The Impact of Soil Texture on Nitrates Leaching into Groundwater in the North Governorate, Gaza Strip

Akram H. Al Hallaq*

Abstract: The main aim of this study is to determine the impact of soil texture on $N0_3$ leaching risk into groundwater wells, and to establish a statistical relationship between soil texture and the concentration of nitrates ($N0_3$) in the North Governorate groundwater. The study shows that there is considerable variation in the soils in the Governorate. The major part of it consists of light or coarse texture. Seven different types of soil have been recognized and mapped. These soils vary in texture from sand to clay, and in permeability from high to low. On average, 71.5% of the soils of two Horizons (A and B) have a relatively high permeability; 28% have imperfect or moderate permeability; and 0.5% have low permeability. In relation to $N0_3$ concentration, almost 94% of the groundwater wells of the Governorate showed a NO_3 concentration of one to four times higher than WHO standards. The study also showed that soil texture affects $N0_3$ leaching. Soil with a coarse texture, such as sands, allows NO_3 to leach into groundwater faster than soil with a fine texture, such as sandy clay loam, clay loams and clay. There is a positive relationship between the percentage of sands (in two Horizons "A" and "B") and NO_3 concentration in groundwater wells (r = 0.78, and 0.76 respectively). The average amount of NO_3 concentration in water wells which are located in areas of surface sandy soil was about 128 mg/L. In areas of loamy sand, sandy loam, sandy clay loam, loam, and clay loam, the average is immediately reduced to about 94, 70, 58, 52 and 29 mg/L respectively, as a result of decreasing soil permeability which is responsible for the leaching of water and then the leaching of NO_3 to the underground reservoir.

* Department of Geography, University of Al-Aqsa, Gaza, Palestine.

Key words: Soil texture, Nitrate (NO_3), Permeability, Leaching, North Governorate.

1. Introduction

Soil is one of the most important natural resources, which supports plants that are the basic source of our nourishment and provide food for domesticated animals. Soil also helps maintain the earth's surface environment in a condition of relative equilibrium (Skinner and Porter, 1992). Soils have varied retentive properties depending on their texture. A very important physical property of soil, from the point of view of both agricultural production and the protection of water quality, is soil texture. This water quality matters because it provides information about the connections between soil texture and soil management practices that protect water quality. During the past two decades, the nitrate ($N0_3$) form of fertilizer nitrogen (N), an essential source of N for plant growth, is now considered to be not only a fertilizer, but also a potential pollutant by the Environmental Protection Agency (EPA) (Federal, 1975). This is because excess amounts of $N0_3$ applied as fertilizer to crops, lawns, nurseries, orchards, and gardens can move into streams by runoff and into groundwater by leaching. Excess $N0_3$ is considered to be a contaminant and environmental hazard to water quality.

Nitrate contamination of groundwater throughout the world is a source of rising concern that has been faced through the introduction of several regulations in different countries. Groundwater nitrate concentrations in Europe exceed the international recommendations for drinking water (50 mg/l (*WHO, 2004*)), in 22% of cultivated land. Similar concentrations have been found in the USA and in China (Laegreid et al., 1999).

Groundwater is one of the most precious natural resources in all the governorates of the Gaza Strip as it is the only source of drinking water for the majority of the population. Its groundwater aquifer is extremely susceptible to surface-derived contamination because of the high permeability of the sands and gravels that compose the soil profile of Gaza (Shomar et al., 2005). Agriculture is considered to be the main source of nitrate contamination in groundwater. Excessive use of chemicals and fertilizers increases the risk of groundwater contamination (Cepuder and Shukla et al., 2002). Contamination can occur if input of $N0_3$ into soil exceeds the consumption of plants. The excess $N0_3$ in the groundwater of the Gaza Strip, especially in the North Governorate, occurred as a result of $N0_3$ leaching from irrigation, wastewater, septic tanks, sewage sludge, animal manure and synthetic fertilizers (Shomer, 2006).

Several studies in Gaza have reported high nitrate $N0_3$ levels in groundwater as one of the major concerns among the public and governmental decision-makers (Abu Maila et al., 2004; Al Hallaq 2002), but these studies did not clarify the impact of soil texture on $N0_3$ leaching risk into groundwater wells, and the relationship between soil texture and NO_3 concentration in groundwater.

2. Objectives of Study

The aim of this study is to determine the impact of soil texture on $N0_3$ leaching risk in the North Governorate groundwater, and to establish a statistical relationship between soil texture and $N0_3$ concentration in groundwater.

3. Area of Study

The Northern Governorate is located in the north of the Gaza Strip (Figure 1). It covers a total area of approximately 60.5 km^2 (17 % of the Gaza Strip's total area). It is bounded by the Green Line (inside occupied Palestine) to the north and east, the Mediterranean Sea in the west and Gaza Governorate in the south (there is about 5 km between Gaza and the northern Gaza cities). For administrative purposes, the governorate is divided into three municipalities: Beit Lahia, Jabaliya, and Beit Hanoun. The total population at the end of 2007 was 270,246, distributed in three main municipalities (Palestinian Central Bureau of Statistics, 2008). Approximately 85% drink from municipal groundwater wells and 15%, mostly in agricultural areas, use private wells to supply their drinking water.

