifer systems, the 75th percentile is above the MCL in the Upper Cenomanian aquifer. The 90th percentile concentration of the 47 undefined wells equals 121.6 mg/l which is extremely higher than the MCL. For the soil types, almost all the maximum nitrate concentrations for each soil type are higher than the MCL. There is an increasing trend in the Mediterranean Sea watershed indicating that it is the most vulnerable major watershed to nitrate contamination. It is known that the nitrate concentration in groundwater decreases with depth. During analysis, it was found that high nitrate concentrations are within the upper 100 m of groundwater in the West Bank. After this depth, nitrate concentration decreases with depth.

The time series of selected wells confirmed that the nitrate concentration has an increasing trend after 1985. In essence, the leaching potential is a function of both groundwater recharge and the availability of soil nitrogen from the on-ground nitrogen loading. Therefore, management options and site-specific hydrological parameters will be highly important. Preventive and corrective management options are needed to prevent future contamination and to preserve the groundwater quality. The management options that can be carried out may include fertilizer and manure application reduction, constructing cesspits in an environmentally sound way, accounting for nitrogen in the irrigation water and soil, and control of on-ground nitrogen loadings.

In light of the above results and observations, the following general conclusions can be made:

1. More frequent sampling will provide better understanding of nitrate occurrences and distribution, interpret correctly the elevated nitrate concentrations and the outstanding trends, describe accurately the nitrate contamination sources, and eventually select the best management alternatives;

2. The analysis of nitrate occurrences in the groundwater of the West Bank shows that agricultural application of inorganic fertilizers and organic manure may be a potential source of nitrate contamination of groundwater;

3. The analysis also shows that cesspits could be a major source of nitrate contamination of groundwater;

4. The analysis confirmed that the nitrate concentration has an increasing trend specifically after the year 1985;

5. High nitrate concentrations are within the upper 100 m of groundwater in the West Bank. After this depth, nitrate concentration decreases with depth;

6. Data collection programs should assess the effects of various land use practices and management alternatives on the quality of groundwater. Such an assessment helps in determining the best management practices to minimize groundwater pollution from nitrate;

7. GIS is an effective tool in analyzing the spatial variability of nitrate occurrences in groundwater. In addition, GIS facilitates the analysis of the relationships between different descriptive parameters and nitrate concentrations;

8. Groundwater transport models must be developed to provide information regarding the distribution of nitrate in groundwater due to current and future land use practices and management options;

9. Once a broad range of management alternatives and the corresponding impacts on groundwater quality are identified, the best alternative can be implemented through discussions between regulators and stakeholders;

10. The public participation is extremely important in developing management options. The preliminary level is through public information via advertisements and brochures which is fine but insufficient. The secondary level is through public consultations which encourage the stakeholders to be more active and powerful as a member of the decision making; and

11. There are a lot of limitations that impede this work and any further studies. The accessibility to data is absent as well as the cooperation of the variable institutions especially for research purposes. The available data needs a lot of processing and arrangement to be ready for research and analysis. In addition, there isn’t an equal number of sampling wells during the study period, there is also overlapping readings with missing information. The spatial distribution of the data is uneven. All these limitations should be coped with for more profound studies in the future.

CHAPTER SIX

CHLORIDE CONTAMINATION IN WEST BANK AQUIFERS

6.1 Introduction

Groundwater resources play a dominant role in the development of countries (Zhu et al, 2004). Many rural and urban centers rely greatly on groundwater resources for public water supply. With the population growth and irrigation agriculture development, the water demand has significantly increased and has led to the overexploitation of groundwater (Wen et al, 2005).

As many other countries, groundwater is almost the only reliable water resource in the West Bank. It has extensively been used to meet the increasing water demand for domestic, irrigational, and industrial requirements. In such an environment, the groundwater chemistry is invoked rapidly and the salinity goes up considerably (Nativ and Smith, 1987; Chourasia and Tellam, 1992; Elango and Ramachandran, 1991; Hamilton and Helsel, 1995; Fisher and Mulican, 1997; Kraft et al, 1999; Wen et al, 2005). In many regions, especially in arid and semi-arid areas such as the West Bank, groundwater salinization limits the supply of potable fresh water (UNEP, 2003). Therefore, in order to utilize and protect the valuable water resources effectively and to professionally predict the changes in groundwater category, it is inevitable to comprehend the salinity of the groundwater and its evolution under natural water circulation processes (Wen et al., 2005).

Aquifers are an important source of drinking water in the West Bank and elsewhere, and these sources are vulnerable to contamination (Solley et al, 1990). The aquifer system in the West Bank is highly permeable in many areas due to its geological nature. It should be kept in mind that the aquifers are easily contaminated in some regions depending on land use, soil type, physical, and geological characteristics (Cornu et al, 2001; Abrahams, 2002). The attenuation or removal of nutrients and pollutants in wastewater percolating to the aquifers is low making aquifers vulnerable to contamination. In some areas, groundwater is unsuitable for drinking because of the salinity. This occurs in part as a result of natural factors, but is expected to worsen over the coming years since over-abstraction of fresh water leads to intrusion of salty water from deeper formations (UNEP, 2003).

For instance, leaching of chloride from the soil profile is primarily controlled by the ability of the soil to receive, store and transmit water, and the excess of water added (precipitation and irrigation) over water transpired (Allison, 1965). These requirements are often met in irrigated agriculture, where high value crops dictate application of fertilizer and water in excess of crop needs to produce optimum yields of high quality produce (Rawlins and Raats, 1975).

Groundwater pollution due to point and nonpoint sources is caused mainly by agricultural practices (noticeable is the use of inorganic fertilizers, pesticides, and herbicides), localized industrial activities (organic pollutants and heavy metals), and inadequate or improper disposal of wastewater and solid waste including hazardous materials (UNEP, 2003). In the West Bank, many field studies regarding chloride concentrations in Jericho District aquifers were performed (Abed and Wishahi, 1999; Nuseibeh and Nasser Eddin, 1995). These studies showed that quality of water is significantly influenced by the distance between the well location and the recharge location. The dilution of salt water in the aquifer by the recharge fresh water was considerable mainly in the nearby areas. In contrast, salinity increased in distant areas due to the continuous dissolution of salt deposits in the aquifer. Moreover, the pumping of water from the aquifer which extremely exceeded the recharge amount led to a drastic increase in the salinity of groundwater. On top of that, an important effect of irrigation agriculture was observed. In Jenin District, high salinity groundwater was noticed in the boundary areas. The dissolution of the volcanic rocks increases the salinity of groundwater in Jenin District. In general, it is known that the weathering and leaching of sedimentary rocks and soils and the dissolution of salt deposits release chlorides into water (Prince Edward Island, 2000). Moreover, the overexploitation of groundwater by the Israelis caused saline water to intrude into the aquifer system in Jenin (Abed and Wishahi, 1999).

The objectives of this chapter are to identify and document the regional long-term trends of chloride concentrations in the groundwater of the West Bank; to qualitatively identify the probable sources of elevated chloride concentrations and to analyze the temporal and spatial variability in chloride concentrations. The assessment is carried out using the geographic information system (ArcGIS 9) tools (ESRI, 2004). This assessment is intended to provide generic recommendations related to future groundwater monitoring, field testing, and aid in the development of a conceptual model for fate and transport of chloride. Overall, the analyses furnished herein are intended to improve our understanding to the chloride contamination extent of the groundwater resources in the West Bank.

6.2 Salt Water Intrusion

In salt-affected soils and water, the principal solutes of interest are the anions carbonate (CO_3), bicarbonate (HCO_3), sulphate (SO_4), and chloride (Cl) and the cations calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K). Boron (B), fluorine (F), and nitrate (NO_3) are usually present in much lower but significant concentrations. The summation of individual ions provides another way of estimating total salinity.

Chloride is a major constituent of most water resources. It is normally present in low concentrations in surface water, while groundwater will contain varying amounts of chloride depending on the surrounding geology (Prince Edward Island, 2000). Chloride is widely distributed in the environment, generally as sodium chloride (NaCl), potassium chloride (KCl), and calcium chloride ($CaCl_2$). The weathering and leaching of sedimentary rocks and soils, specifically in the Jordan Valley, and the dissolution of salt deposits release chlorides into water (Nuseibeh and Nasser Eddin, 1995; Wishahi and Awartani, 1999; Prince Edward Island, 2000). Therefore, chlorine is one of the main anions present in the groundwater of the West Bank (Abed and Wishahi, 1999).

Salt water contamination of fresh water aquifers can be a major water quality problem in island locations, in coastal areas, and occasionally inland. Because fresh water is lighter than the salt water, it will usually float above a layer of salt water. When an aquifer is pumped, the original equilibrium is disturbed and salt water replaces the fresh water. It was shown that under equilibrium conditions, a drawdown of 1 ft in the fresh water table will result in a rise by the salt water of approximately 40 ft. Pumping rates of wells subject to salt water intrusion must therefore be strictly controlled (Viessman and Hammer, 2005; Wikipedia, 2006).

This intrusion may also occur as the result of a natural process like a storm surge from a hurricane. More often, however, saltwater intrusion results from human activities such as construction of navigation channels or oil field canals (LaCoast, 1996). In coastal areas, recharge wells are sometimes used in an attempt to maintain a sufficient head to prevent sea water intrusion. Injection wells have been used effectively in this manner in many locations all over the world (Viessman and Hammer, 2005; USGS, 2005).

Deep recharge wells create groundwater ridge and maintain the proper balance between water being pumped from the aquifer and the amount of water recharging it. Therefore, recharge wells have proven to be very useful in maintaining the proper equilibrium between groundwater recharge and pumping. Proper groundwater monitoring techniques, groundwater management, combined with groundwater conservation are needed to keep salt water intrusion under control (Solinst, (2006).

In the West Bank, groundwater in the Jordan Valley is unsuitable for drinking because of its high salinity. This occurs partly as a result of natural factors such as geology and geography of the region, yet is expected to worsen over the coming years since over-abstraction of freshwater leads to intrusion of salty water from deeper levels (Wishahi and Awartani, 1999; UNEP, 2003). Wastewater discharges, leachate from waste deposits and industrial effluent may also contribute significantly to the elevated chloride concentrations (UNEP, 2003).