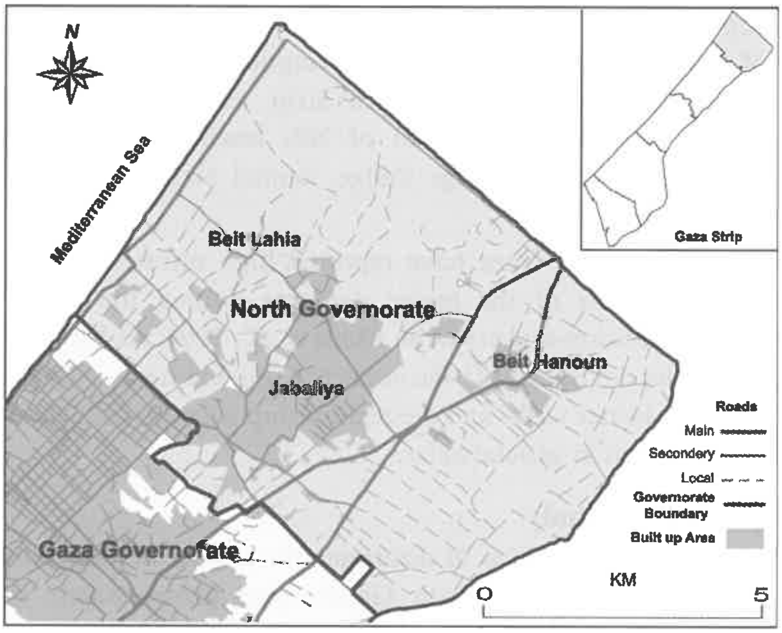

Figure (1) Location of the North Governorate (Area of Study)

Source: by researcher.

The study area is part of the coastal zone in the transitional area between the temperate Mediterranean climate to the east and north, and the semi-arid climate of the Negev and Sinai deserts to the east and south. As a result, the study area has a moderate climate. The annual average rainfall ranges between 430 in the east (Beit Hanoun), (Al Hallaq, 2008), and 445 millimeter (mm) in the west (Beit Lahia).

The hydro-geological features of the study area aquifer are well known. The coastal aquifer consists primarily of Pleistocene Age Kurkar Group deposits, including calcareous and silty sandstones, silts, clays, unconsolidated sands, and conglomerates. Near the coast, coastal clays extend about 2-5 km inland, and divide the aquifer sequence into three or four sub-aquifers, depending upon the location (Al Hallaq, 2004). Within the North Governorate, the total thickness of the Kurkar Group is about 160m at the shore. At the Eastern Governorate border, the saturated thickness is about 60m.

Under natural hydraulic gradients, groundwater flows in the north governorate from east to west towards the Mediterranean Sea, where fresh groundwater discharges into the sea. However, natural flow patterns have been significantly disturbed by pumping and artificial recharge *(PWA, 2000)*. The water flows because over-pumping in Gaza has caused a depression in the water-table topography. When one area of the water-table is lowered compared with another, a gradient between the two is created. The contaminated water flows across the gradient toward the depression.

About 25,000 dunums (dunum = 1000 m^2) of the governorate's land are used for agriculture (41.7% of the North Governorate total area). About 81.2% of agricultural land is considered to be irrigated land (Palestinian Central Bureau, 2007). Most of the governorate's people work in the agricultural sector, and many of them live in farms and use water wells for irrigation and drinking.

In this governorate, near Beit Lahia, the wastewater treatment plant is located. It was constructed in 1973. It is located near one of the finest groundwater aquifers in the Gaza Strip. It has had an impact on $N0_3$ pollution of groundwater through leaks to the aquifer. Recent research has demonstrated that it can cause $N0_3$ contamination of groundwater in the governorate (Aish, 2000, PWA, 1999; Sharif, 2003).

4. Data and Methodology

The data of this study have been derived from the results of the analysis of soil, (see Table 1), and water samples collected from the field (see Table 3). To determine the relationship between soil texture and $N0_3$ leaching, 63 soil samples with a diverse soil texture were studied. A particle size analysis was made to determine the soil texture. Soil samples from 63 locations surrounding 63 wells in the North Governorate were taken at two different horizons, (Horizon A: 0-30 cm and Horizon B: 30-60 cm), and analyzed mechanically in the central laboratory for water and soil. This laboratory belongs to the Ministry of Agriculture. The sites of water samples covered most of the study area from east to west and from north to south. Therefore, their sites were selected to be commensurate with the flow of groundwater. Groundwater samples from 63 wells penetrating the North Governorate aquifer and located close to the sites of soil samples were collected in the winter season (December-February 2007/2008) and analyzed for $N0_3$ in the same laboratory (Figure 2). The winter season was chosen for sampling because the highest levels of contamination are predominant in this season (Sharif, 2003). Both soil and water samples were selected to represent the three geographical areas: Beit Lahia, Jabaliya, and Beit Hanoun.