Based on detailed studies and Figure 19, the main groundwater drainage basin of the Jordan Valley region is the Eastern basin. The groundwater flows generally south-east towards the Jordan Rift Valley (EXACT, 1998). Therefore, wells located within the West Bank are upstream the Dead Sea. In addition, the water level of the Dead Sea has been dropping dramatically since 1970, at a rate of 80 cm to 1 m per year, attributed to upstream water diversion and the mineral extraction industry on its shores (IMoE, 2002). This indicates that salt water intrusion from the Dead Sea is normally impossible unless excessive pumping occurs from these wells that causes drastic changes to the dynamic of the groundwater in the region.

There is relatively little information concerning the impacts of the Dead Sea on the salinity of the groundwater in the Jordan Valley. Further studies and models are required to demonstrate the dynamics of groundwater in the Jordan Valley region and to explore the impact of excessive pumping on the expected groundwater flow direction. However, a detailed study showed that the salinity of this water is high, due to the presence of saline springs and to returns of irrigation water (UNEP, 2003). Another study showed that the salinity of groundwater which dramatically exceeded 4000 mg/l was due to the Jordan river water (Wishahi and Awartani, 1999).

6.3 Chloride in Drinking Water

6.3.1 General Background

Chloride in drinking water is generally not harmful to the human beings until high concentrations are reached. Nevertheless, it may be harmful to people suffering from heart or kidney diseases. Restrictions on chloride concentrations in drinking water are generally based on palatability requirements rather than health (Prince Edward Island, 2000).

Chloride concentration is one of the secondary drinking water standards. Secondary standards are non-enforceable guidelines regarding contaminants that may cause cosmetic effects or aesthetic effects to drinking water. However, the international guidelines for drinking water quality have set the aesthetic objective for chloride concentration in drinking water at 250 mg/l (US EPA, 2006; PSI, 2005; Prince Edward Island, 2000).

In agricultural regions, heavy fertilizer application results in unused chloride migrating down into the groundwater. As a result, groundwater withdrawn by private and public wells is likely to have measurable concentrations of chloride that may exceed the MCL of 250 mg/l (Saffigna and Keeney, 1977).

6.3.2 Properties

Chloride is widely distributed in nature as salts of sodium (NaCl), potassium (KCl), and calcium (CaCl2) (WHO, 2003; Health Canada, 2004; Prince Edward

Island, 2000). The taste threshold of the chloride anion in water is dependent on the associated cation. Taste thresholds for sodium chloride and calcium chloride in water are in the range 200–300 mg/l (Zoeteman, 1980; Weast, 1986).

6.3.3 Occurrence

The presence of chloride in drinking water sources can be attributed to the dissolution of salt deposits, salting of highways to control ice and snow, effluents from chemical industries, oil well operations, wastewater, irrigation drainage, refuse leachates, volcanic emanations, sea spray, and seawater intrusion (National Academy of Sciences, 1974; Murray and Ennst, 1976; Ralston, 1971; Little, 1971; Pettyjohn, 1971; Pettyjohn, 1972; Bond and Straub, 1973; Schneider, 1970; National Research Council of Canada, 1977). Chloride is also leached from various rocks into water by weathering (WHO, 2003; Prince Edward Island, 2000).

The chloride ion is highly mobile and is transported to close basins or oceans (National Research Council of Canada, 1977). Therefore, each of these sources may result in hydraulic interaction of surface water and groundwater. However, higher concentrations of chloride are most often present in drinking water derived from groundwater sources. This could be due to naturally high concentrations or to contamination (Health Canada, 2004; UNEP, 2003).

6.3.4 Health Impacts

Chloride is an essential element and is the main extracellular anion in the body. It is a highly mobile ion that easily crosses cell membranes and is involved in maintaining proper osmotic pressure, water balance and acid-base balance (Health Canada, 2004).

The toxicity of chloride salts depends on the cation presence. Although excessive intake of drinking water containing sodium chloride at concentrations above 2.5 g/l has been shown to produce hypertension (Fadeeva, 1971). This effect is believed to be related to the sodium ion concentration (WHO, 2003; Department of National Health and Welfare, 1978). Chloride toxicity has not been observed in humans except in the special case of impaired sodium chloride metabolism, e.g. in congestive heart failure (Wesson, 1969).

Until recently, it had been assumed that the physiological role of the chloride ion was simply that of a passive counterion. Over the past few years, however, several studies have suggested that the chloride ion may play a more active and independent role in renal function (Jaina et al, 1980; Toto, 1984), neurophysiology (Sackmann, 1984), and nutrition (Honeyfield, 1985).

6.3.5 Other Considerations

Chloride increases the electrical conductivity of water and thus increases its corrosivity. In metal pipes, chloride reacts with metal ions to form soluble salts (WHO, 1978). As a result, this will lead to an increase in the levels of metals in drinking-water. In lead pipes, a protective oxide layer is built up yet chloride enhances galvanic corrosion (Gregory, 1990). It can also increase the rate of pitting corrosion of metal pipes (WHO, 1978; Prince Edward Island, 2000).

6.3.6 Treatment

Treatment techniques for the removal of chloride from the drinking water include demineralization processes such as reverse osmosis, electrodialysis, ion exchange, distillation, or separation by freezing. Another method of removing chloride from the drinking water would be the construction or reconstruction of water well. This frequently involves the installation of additional casing beyond the length (depth) normally required by regulation (Prince Edward Island, 2000; APEC, 2000).

6.4 Methods and Data Analysis

6.4.1 Data Collection

The chloride concentration data used in this study were obtained entirely from PWA. The corresponding well data were aggregated using the database of the Water and Environmental Studies Institute at An-Najah National University. All available data were assembled into a single composite database to facilitate the analysis. The total number of wells in the West Bank is 623 while the total number of wells in the database is 479 with 6,875 measurements of chloride concentrations covering the period from 1968 to 2004.

That great deal of data is available in a format that is accessible via GIS technology. The use of the GIS capabilities and techniques provides the ease of data processing, visualization, assessment, analysis, and map preparation. Many problems were encountered in the original database. First, some of the parameters were never been precisely determined such as the district and the basin. A GIS polygon shapefile for the districts of the West Bank was spatially joined to the original database, and thus a GIS polygon shapefile for the basins of the West Bank was obtained. Second, a lot of important parameters are missing from the database. A GIS polygon shapefile for the major watersheds of the West Bank was spatially joined with the database, and a GIS polygon shapefile for the minor watersheds of the West Bank was obtained. In the same way, the irrigation category of each well was determined. A GIS point shapefile of well spatial locations and the corresponding data was developed and used in the analysis as shown in Figure 47.

At the end in its final form, the database includes well ID, well coordinates, concentration, measurement year, locality, district, aquifer, basin, well use, soil type, minor watershed, major watershed, average long-term pumping rate, sampling depth, and irrigation category.

It was noticed that the variability in the number of readings of chloride concentration sampled from each well for the period from 1968 to 2004 was too high. Further analysis showed that the frequencies of readings of chloride concentrations for each well vary between 1 to 35 as depicted in Figure 48 with an average value that exceeds 13 readings.

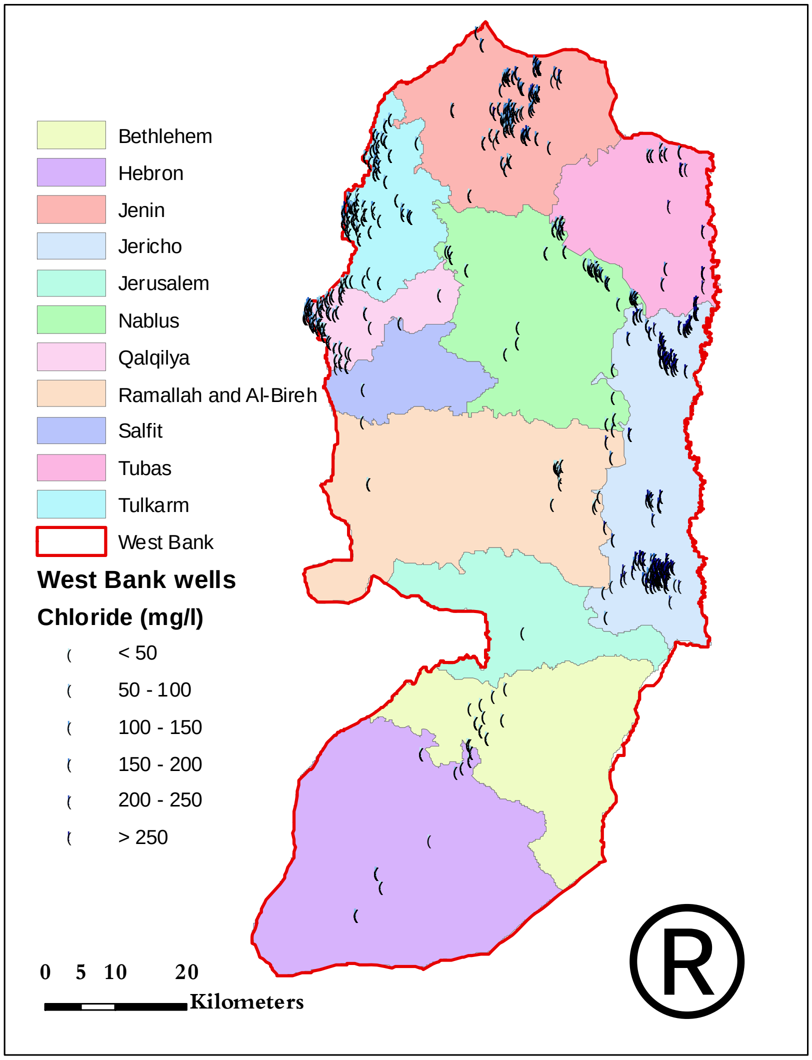


Figure 47: The spatial distribution of chloride sampling wells across the West Bank for the period from 1968 to 2004

Figure 48: Frequency distribution of chloride concentration readings for the period from 1968 to 2004 and the corresponding number of wells

The following analyses furnished in the following subsections do pertain to the chloride occurrences in the groundwater of the West Bank at different levels and for different explanatory parameters.

6.4.2 The Temporal Distribution of Chloride Concentration Across the West Bank

Since the objective of the analysis is to study the overall temporal trends in chloride concentration in the groundwater of the West Bank, no attempt was made to remove wells of short time series that do not represent the complete period from 1968 to 2004. Figure 49 illustrates the frequency of annual chloride concentration readings distributed over the period from 1968 to 2004. This Figure was drawn using the capability of "summarizing tables" as provided by GIS. The average number of annual readings is approximately 186, which means that about 39% out of the 479 wells were annually sampled for chloride.