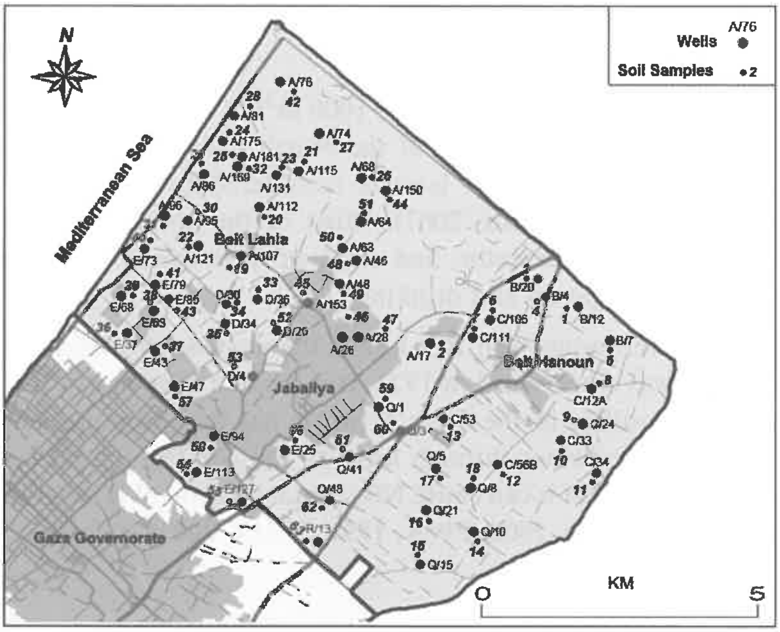

Figure (2) Location of Investigated Groundwater Wells and Soil Samples

Source: by researcher.

United States Department of Agriculture (USDA) texture triangle software was used to obtain the soil texture class in the North Governorate (*USDA, 2008*), where samples of soil from Horizon "A" and Horizon "B" are plotted on the soil texture triangle. American Hydraulic Properties Calculator (AHPC) software was also used to compute the permeability of each soil class.

The soil and water data of 63 locations for each were used for analysis in this study. The data were converted from MS Excel files to MS Access as DBF files, and then the soil and water locations were used to create maps of soil texture and No_3 distribution by using ArcView 3.2 within the X and Y Axis coordinates.

5. Results and Discussion

5.1 Soil Texture

Accurate estimation of soil texture over large areas is important for a range of agricultural and environmental applications (Grot and Anger, 2005). Soil texture is a physical indicator of the size ranges of particles within soil. All soil particle sizes can be sorted into three convenient size ranges called soil separates (Christopherson, 1992; Fernandez-Illescas et al, 2001) or textural fractions, namely: sand, silt and clay, with definite size limits expressed as a diameter in millimeters. According to the official definition of the United States Department of Agriculture (USDA), sand particles are the largest (Diameter limits: 0.05 - 2 mm), silt particles are medium sized (0.002 - 0.05 mm), and clay constitutes the finest material (less than 0.002 mm) in soil (De Blij and Muller, 1993). Conventionally, the overall textural classification of a soil is determined as a function of the mass ratios of these three textural separates. Within the USDA soil textural classification (*USDA, 1951*), soils with different percentages of sand, silt, and clay are assigned to 12 different classes (see Figure 3).

Texture is an important soil property which is strongly related to many soil physical properties, such as percolation or permeability. Texture affects the water permeability rate of a soil. Permeability is the downward movement of free water and is often referred to in the laboratory as the saturated hydraulic conductivity rate. The coarser the soil has the faster rate, and the finer the soil has the slower rate. Texture also indicates the amount of water a soil can hold. Soil scientists classify soils according to their physical properties in much the same way that geographers classify climate or geologists classify rocks. Such classification makes it easier to map, study, and understand how soils are distributed on the landscape and how their properties reflect soil-forming factors (Skinner and Porter, 1992). Samples of soils from Horizon "A" and Horizon "B" in the North Governorate are plotted on the soil texture triangle (Figure 3 and Figure 4). Textural analyses of the samples are summarized in Table (1).

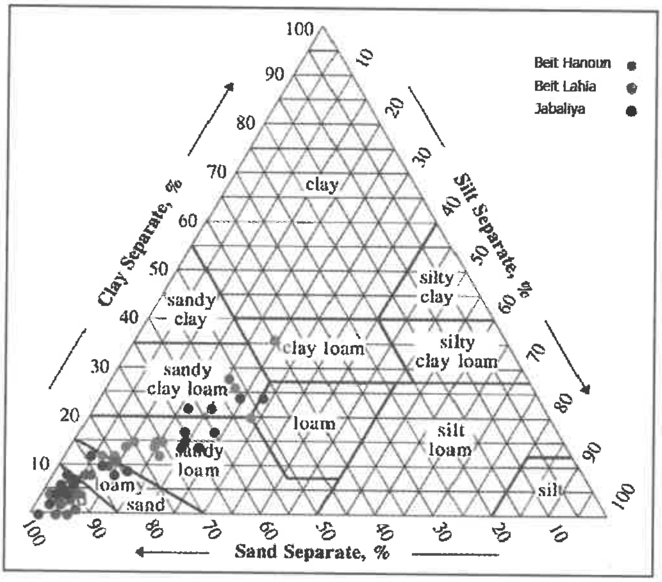

Figure (3) Textural Soil Classification in Horizon "A"

Source: by researcher.