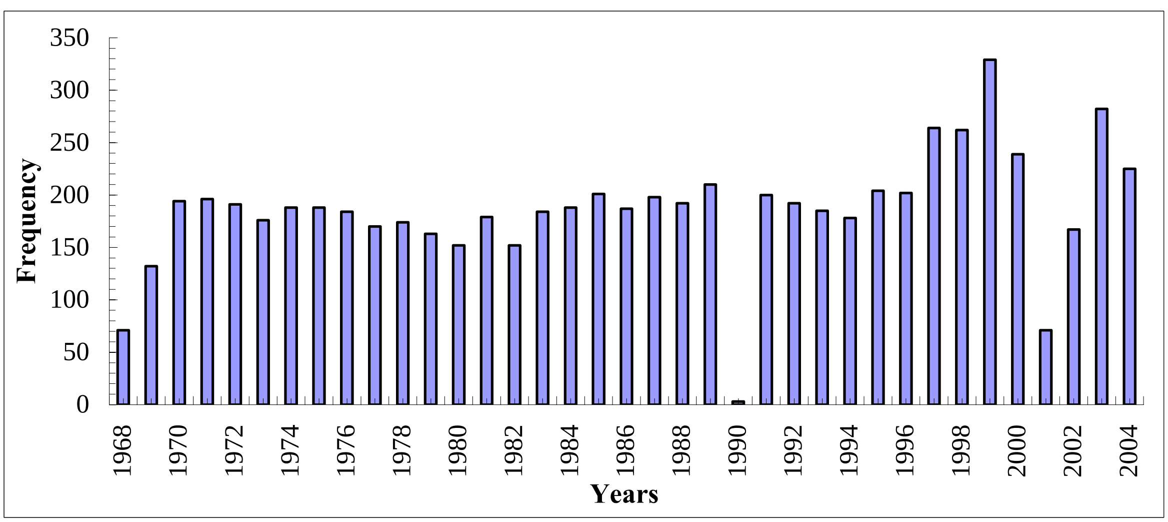


Figure 49: Frequency of annual chloride concentration readings for the period from 1968 to 2004 for the entire West Bank

It is obvious from Figure 49 that the maximum number of samples is 329 in 1999, while the minimum number of samples is 3 in 1990. This variation in the number of observations could reflect the political situation or technical problems. Nevertheless, the frequency of chloride concentration readings should be increased to include all sampling wells.

Annual chloride concentration statistics from 1968 to 2004 are shown in Figure 50. The distribution of chloride concentrations in 1990 were as excepted and as shown in Figure 50. This expectation is due to the low number of readings in that year.

The results show that the median is always below the MCL, indicating that at least 50% of the chloride concentrations are below 250 mg/l from 1968 to 2004. It is also noticeable that the average is always higher than the median and much closer to the MCL. As can be concluded from Figure 50, the 75% percentile (3^{rd} quartile) is generally close to the MCL. The MCL was exceeded in 14 years.

The annual maximum chloride concentration exhibits an overall increasing trend before the year 1991. In contrast, the maximum concentration exhibits a decreasing trend after that time period. These trends have a peak at 1991. The same trends are noticed for the average and the 3^{rd} quartile concentrations. The annual maximum concentrations are always above the MCL. A value of 4,660 mg/l is observed in 1991 in Jericho district. The average concentrations exceed the MCL in the period from 1978 to 1997 except for the year 1982. While the 3^{rd} quartile concentrations exceed the MCL in the period from 1981 to 1996 except for the year 1982. The median concentrations are almost constant throughout the period from 1968 to 2004 as well as the 1^{st} quartile concentrations.

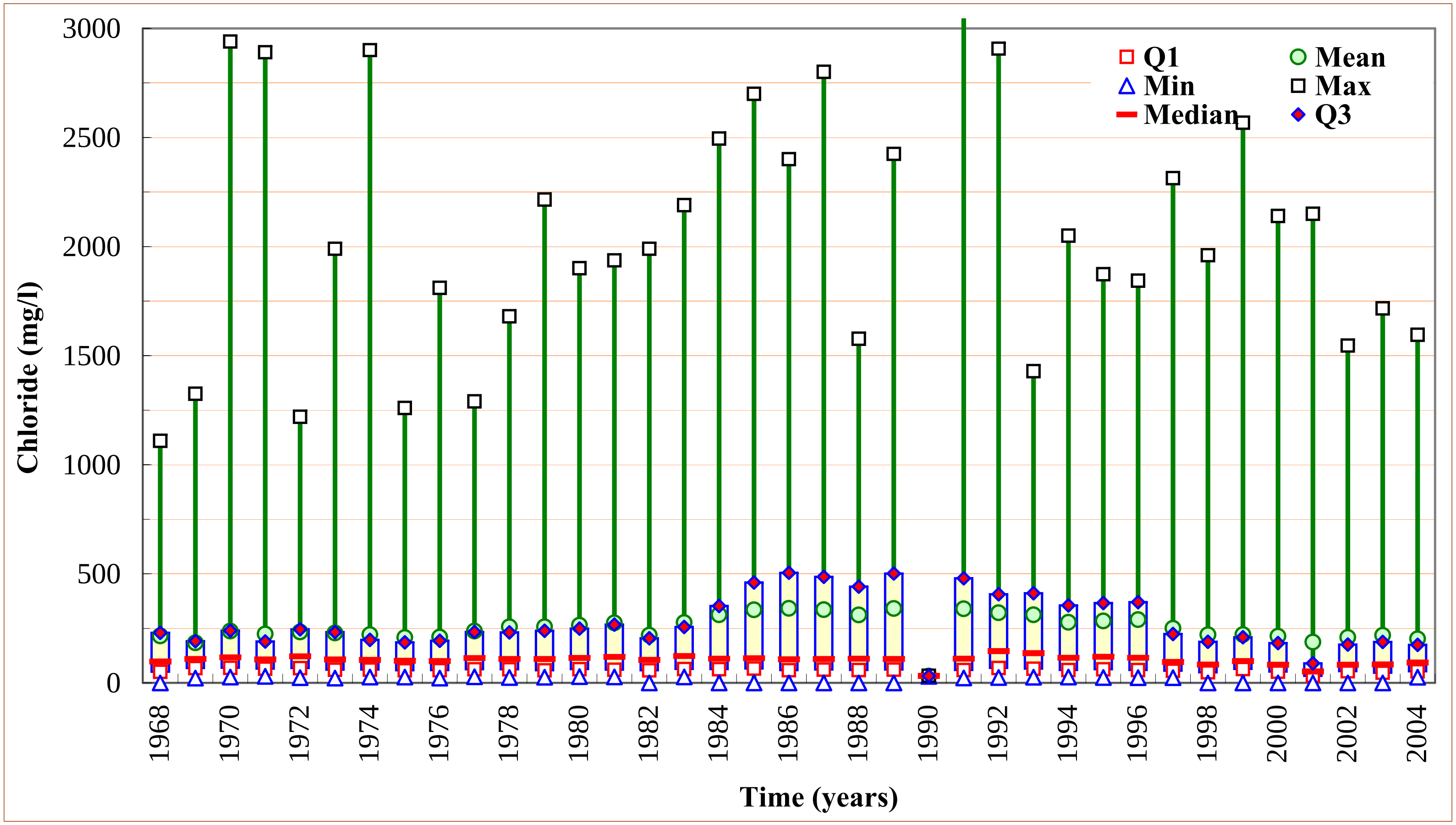


Figure 50: Annual chloride concentration statistics for the entire West Bank for the period from 1968 to 2004. For a better visualization of the boxplots, the concentration was limited to 3,000 mg/l. However, a value of 4,660 mg/l was observed in groundwater for the year 1991 in Jericho district.

6.4.3 The Spatial Distribution of Chloride Concentration Across the West Bank

The map of the spatial distribution of chloride concentrations across the West Bank for the year 2004 was developed using the inverse distance weighting (IDW) interpolation method as supported by GIS. This map is shown in Figure 51. In 2004, a total of 225 samples were taken from the wells across the West Bank and were used in the development of the map.

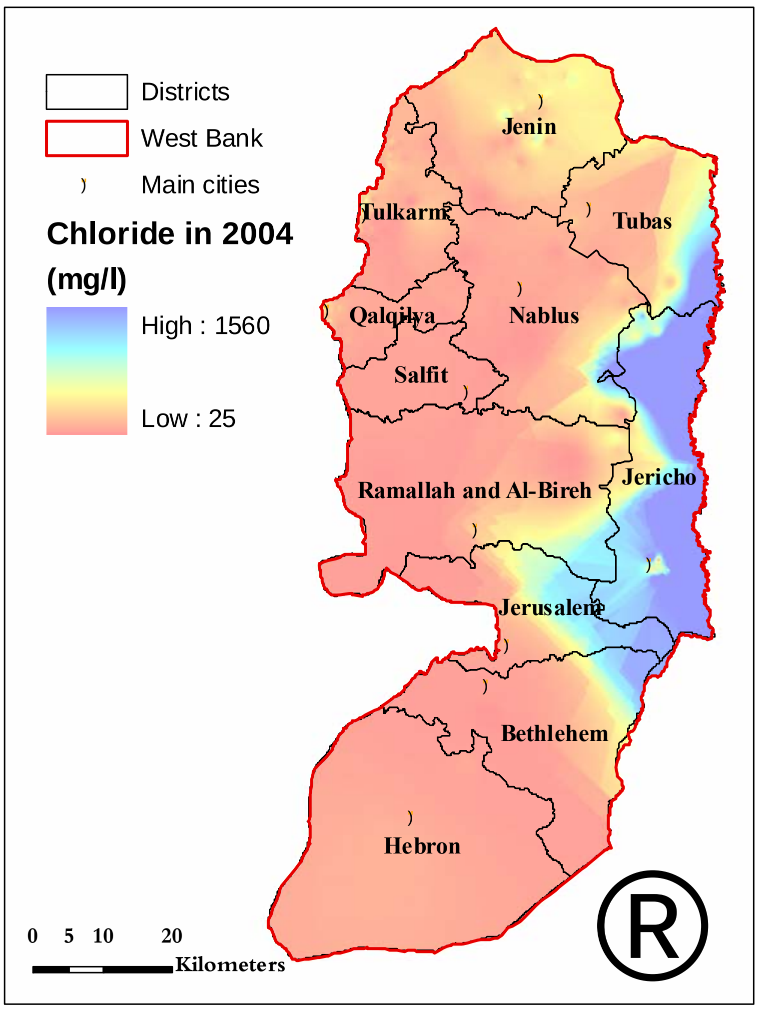


Figure 51: The distribution of chloride concentration across the West Bank for the year 2004 as interpolated using the IDW method

In this chapter, an independent classification scheme was used in order to identify the possible anthropogenic effects on the groundwater quality. To assess these effects, chloride concentrations were classified into four groups. The four concentration ranges were approximated as shown in the legend of Figure 51 and these are: less than 25 mg/l to indicate the most likely background concentration; 25-75 mg/l to indicate a possible human influence; 75-250 mg/l to indicate pollution due to human influence; and greater than 250 mg/l to indicate that the MCL was exceeded as a result of human excessive activities.