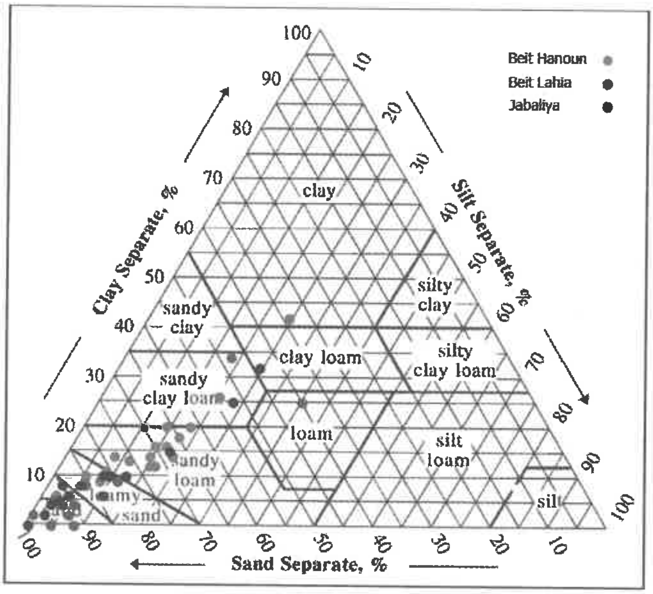

Figure (4) Textural Soil Classification in Horizon "B"

Source: by researcher.

Table (1)
Textural Analysis and Permeability of Soil in the North Governorate.*

P "B" cm/h	P "A" cm/h	Texture Class "Hor. B"	Texture Class "Hor. A"	Horizon "B" (30-60 cm)			Horizon "A" (0-30 cm)			Soil Samples N0.	Area
				Silt	Clay	Sand	Silt	Clay	Sand		
1.52	2.09	SL	SL	8	14	78	8	12	80	1	
2.03	10.02	SL	S	16	12	72	4	4	92	2	
0.69	1.52	SCL	SL	14	20	66	14	14	72	3	
6.80	4.51	S	S	2	6	92	2	8	90	4	
0.90	1.33	SL	SL	17	18	65	19	15	66	5	
3.49	2.03	LS	SL	8	9	83	16	12	72	6	
1.15	1.32	SL	SL	14	16	70	15	15	70	7	
1.52	1.32	SL	SL	14	14	72	15	15	71	8	
2.04	1.31	SL	SL	15	12	73	10	15	75	9	
2.46	2.92	SL	LS	8	11	81	8	10	82	10	B. Hanoun
0.40	0.41	SCL	SCL	20	26	54	22	26	52	11	
2.99	2.11	LS	SL	5	10	85	6	12	82	12	
1.76	1.52	SL	SL	11	13	76	9	14	77	13	
0.68	0.56	SCL	SCL	10	20	70	16	22	62	14	
1.52	1.52	SL	SL	18	14	68	19	14	67	15	
0.18	0.22	C	CL	24	42	34	24	36	40	16	
1.15	0.77	SL	L	16	16	68	28	20	52	17	
0.71	0.58	SCL	SCL	18	20	62	20	22	58	18	
9.52	10.28	S	S	6	4	90	4	4	93	19	
10.56	6.80	S	S	2	4	94	2	6	92	20	
10.02	9.52	S	S	4	4	92	6	4	90	21	
3.93	1.04	LS	SL	11	9	80	23	17	60	22	
6.55	2.45	S	SL	4	6	90	9	11	80	23	
9.22	9.76	S	S	2	2	96	4	4	91	24	B. Lahia
4.28	4.34	LS	LS	6	8	86	5	8	87	25	
10.56	10.56	S	S	2	4	94	2	4	94	26	
0.53	1.02	L	SL	35	25	40	18	17	65	27	
2.90	2.90	LS	LS	8	10	82	8	10	82	29	
18.07	15.29	S	S	0	2	98	4	2	94	28	

Cont. Table (1)
Textural Analysis and Permeability of Soil in the North Governorate.*

P "B" cm/h	P "A" cm/h	Texture Class "Hor. B"	Texture Class "Hor. A"	Horizon "B" (30-60 cm)			Horizon "A" (0-30 cm)			Soil Samples N0.	Area
				Silt	Clay	Sand	Silt	Clay	Sand		
18.07	9.22	S	S	0	2	98	2	2	96	30	B. Lahia
6.55	12.04	S	S	4	6	90	3	3	92	31	
14.68	6.55	S	S	5	2	93	4	6	90	32	
6.55	4.28	S	LS	4	6	90	6	8	86	33	
0.22	0.34	SCL	SCL	18	34	48	20	28	52	34	
9.22	10.85	S	S	2	2	96	2	4	95	35	
24.00	18.15	S	S	0	0	100	6	0	94	36	
10.56	14.91	S	S	2	4	94	7	1	92	37	
10.02	5.43	S	S	4	4	92	3	7	90	38	
15.71	12.83	S	S	8	0	92	3	3	94	39	
10.02	8.26	S	S	4	4	92	3	5	92	40	
10.02	5.43	S	S	4	4	92	3	7	90	41	
8.45	15.29	S	S	4	5	93	4	2	94	42	
21.00	21.00	S	S	4	0	96	4	0	96	43	
16.60	16.60	S	S	2	2	96	2	2	96	44	Jabaliya
6.55	6.55	S	S	4	6	90	4	6	90	45	
6.55	5.35	S	S	4	6	90	4	7	89	46	
10.56	10.56	S	S	2	4	94	2	4	94	47	
16.60	8.26	S	S	2	2	96	3	5	92	48	
16.60	16.60	S	S	2	2	96	2	2	96	49	
2.84	3.36	SL	SL	12	10	78	12	9	79	50	
4.51	4.51	S	S	2	8	90	2	8	90	51	
10.02	6.80	S	S	4	4	92	2	6	92	52	
10.56	10.02	S	S	2	4	94	4	4	92	53	
6.55	16.60	S	S	4	6	90	2	2	96	54	
2.92	2.13	LS	LS	8	10	82	4	12	84	55	
0.45	0.50	SCL	SCL	23	25	52	24	24	52	59	
5.92	4.09	LS	LS	10	6	84	10	8	82	60	
4.34	2.94	LS	LS	5	8	87	7	10	83	56	