It can be deduced from this Figure that the highest chloride concentrations are entirely encountered in the eastern side of the West Bank specifically in Jordan Valley where intensive evapotranspiration occurs. Evapotranspiration causes chemical components to concentrate in the groundwater and results in the occurrence of salt crust in the basin (Wishahi and Awartani, 1999; Wen et al, 2005).

However, the highest chloride concentrations are partially encountered in Tubas, Jerusalem, Ramallah and Al-Bireh, and Bethlehem districts. Those chloride concentrations exceed the MCL of 250 mg/l exhibiting excessive human activities based on the classification mentioned above. Moreover, high chloride concentrations of water in many wells in Jordan Valley impeded the utilization of these wells for domestic and agricultural uses (Wishahi and Awartani, 1999).

These observations can be attributed to the agricultural activities that are associated with the elevated on-ground chloride loadings due to the use of chloride-based fertilizers (Saffigna and Keeney, 1977). In addition, weathering and leaching of sedimentary rocks and soils and the dissolution of salt deposits release chlorides in those areas (Abed and Wishahi, 1999; Nuseibeh and Nasser Eddin, 1995). The low annual rainfall along with the high evapotranspiration and elevated atmospheric temperatures in Jordan Valley, all concurrently contribute to the higher chloride concentrations in the groundwater (Wishahi and Awartani, 1999).

It can be noticed that the majority of the areas in Jenin and Tubas districts have chloride concentrations in the range of 75-250 mg/l. Considerable areas in Tulkarm district have chloride concentrations in that range. However, chloride concentrations approach that range in the areas encompassing Qalqilya city only. The situation in Hebron district for chloride concentrations is not alerting. Yet, there was only five chloride samples in Hebron district ranged from 39 to 79 mg/l while no samples were taken from Salfit district in the year 2004 (see Figure 52).

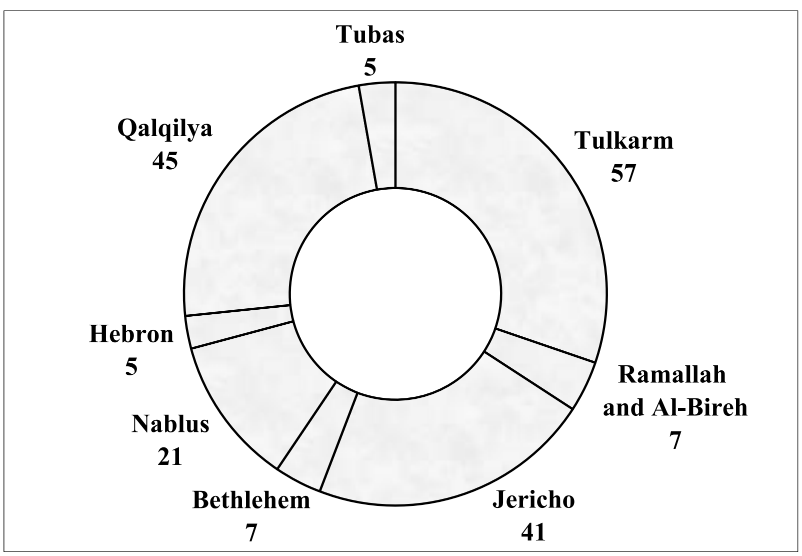


Figure 52: Number of chloride samples taken in the year 2004 based on the district

In 2004, only seven samples were taken in Bethlehem district as well as in Ramallah and Al-Bireh district. This low number of samples does not represent the actual situation of chloride occurrences in these districts (see Figure 52). Further analysis is certainly required to assess the actual situation of chloride concentration in all the districts and determine the hot areas. Further studies ought to be carried out using advanced techniques and models to identify sources of contamination, impacts and consequences, and eventually efficient treatment schemes.

Based on the above discussion and Figure 51 as well, the overall spatial variability in chloride concentrations in the year 2004 could be demonstrated in two steps. Firstly from the east to west, the highest chloride concentrations were witnessed in the eastern portion of the West Bank with a subsequent drastic drop within the western boundary of the Jordan Valley. The chloride concentrations remained constant for a large extent. Secondly from north to south, higher chloride concentrations were encountered in the northern portion of the West Bank with subsequent gentle drop near the southern boundary of Jenin district. Then, the chloride concentrations remained constant for a large extent. However, the Jordan Valley was excepted since chloride concentrations increased from north to south therein. As a result, there are general increasing trends in chloride concentrations across the West Bank from east to west and from south to north.

6.4.4 The Combined Temporal and Spatial Distributions of Chloride

It should be kept in mind that the spatial distribution of chloride concentration in the West Bank depicted earlier was only for the year 2004. Whilst, the temporal distribution of chloride concentration was for the entire West Bank. For a better assessment of the chloride occurrences in the West Bank, both distributions ought to be highlighted concurrently.

The Spatial Distribution of Chloride Concentration for Different Years

This is carried out by drawing the spatial distribution of the chloride concentration across the West Bank for different years in the period from 1968 to 2004. Different maps of the spatial distribution of chloride concentration across the West Bank for the years 1969, 1974, 1979, 1984, 1989, 1994, 1999, and 2004 were developed. For a better visualization and ease of comparison, these maps were grouped together in Figure 53.

From Figure 53, the worst situation of chloride distribution across the West Bank is reported in 1969. This is because 23 out of the 132 samples taken in that year exceeded the MCL. The lowest number of samples is encountered in the year 1969 among the selected eight years. The maximum concentration for the year 1969 is 1,325 mg/l. In 1979, it seems that south of the West Bank has higher chloride concentrations but this is not the case. None of the samples in 1979 was taken in the south. Almost, 40 out of the 160 samples in 1979 exceeded the MCL. Shortage of data in some areas significantly affects the accuracy of the interpolated map. Considering Jenin district, there is a noticeable increasing trend of chloride concentration along the district especially in the last 10 years.

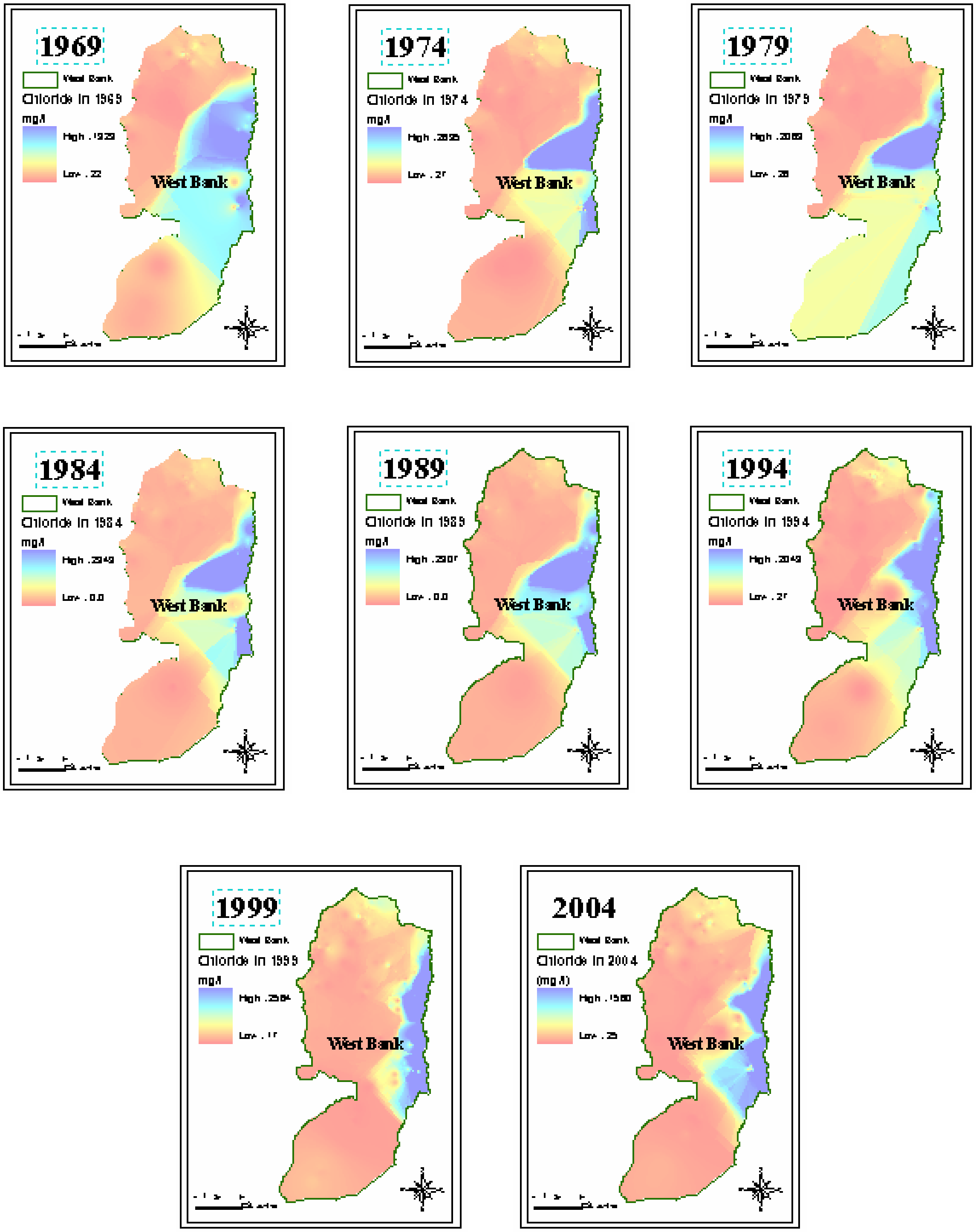


Figure 53: Different maps of the spatial distribution of chloride concentration across the West Bank for the years 1969, 1974, 1979, 1984, 1989, 1994, 1999, and 2004 as interpolated using the IDW method of GIS.

Whilst when focusing to north of the Jordan Valley, the peak of chloride diminishes with time till 1999 where the highest number of samples were taken from 1968 to 2004. In 2004, a small increment in the peak is observed with 225 samples which is a low number of samples compared to those taken in 1999. On the other side, the chloride concentration increases with time in south of the Jordan Valley. Another peak is building up with time mainly in the surrounding area of Jericho city where excessive agricultural activities exist, in addition to its geology and geography. This lower peak was encountered in 1999 because one sample was taken in Jerusalem district with a very low chloride concentration (24.5 mg/l).

Based on the above discussion and Figure 53, the eastern portion of the West Bank has the highest chloride concentrations and specifically within the boundary of Jordan Valley. There is no evidence of susceptibility to contamination in Jerusalem district.

Time Series of Chloride Concentration for Selected Wells

Figure 54 shows the time series of chloride concentration for different wells with high sampling frequency. The spatial locations of these wells are also demonstrated in Figure 54.

As can be noticed, the selected wells are well distributed across the West Bank. The figures of the time series provide a qualitative understanding of the general temporal trends of chloride concentrations in the groundwater of the West Bank.

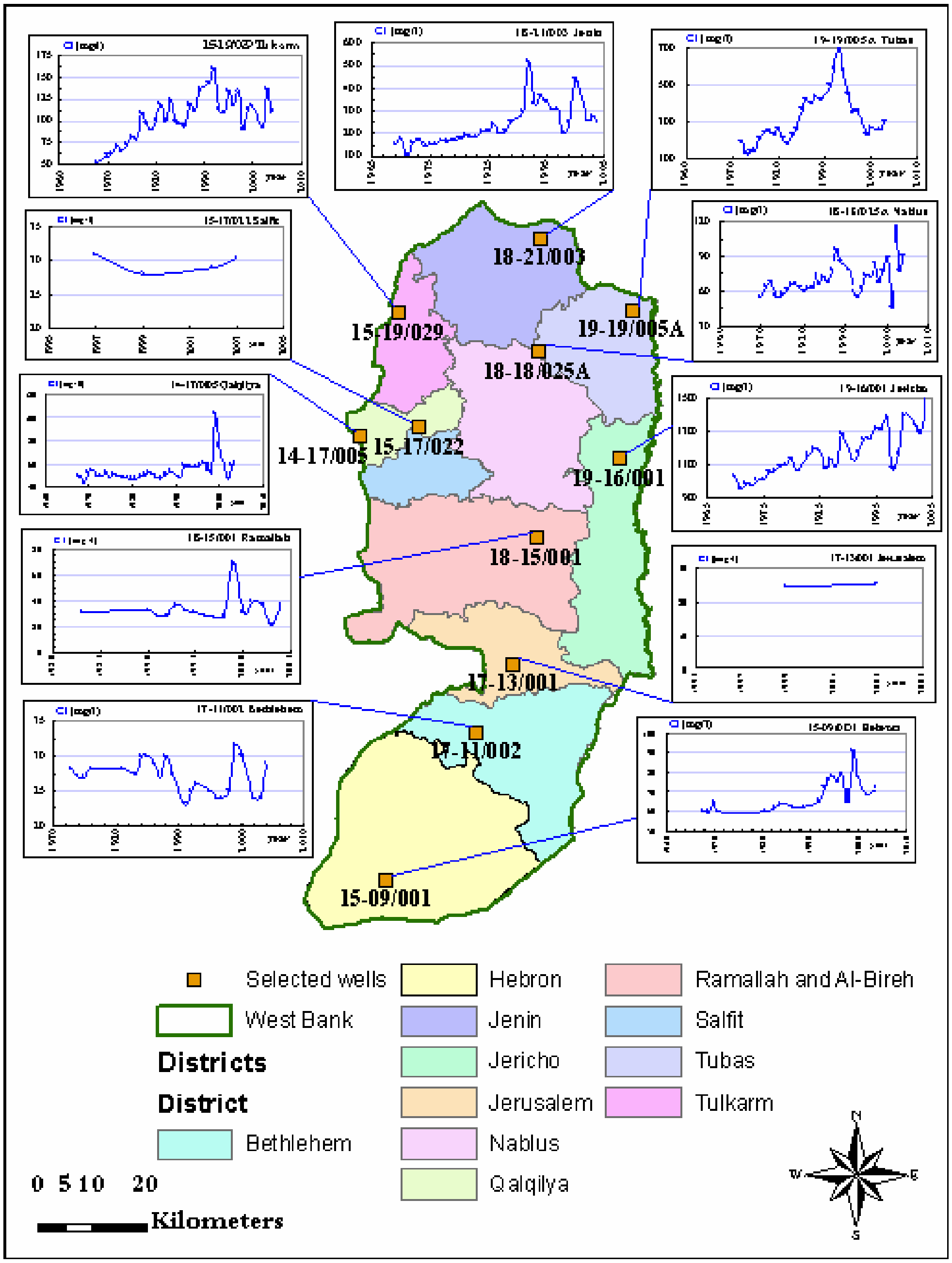


Figure 54: Time series of chloride concentration for selected wells in the West Bank for the period from 1968 to 2004

Let us consider the agricultural *well 19-16/001* that is located in Jericho district and taps the Alluvium aquifer of the Eastern basin. In this well, all the 32 samples that were taken did extremely exceed the MCL throughout the period from 1970 to 2004. A significant increasing trend in chloride concentrations over time is observed. This situation is highly alarming and indicates a considerable pollution of the water being withdrawn from that well.

Consider the agricultural well 19-19/005A located in Tubas district that taps the Neogene aquifer of the Eastern basin. In this well, a total of 17 samples out of 29 exceeded the MCL throughout the period from 1972 to 2003. Although there is an increasing trend in chloride concentrations for the period before 1993 with a subsequent decline, yet it is still higher than the MCL from 1984 to 2003 except in 1999. This indicates that the eastern side of the West Bank witnesses high elevated chloride concentrations and a remarkable presence of it as well.

Well 18-21/003 located in Jenin district and taps the Eocene aquifer of the North-eastern basin is used for domestic and agricultural purposes. In this well, a total of 11 samples out of 34 exceeded the MCL throughout the period from 1969 to 2004. It is noticeable that the remaining chloride concentrations are close to the MCL.

None of the samples taken from Well 15-19/029 that is located in Tulkarm district and taps the Upper Cenomanian aquifer of the Western basin exceeded the MCL. Nevertheless, there is an increasing trend of chloride concentration for that well. There is a gentle increasing trend in chloride concentration in well 15-09/001 located in Hebron district. However, there is no risk because chloride concentrations are far below the MCL.

For Jerusalem and Salfit districts, few wells within these districts have significant data, therefore, they were not considered in this analysis. The chloride concentration in the remaining districts is almost constant without drifting.

To better comprehend and assess the distribution of chloride concentrations in the groundwater of the West Bank, the on-ground chloride loadings ought to be computed. This will enable the correlation (spatially) between the on-ground chloride loadings and the corresponding chloride concentrations in groundwater. In order to compute the chloride loadings, the land use map for the West Bank should be available in a processable format which is not the case herein. The land use map enables the spatial allocation of the chloride loadings according to the land use class and corresponding practices.

The chloride sources in the study area may include (but not limited to) the inorganic fertilizers mainly potassium (potassium chloride) fertilizers, excessive pumping from deep depths, salt water intrusion, and irrigation with chloride-contaminated groundwater. It is important to keep in mind that the sources might be at a remote distance from the detection wells due to the possible fate and transport processes that may act on the chloride once in the groundwater. This is true when considering that chlorine is conservative and does not undergo and decay reactions once in the groundwater.

6.4.5 Chloride Distribution and Irrigation Category

The study of Saffigna and Keeney (1977) in Central Wisconsin indicated that the chloride concentrations in the groundwater were significantly above background concentration due to the irrigated agriculture in their study area. Chloride concentrations varied widely between adjacent wells, thus suggested similar relative inputs of chloride presumably from potassium (potassium chloride) fertilizers. Therefore, differences in concentration of chloride between wells closely reflected the irrigation and fertilizer practices on the surrounding fields (Saffigna and Keeney, 1977).

With irrigated lands that do not have under-drains, excess water and solutes either leave as tailwater or become part of the local groundwater. It appears that irrigation water reaching the groundwater will be defined as nonpoint discharge (Moore, 1975).

The total area of the *irrigated* and *irrigable* lands in the West Bank is approximately 1,025 km2 (18%). Even though annual precipitation in this region is in excess of evapotranspiration, significant water deficits occur in the summer months and economic crop yields are seldom possible without irrigation.

The GIS polygon shapefile of the *irrigated* and *irrigable* areas of the West Bank was spatially joined with well locations. There were three types of land based on the irrigation category; *irrigated* areas, *irrigable* areas, and areas which are *neither irrigated nor irrigable*. A GIS point shapefile of well spatial locations and the corresponding data was developed and used in the analysis shown in Figure 55.