Cont. Table (1)
Textural Analysis and Permeability of Soil in the North Governorate*

P "B" cm/h	P "A" cm/h	Texture Class "Hor. B"	Texture Class "Hor. A"	Horizon "B" (30-60 cm)			Horizon "A" (0-30 cm)			Soil Samples N0.	Area
				Silt	Clay	Sand	Silt	Clay	Sand		
2.90	5.35	LS	S	9	10	81	4	7	89	**61**	**Jabaliya**
8.26	10.56	S	S	3	5	92	2	4	94	**62**	
0.27	0.52	CL	L	24	32	44	28	24	48	**57**	
24.00	23.24	S	S	0	0	100	1	0	99	**58**	
1.32	1.53	SL	SL	17	15	68	22	14	64	**63**	

* P "A", P "B"= Permeability in Horizon "A" and "B", S=Sand, LS=Loamy Sand, SL= Sandy Loam, L=Loam, SCL= Sandy Clay Loam, CL= Clay Loam, C= Clay. *Source: by researcher.*

According to the USDA soil textural classification, soils with different percentages of sand, silt, and clay in the study area are assigned to six different classes in Horizon "A" (sand, loamy sand, sandy loam, loam, sandy clay loam and clay loam), and seven different classes in Horizon "B" (sand, loamy sand, sandy loam, loam, sandy clay loam, clay loam and clay).

a) Sand: Soil materials classified as sands must contain 85-100% sand-sized particles, 0-15% silt-sized particles, and 0-10% clay-sized particles. These percentages are given by the boundaries of the sand portion of the USDA textural triangle. Sands are considered light and coarse-textured soil. Sandy soils hold very little water, allowing it to percolate downward. Sandy soils in Horizon "A" make up about 43% of the North Governorate total area (Table 2). In Horizon "B", they make up about 46% (Figures 5 and 6).

From Table (1) and two Figures (5 and 6), it is noted that sand class dominates in Horizon "A" (surface) and in Horizon "B", particularly in the Beit Lahia (west of the governorate) and Jabaliya (middle of the governorate) areas. Materials in the sand class have very low proportions of silt or clay size particles, so that is why sand has higher water permeability rates than others, such as clay. By using American Hydraulic Properties Calculator (AHPC) software, physical analysis showed that the water permeability rates ranged between 4.51 - 24 cm/hr for the sand class depending on the proportion of sand, clay and silt in the soil. This is an indication of the high permeability of sandy soil (Table 1).