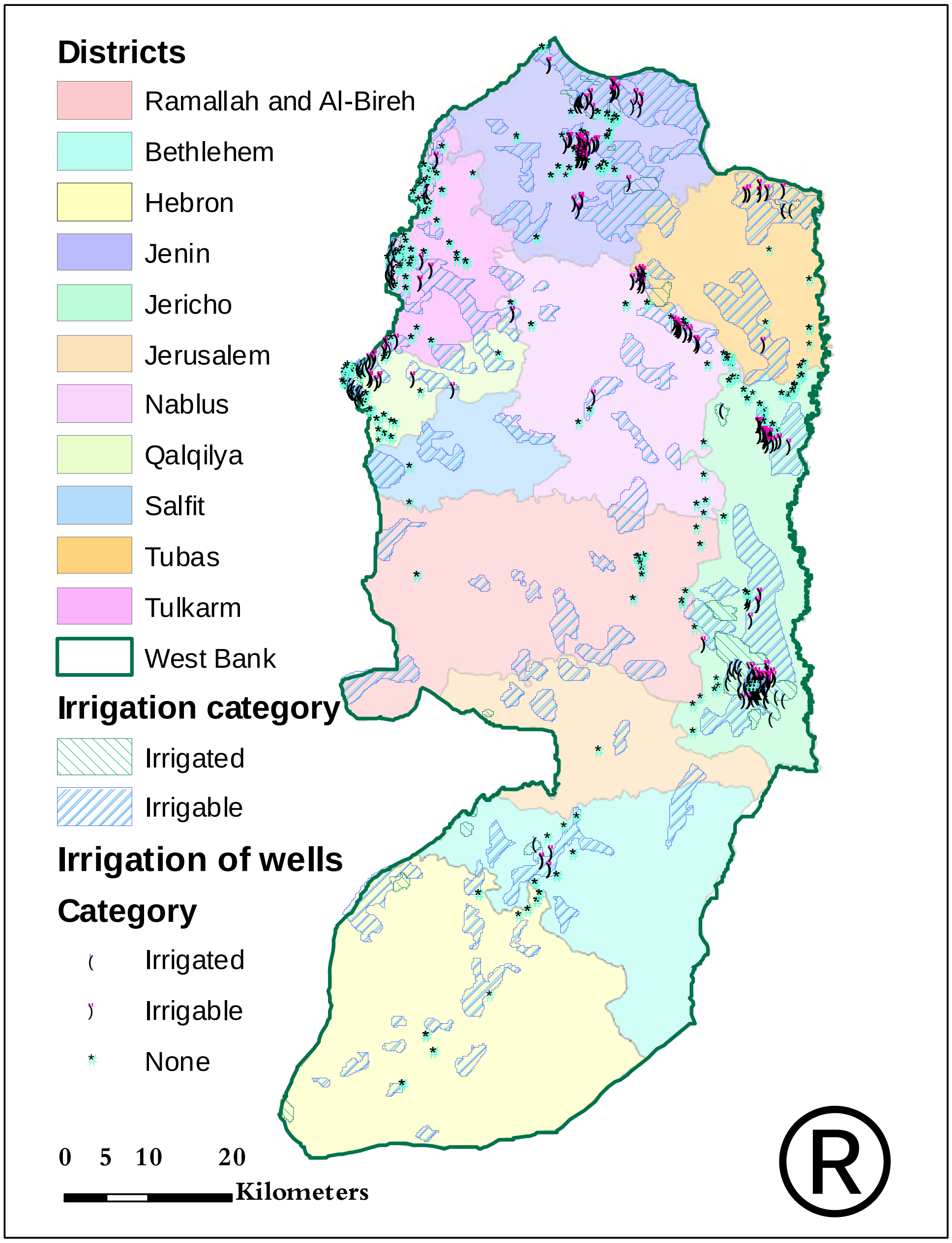


Figure 55: The spatial distribution of chloride wells based on the irrigation areas across the West Bank

The statistics of chloride concentrations based on the irrigation category across the West Bank for the period from 1968 to 2004 are summarized in Table 13. From Table 13, it is noticed that the number of samples taken in areas *with no irrigation* approximately equals the number of samples taken in both *irrigated* and *irrigable* areas. Nevertheless, the chloride concentrations of areas *with no irrigation* are the most consistent since it has the minimum standard deviation. This signifies how the dispersion in chloride concentrations is influenced by irrigation.

Table 13: Statistics of chloride concentrations based on irrigation category in the West Bank for the period from 1968 to 2004

Parameter	**Chloride**		
	No irrigation	**Irrigable**	**Irrigated**
Count	3,095	2,688	1,092
Average	198	320	279
Minimum	0	0	0
10^{th} Percentile	34	50	50
25^{th} Percentile	50	67	88
Median	80	124	143
75^{th} Percentile	171	390	368
90^{th} Percentile	636	974	595
Maximum	2,075	4,660	2,940
Range	2,075	4,660	2,940
Mode	34	55	110
Standard Deviation	290	411	359
Variance	84,629	169,164	129,253
Skewness	2.7	2.2	3.6
Kurtosis	7.9	7.4	17.5

The maximum chloride concentration was reported in an *irrigable* area which is much higher than the maximum concentrations in the remaining areas. This is the reason why the average chloride concentration of *irrigable* areas is the highest. The median chloride concentration in *irrigated* areas is higher than that in *irrigable* areas and both are much higher than that of areas with *no irrigation*.

This is a reasonable result since *irrigated* areas certainly encounter higher irrigation practices. The 3rd quartiles of both *irrigated* and *irrigable* areas are significantly higher than the MCL of 250 mg/l. Surprisingly, the 90th percentile of areas *with no irrigation* is higher than that of *irrigated* areas. This can be attributed to other sources of chloride and possible movement of chloride with flowing groundwater from nearby areas. For instance, consider Qalqilya and Jericho where the wells are very close to each other. Thus, this kind of spatial correlation may not be informative yet it is good for preliminary analysis.

As a result, the irrigation and fertilization practices need more surveillance, documentation, and regulation. However, many farmers fertilize and irrigate in excess of the recommended limits. These practices do not appear generally feasible unless economic and technologic breakthroughs in fertilizer and irrigation management occur (Saffigna and Keeney, 1977).

6.4.6 Chloride Distribution and Potentiometric Head

In the last section, it is found that differences in concentration of chloride between wells closely reflected the irrigation and fertilizer practices on the surrounding fields. The irrigation category becomes a significant factor influences the occurrence of contaminants. However, rainfall is the natural potential to transport the contaminant downward to the groundwater. Therefore, the relationship between the chloride concentration and the rainfall will be demonstrated in this section.

Groundwater recharge is the main vehicle to transport pollutants downward. Groundwater recharge is a function of many factors including soil type, antecedent soil water content, precipitation, and land cover. Therefore, multiple mathematical equations are used to estimate the groundwater recharge from the rainfall. Rainfall characteristics are becoming an increasingly important component that needs to be taken into consideration in managing scarce water resources that are under pressure from rapidly growing demands due to population increase as well as economic development (Herath and Ratnayake, 2004). While the temperature has shown an increasing trend globally, the behavior of rainfall vary depending on the location.

The timing and quantity of recharge reaching the water table has significant consequences for water resources and for the movement of pollutants into groundwater (Lee et al, 2006). Quantification of the rate of groundwater recharge is a basic prerequisite for efficient groundwater resource management (Sophocleous, 1991). This constitutes a major issue in regions with large demands for groundwater supplies, such as in arid and semi-arid areas, where such resources are the key to agricultural development (Marechal et al, 2006). However, the rate of aquifer recharge is one of the most difficult components to measure when evaluating groundwater resources (Sophocleous, 1991). Its determination in arid and semi-arid areas is neither straightforward nor easy (Marechal et al, 2006). This is a consequence of the time variability of precipitation in arid and semi-arid climates, and spatial variability in soil characteristics, topography, vegetation, and land use (Lerner et al, 1990). The more arid the climate, the smaller and potentially more variable is the recharge flux (Allison et al, 1994).

In the West Bank, the climate is gradually changing from semi-arid regions in the western portion to arid regions in the eastern portion. This implies difficulties to estimate the recharge. Therefore, it is much easier and practical to use water table elevation for this study. Furthermore, observations of potentiometric head of the groundwater in many wells were gathered and processed. In the same way, the time series of chloride concentration were previously plotted. The correlation between those two parameters will be elucidated.

The potentiometric heads for the wells in the West Bank were measured in the period from 1965 to 2003. For time series analysis, it is assumed that observations are equally spaced in time (Hipel and McLeod, 1994). Monthly data offer consistent time base for the potentiometric head series. However, there are periods when sampling is less frequent and/or data is missing.

Due to the high chloride occurrences in wells located within the Jordan Valley and specifically in Jericho district, analysis carried out in this work will concentrate on the wells located therein. In general, chloride concentrations were taken annually in the period from 1968 to 2004. Nevertheless, pumping from wells used for inspection ought to drastically influence the potentiometric heads. Erroneous relationships and deductions may result due to this external factor.

In Jericho district, the chloride concentrations were found for almost 129 wells. While the potentiometric heads were found for 40 wells tap the Alluvium aquifer in the eastern basin. The spatial locations of these wells were identified by the GIS. Five wells distributed in Jericho district were selected for the analysis. These wells are distinctive in considerable time series and noticeable trends.

Since most of the water pumped in the basin is used for irrigation, a large part of it can return to the aquifer through return flow. Therefore, the potentiometric head may increase due to precipitation or any other water source. As the potentiometric head of the groundwater increases, the chloride concentration in the aquifer is expected to decrease.

Figure 56 shows the spatial locations of the selected wells in Jericho district.

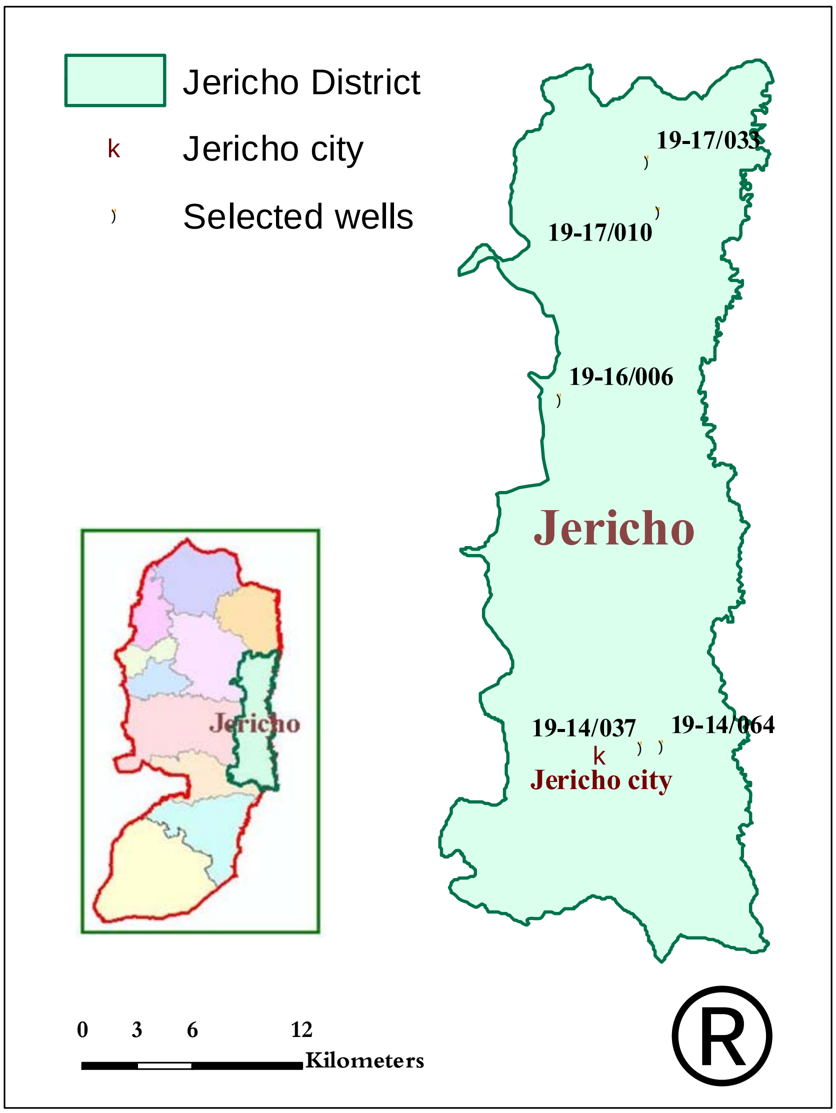
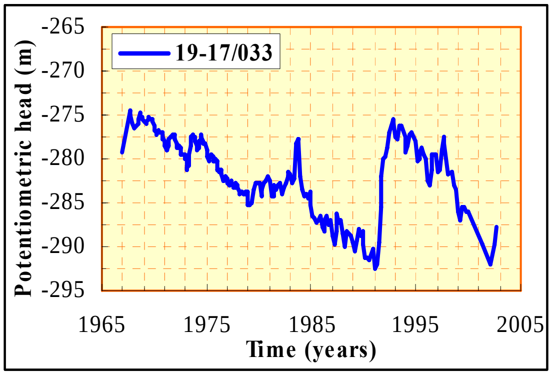
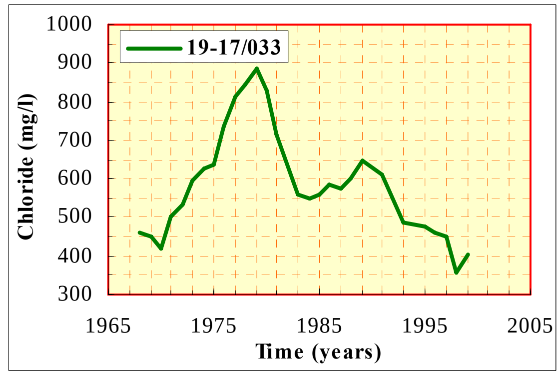


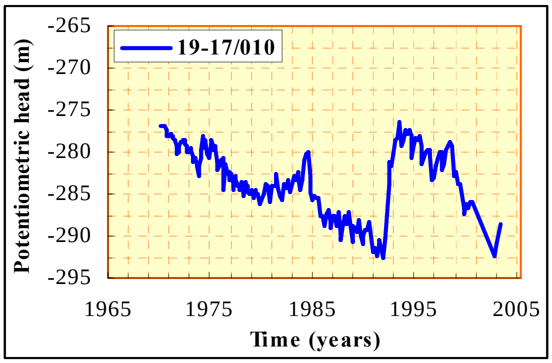
Figure 56: The spatial locations of the selected wells in Jericho district and the location of Jericho city

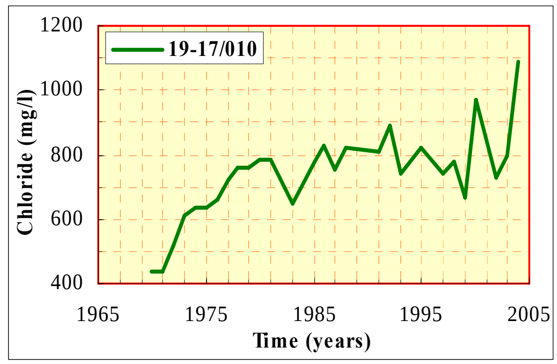
Figure 57 shows the times series of the potentiometric heads and the time series of the chloride concentrations for the selected wells in Jericho district. From Figure 57 and for *well 19-17/033*, the potentiometric head decreases in the period from 1968 to 1979, increases in the period from 1979 to 1984, decreases in the period from 1984 to 1991, and increases till 1993. While the opposite trends were noticed for the chloride concentration in the corresponding periods. In the period from 1993 to 1999, the potentiometric head and the chloride concentration decreases together. This may be attributed to the pumping rate. Nevertheless, about a five meters increase in the potentiometric head in 1984 caused approximately a 10 mg/l decline to the chloride concentration. While in 1992, almost a 10 meters increase in the potentiometric head caused approximately a 60 mg/l decline to the chloride concentration. To justify this, it is necessary to provide the time series of the pumping rate of the well. Furthermore, the response of that well could be influenced by adjacent wells and the time series of their pumping rate.

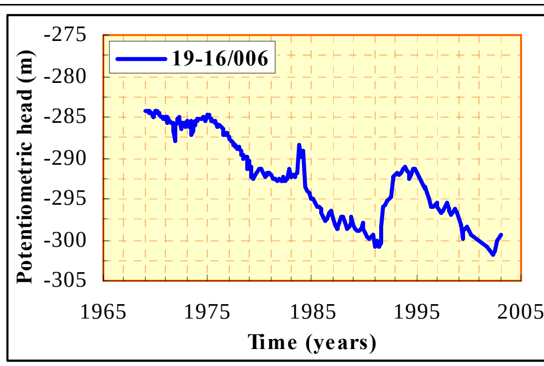
In *well 19-17/010*, the potentiometric head exhibits the same trends as those of *well 19-17/033*. The chloride concentration exhibits certainly the opposite trends of those pertaining to those of the potentiometric head. The higher the potentiometric head, the lower the chloride concentration and vise versa. In 1984, almost an increase of five meters in the potentiometric head caused approximately a 60 mg/l decline in the chloride concentration. However, in 1992 an increase of 12 meters in the potentiometric head caused approximately a decline of 65 mg/l in the chlorine concentration. In 1984, the response of chloride concentration to the change in the potentiometric head is much higher for *well 19-17/010*, yet that response is lower in 1992.

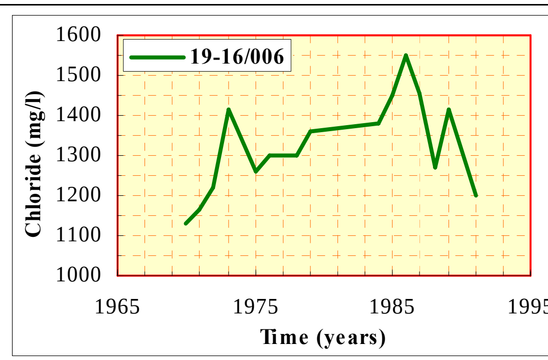

19-17/033
Potentiometric head (m)
-265
-270
-275
-280
-285
-290
-295
1965
1975
1985
1995
2005
Time (years)

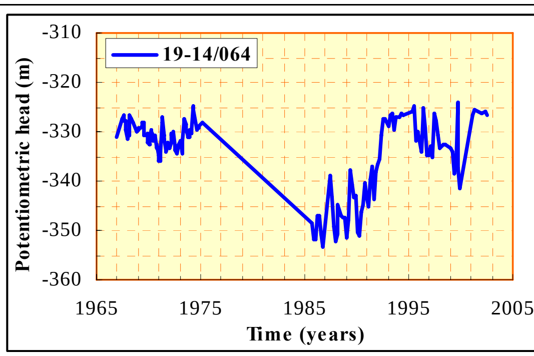

19-17/033
Chloride (mg/l)
1000
900
800
700
600
500
400
300
1965
1975
1985
1995
2005
Time (years)

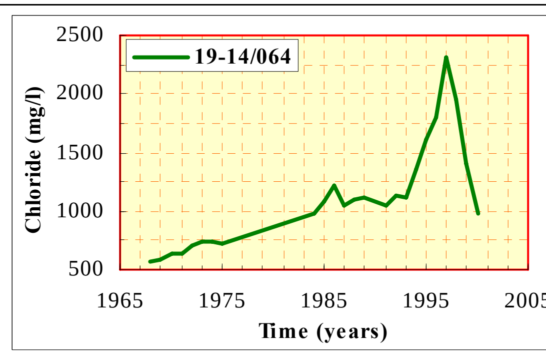

19-17/010
Potentiometric head (m)
-265
-270
-275
-280
-285
-290
-295
1965
1975
1985
1995
2005
Time (years)


19-17/010
Chloride (mg/l)
1200
1000
800
600
400
1965
1975
1985
1995
2005
Time (years)


19-16/006
Potentiometric head (m)
-275
-280
-285
-290
-295
-300
-305
1965
1975
1985
1995
2005
Time (years)


19-16/006
Chloride (mg/l)
1600
1500
1400
1300
1200
1100
1000
1965
1975
1985
1995
Time (years)


19-14/064
Potentiometric head (m)
-310
-320
-330
-340
-350
-360
1965
1975
1985
1995
2005
Time (years)


19-14/064
Chloride (mg/l)
2500
2000
1500
1000
500
1965
1975
1985
1995
2005
Time (years)

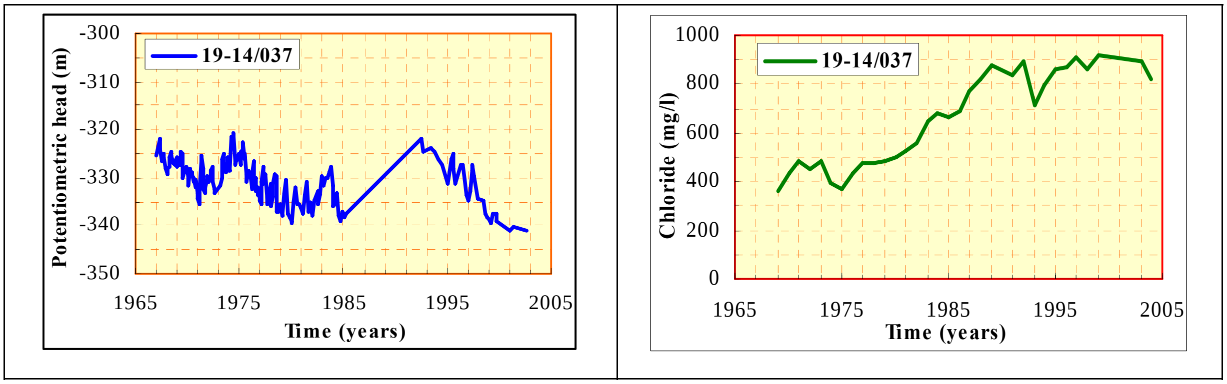


Figure 57: The time series of potentiometric head and chloride concentration of the selected wells in Jericho district

The potentiometric head in *well 19-16/006* exhibits a general decreasing trend with time. However, the chloride concentration drastically increases. For instance, the potentiometric head decreased almost 12 meters in the period from 1970 to 1986 while the increase in the chloride concentration in that period exceeded 400 mg/l. The reason of this is due to the excessive pumping which reaches 100 cubic meters per hour. This high pumping rate may increase the chloride concentration. *Well 19-16/006* gives an alarming indication that further monitoring is required since the concentration is increasing.