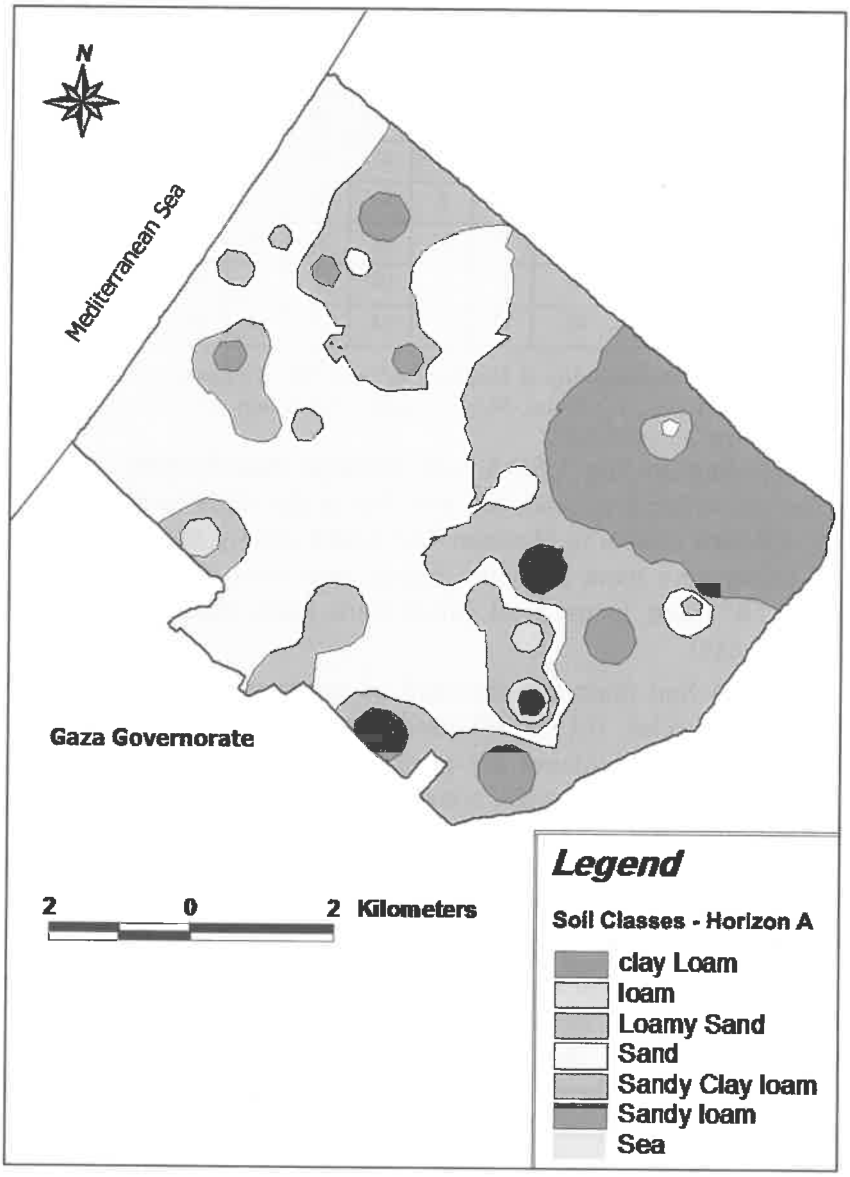

Figure (5) Distribution of Soil Texture of Topsoil (Horizon "A") within the North Governorate

Source: by researcher.

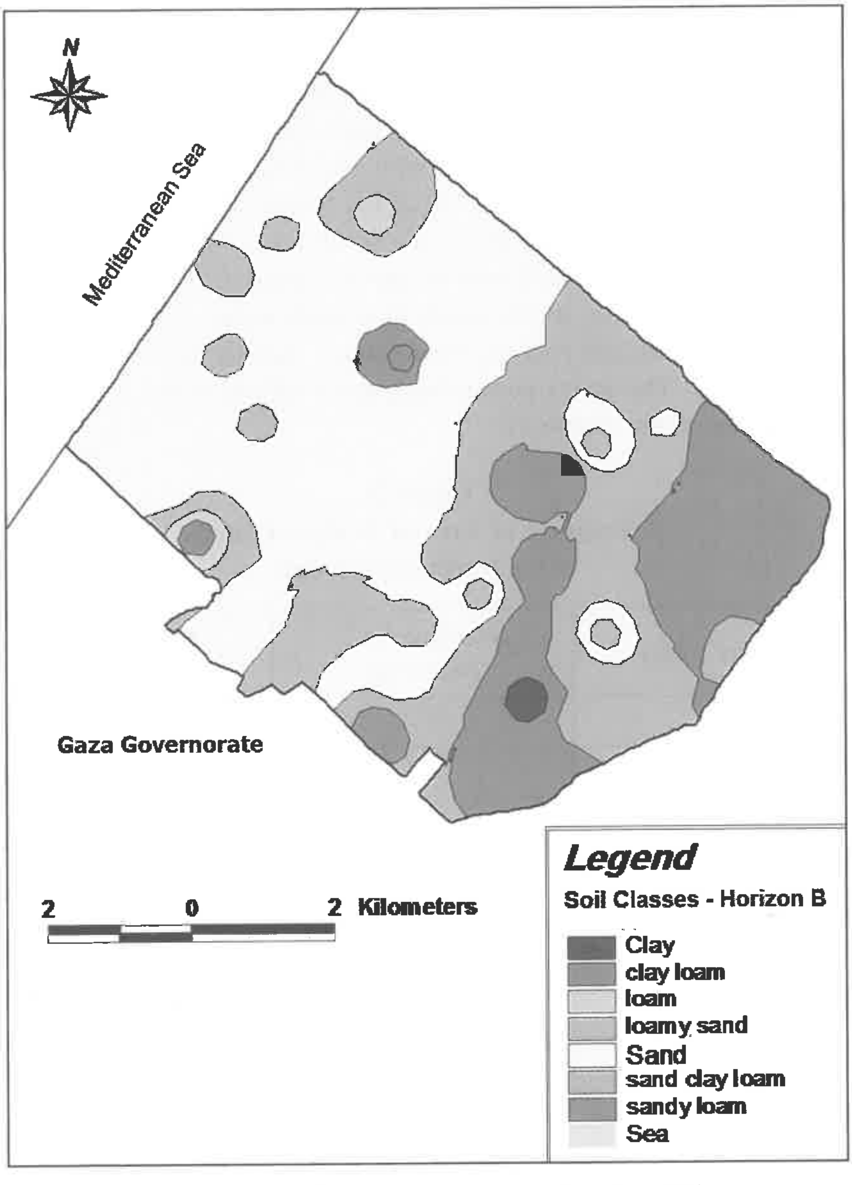

Figure (6) Distribution of Soil Texture of Horizon "B" within North Governorate

Source: by researcher

b) Loamy Sand: Loamy sands consist of soil materials containing between 70-91% sand, 0-30% silt, and 0-15% clay (Soil Survey Division Staff, 1993). As such, they resemble sands in that they are loose and single-grained, and most individual grains can be seen and felt. However, because they do contain slightly higher percentages of silt and clay than sands do, the loamy sands are slightly cohesive when moist, and fragile casts can more readily be formed with them than with sands. Loamy sands in Horizon "A" make up 5.7% of the North Governorate total area (Figure 5), and 10% of the total area in Horizon "B" (Figure 6). This class of soil covers a small area of the governorate, especially in Beit Lahia. As stated above, loamy sands have high water permeability rates, but less than sandy soil because they contain slightly higher percentages of silt and clay. The water permeability rates ranged between 2.13 - 4.34 cm/hr for this class (Table 2).