In *well 19-14/064*, the potentiometric head hasn't a specific trend with time while the chloride concentration drastically increases in the period from 1968 to 1997. The increase in the chloride concentration in that period exceeded 1700 mg/l while the increase in the potentiometric head was negligible. Nevertheless, a significant decline occurred in the chloride concentration in the period from 1997 to 2000 which exceeded 1300 mg/l, yet coincided to a decline in the potentiometric head of about 12 meters. It should be mentioned hereby that the potentiometric head readings were missed in the period from 1976 to 1985. In general, the steep changes in the chloride concentration indicate the risky situation in which this well encounters.

In *well 19-14/037*, the potentiometric head has a general decreasing trend with frequent fluctuations. In the same time, the chloride concentration steadily and smoothly increases in the period from 1969 to 2004. In the period from 1993 to 2003, a decline of almost 20 meters in the potentiometric head caused approximately a 180 mg/l increase in the chloride concentration. This indicates a significant increase in the chloride concentration as a response to any change in the potentiometric head. Although it has a moderate pumping rate, but it is the closest to Jericho city where the highest density of wells. Therefore, the behavior of the well could be influenced by the adjacent wells.

6.5 Summary and Conclusions

The main aim of this chapter is to evaluate chloride levels, trends, and distributions over the period from 1968 to 2004 within the districts of the West Bank. Quality problems with respect to chloride were found among the districts. The levels showed general increasing trends from west to east and from south to north throughout the West Bank. Almost, 25% of the analyzed wells were significantly higher than the US EPA and PSI guidelines for chloride.

It was noticed that the variability in the numbers of readings of chloride concentrations sampled from each well for the period from 1968 to 2004 was too high. It ranged from 1 to 35 readings with an uneven allocation of wells. Therefore, the analysis indicates that the chloride in the groundwater was highly variable, randomly distributed, and inconsistently measurable along the West Bank. Yet, this did not suppress a sound statistical analysis out of the available data.

Annual chloride concentration statistics from 1968 to 2004 showed that the median concentration is always below the MCL but the 3rd percentile exceeds the MCL in 14 years. It also showed that the annual maximum concentrations are always above the MCL. The annual maximum, 3rd quartile, and average chloride concentrations exhibit an overall increasing trend before the year 1991. In contrast, they all exhibit a decreasing trend after that time period.

The spatial distribution of chloride concentrations across the West Bank for the year 2004 was developed. The highest chloride concentrations are entirely encountered in the east, specifically in Jericho district, where intensive evapotranspiration occurs in addition to the excessive agricultural activities. The MCL were extremely exceeded in this district. Tubas district had the 2nd rank indicating high occurrence of chloride contamination.

Statistics of chloride concentrations based on the irrigation category in the West Bank for the period from 1968 to 2004 were calculated. The high standard deviations of chloride concentrations for irrigated and irrigable areas indicate that the dispersion in chloride concentrations is influenced by irrigation. The maximum chloride concentration was reported in an irrigable area where this concentration is much higher than the maximum concentrations in the remaining areas.

The relationship between the chloride concentration and the potentiometric head of the groundwater is studied. Since most of the water pumped in the basin is used for irrigation, a large part of it can return to the aquifer through return flow. Therefore, the potentiometric head may increase due to precipitation or any other water source. As the potentiometric head of the groundwater increases, the chloride concentration in the aquifer is expected to decrease. This relationship is expected because the excessive water will dilute the chloride concentration. The expected relationship was actually found with slim exceptions. However, sometimes the relationship varies for the same well. It should be mentioned here that there is a noticeable spatial variability in the behavior of the selected wells in Jericho district.

In light of the above analysis, the following general conclusions are made:

1. One of the main groundwater quality problems in the West Bank is the elevated chloride concentrations. Chloride concentrations exceed the MCL in 25% of the samples collected from wells in the West Bank for the period from 1968 to 2004;

2. The analysis of chloride occurrences in the groundwater of the study area showed that agricultural and irrigation applications of inorganic fertilizers is a potential source of chloride contamination of groundwater;

3. The wells in the Jordan Valley have the highest concentrations of chloride. Higher occurrences of chlorine encountered when moving from north to south. The same trend encountered the response in chlorine concentrations for any change in the potentiometric head. In general, the chloride concentration in the groundwater is inversely proportional to the potentiometric head of the groundwater;

4. There are numerous sources of chloride contamination including weathering of rocks, dissolution of salt deposits, volcanic emanations, effluents from chemical industries, mining operations, wastewater,

refuse leachates, agricultural fertilizers, irrigation drainage, excessive pumping from deep depths, and salt water intrusion;

5. There are general increasing trends across the West Bank from west to east and from south to north in terms of chloride concentrations;

6. GIS is an effective tool in analyzing the spatial variability of chloride occurrences in groundwater. In addition, GIS facilitates the analysis of the relationships between different descriptive parameters and chloride concentrations;

7. The main limitations of this work are that the analysis conducted to evaluate the chloride occurrences in the study area was not limited to the same well locations across all years. Although, from a theoretical point of view, the same wells are desirable to avoid any bias, yet practically this is not possible because groundwater quality monitoring in the study area does not necessarily follow a well-developed plan. On the other hand, sampling wells were not well-distributed to find out the spatial variability of chloride across the study area;

8. There is a dire need to develop a good sampling and monitoring plan of chloride occurrences that are temporally more frequent and spatially well distributed; and

9. Groundwater transport models need to be developed to provide information related to the chloride mass and concentrations in groundwater due to current and future land use practices and management alternatives. Once a broad range of management

alternatives and the corresponding impacts on groundwater quality are identified, the best alternative can be implemented through discussions between regulators and stakeholders.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This section lists the key conclusions of this research. However, detailed conclusions are provided by the end of the main chapters. In light of the furnished analyses and the corresponding discussions, the following are the conclusions:

1. GIS is an effective tool for analyzing the spatial variability of the key parameters. In addition, GIS facilitates the analysis of the interrelated relationships between the different explanatory parameters;

2. The nitrate concentration has an increasing trend specifically after the year 1985 across the West Bank aquifers; and

3. There are general increasing trends across the West Bank from west to east and from south to north in terms of chloride concentrations. The wells in the Jordan Valley have the highest chloride concentrations.

7.2 Recommendations

The research encompasses a multitude of parameters at different spatial levels. Many recommendations as such can be drawn out of this research. The recommendations listed herein support future studies that can address the following issues:

1. A well developed plan should be developed to consider the installation of monitoring network for the sampling of water for quality analysis. This network should be designed to cover the entire area of the West Bank and to tap the major aquifer systems at different depths and for different formations;

2. The current sampling frequency of the quality parameters is annual. However, in many hot areas that witness high concentrations of contaminants, a more frequent sampling is warranted. Overall, a unified monitoring policy should be promoted wherein all potential monitoring wells are considered concurrently;

3. Since the analysis carried out in this research considers sort-of one-to-one relationships, a multiple parameter analysis should be considered such that the impacts of different parameters are evaluated and assessed at the same time;

4. The development of contaminant fate and transport models is important. From the one side, these models permits the mapping of the spatial extent of a contaminant of interest while on the other hand the impact of potential management options to restore the aquifers can be assessed; and

5. There is a dire need to develop an Environmental Information System and a Groundwater Information System such that available data pertaining to the West Bank aquifers can be easily accessed and conveniently processed. Such proposed system would facilitate the accessibility to the data, enhance research, and will enable data sharing among the interested parties at the national level.

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جامعة النجاح الوطنية
كلية الدراسات العليا

تقييم وجود النترات والكلورايد في مصادر المياه الجوفية في الضفة الغربية باستخدام أنظمة المعلومات الجغرافية

إعـــداد
فتــحي "محــمد أمــين" يوســف عنايــة

إشـــراف
د. محــمد نهــاد الــمصري

قدمت هذه الأطروحة استكمالا لمتطلبات نيل درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين.

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الملـخص

تعتبر المياه الجوفية المصدر الرئيس للمياه بالنسبة للفلسطينيين. ولإدارة فاعلة لهذا المصدر، لا بد من فهم عميق لوضع المياه الجوفية يمكننا من تحديد كمية المياه ذات الجودة العالية والقابلة للاستغلال. ركز البحث على تردّي جودة المياه في أحواض الضفة الغربية والمتأثر بالتغيرات في مخزون هذه المياه. تم عمل تحليل إحصائي للتوزيع الزماني والمكاني لتراكيز النترات والكلوريد لمياه الآبار في أحواض الضفة الغربية. استخدمت تكنولوجيا أنظمة المعلومات الجغرافية (GIS) لتسهيل عملية التحليل وإبراز أهمية التوزيع المكاني للعناصر المختلفة المؤثرة في مصادر المياه. أكدت نتائج هذا البحث أن تركيز النترات لمياه الآبار في أحواض الضفة الغربية في ازدياد ملحوظ منذ عام 1985. بينما امتازت مياه الآبار التي تقع في وادي الأردن بتراكيز كلوريد تعــدّ \الأكــثر ارتفاعاً. وبشكل عام، فقد جاءت توصيات هذا البحث لتؤكد أن وضع المياه الجوفية في أحواض الضفة الغربية بحاجة مـــاسة لتدخلات عاجلة وفاعلة على كافة المستويات لإيجاد الحلول المناسبة للمشكلات المائية كــماً ونـــوعاً على حد سواء.