Table (2)
Percentage of Area of Texture Classes in the North Governorate

Texture Class	Horizon "A" Area (%)	Horizon "B" Area (%)
Sand	43.1	46.2
Loamy Sand	5.7	10.0
Sandy Loam	17.9	19.7
Loam	0.9	0.9
Sandy Clay Loam	32.2	22.3
Clay Loam	0.2	0.3
Clay	--	0.5
Total	100	100

Source: by researcher.

c) Sandy Loam: sandy loam is soil that is moderately coarse-textured. Sandy loams consist of soil materials containing somewhat less sand (more than 52%), more silt (less than 50%), and clay (7-20%), than loamy sands. As such, they possess characteristics which fall between the finer-textured sandy clay loam and the coarser-textured loamy sands. This class of soil occupies an area of land estimated at about 18% of the North Governorate's total area in Horizon "A" and about 20% in Horizon "B" (Table 2). The water permeability rates for this class ranged between moderate (0.9 cm/hr) and high (3.36 cm/hr).

d) Loam: Loam is soil material that is medium-textured. It feels as though it contains a relatively even mixture of sand, silt, and clay because clay particles, with their small size, high surface areas, and high physical and chemical activities, exert a greater influence on soil properties than do sand or silt. Loam is soil composed of sand, silt, and clay in relatively even concentrations (about 40%, 40% and 20% concentration respectively), and is considered ideal for gardening and agricultural uses. Loam soils have better infiltration and drainage than silty soils, and are easier to till than clayey soils. Loam soil spreads on 0.9% of the governorate's total area of both Horizon "A" and Horizon "B" (Table 2). It appears in Beit Lahia and Beit Hanoun. The water permeability rates for this class are moderate and range between 0.53 - 0.77 cm/hr.

e) Sandy Clay Loam: Soil having this texture consists of materials whose behavior is dominated by sand (+45%) and clay (20 - 35%). However, as the name implies, sandy clay loam has more clay than sandy loams and thus possesses greater cohesive properties, such as stickiness and plasticity, when moistened. Sandy clay loam is soil material that is moderately fine-textured. In Horizon "A", it makes up about 32% of the North Governorate's total area. In Horizon "B", it makes up about 22% of the total area. The water permeability rates are moderate and range between 0.22 - 0.71 cm/hr (Table 2).

f) Clay Loam: Clay loam consists of soil material having the most even distribution of sand (20-46%), silt, and clay (27-40%) of any of the soil textural grades. This class of soil occupies an area of land estimated to be about 0.2% and 0.3% of the North Governorate's total area in Horizon "A" and in Horizon "B" respectively. The water permeability rates for this class range between 0.22 - 0.27 cm/hr (Table 2).

g) Clay: Clay is the finest and heaviest textured of all the soil classes. It usually forms extremely hard clods or lumps when dry and is extremely sticky and plastic when wet. It holds the most water and does not allow water to percolate downward (De Blij, 1987). It consists of soil materials containing between 45% or less sand, less than 40% silt, and 40% or more clay. It forms a small area of Horizon "B" (0.5% of the North Governorate's total area), and disappears from Horizon "A". The water permeability rate is low and reaches 0.18 cm/hr (Table 2).

It is noted from the data of Horizon "A", (Table 1), that the 63 soil samples were diverse in soil texture as the maximum percent silt and clay increased from 7 and 8%, respectively, for sand, to 10 and 12% for loamy sand, to 23 and 17% for sandy loam, to 28 and 24% for loam, to 24 and 28% for sandy clay loam, and to 24 and 36 for clay loam (Table 1). In Horizon "B", the maximum percentage of silt and clay also increased from 8 and 8%, respectively, for sand, to 11 and 10% for loamy sand, to 19 and 18% for sandy loam, to 35 and 25% for loam, to 23 and 34% for sandy clay loam, to 24 and 36% for clay loam, to 24 and 42% for clay.

It is also noted from textural analyses of these samples that sand dominates in all samples of Horizon "A" (the surface) in the three areas of the Governorate (Beit Lahia, Beit Hanoun and Jabaliah), and in 98.4% of total samples of Horizon "B" (Table 1). Sand holds very little water, allowing it to percolate downward and also allowing contaminants, like nitrates, to permeate aquifers; silt retains an intermediate quantity of water; and clay holds most of the water (De Blij, 1987).

The major part of the North Governorate consists of light or coarse textured, adequately drained soils. Seven different types of soil were recognized and mapped in the North Governorate. The soils vary in texture from sand to clay. Light textured soils in Horizon "A" (sands, loamy sands, and sandy loams) make up about 67% of the total area, and, in Horizon "B", about 76% of the total area. Medium-textured soils (loams and sandy clay loams) in Horizon "A" and Horizon "B" comprise about 33% and 23%, respectively, of the total area. The remainder consists of heavy-textured soils (clay loams and clays) that occur less widely (Figures 7 and 8). On average, 71.5% of the soils of the two horizons have a relatively high permeability; 28% have imperfect or moderate permeability; and 0.5% have low permeability.

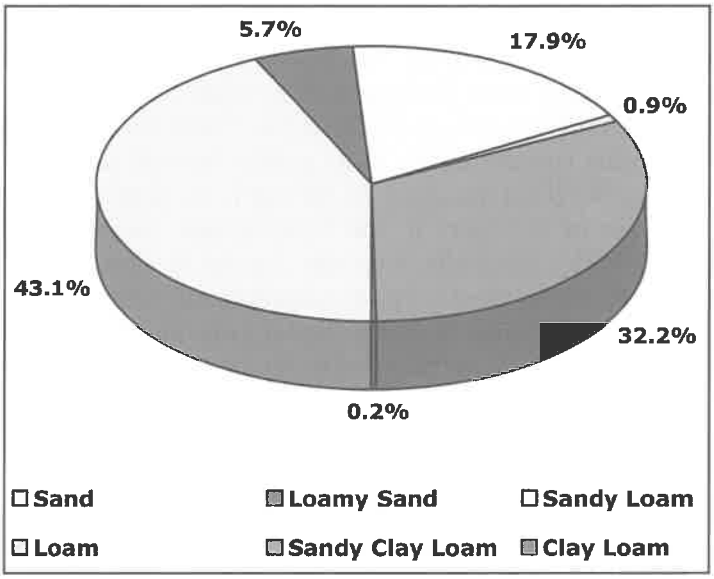

Figure (7) Variation in Soils in the North Governorate - Horizon "A"

Source: by researcher

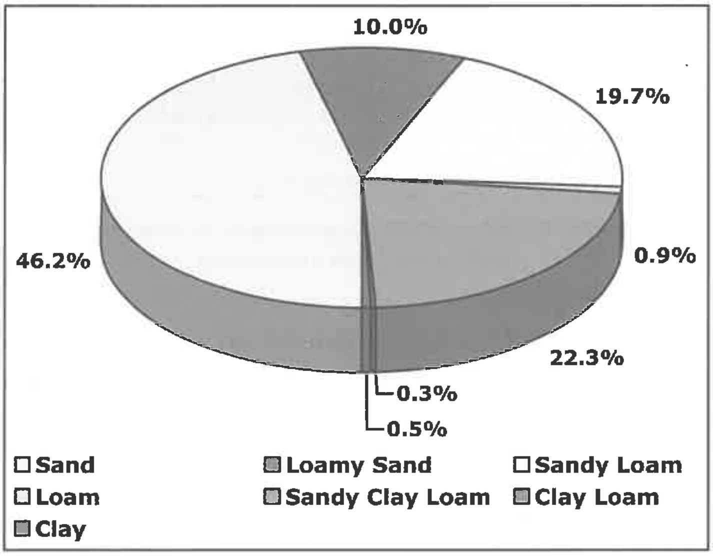

Figure (8) Variation in Soils in the North Governorate - Horizon "A"

Source: by researcher

5.2 Nitrate (NO_3) in Groundwater Wells

The main sources of NO_3 are fertilizers, pesticides and domestic sewage effluent. Heavy agricultural activities, urban areas and the excessive use of nitrogen fertilizers and pesticides in the North Governorate have led to elevated nitrate concentrations in its aquifer beyond the World Health Organization's (WHO's) standard of 50 mg/L as depicted in Figure 9. Unregulated use of fertilizers in the Governorate contributes to severe pollution with NO_3, especially since the aquifer is close to the surface. During the vegetative cycle of citrus, for example, the optimum amendment of fertilizer for citrus should be 20 kg/dunum/year. However, in reality and with information given by agronomists in the Governorate, this quantity is more than double for citrus (40-45 kg/dunum/year). This fertilization will affect the concentration of NO_3 in the soil and groundwater, especially in areas of sandy, loamy sand and sandy loam soil.

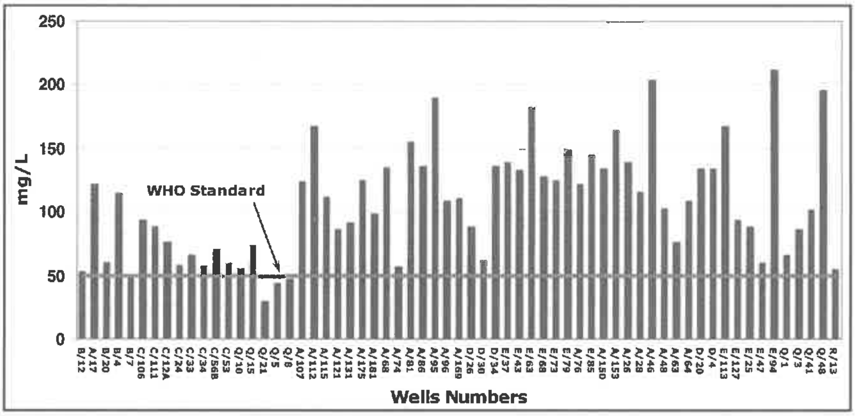

Figure (9) Variation of NO_3 Concentrations in Groundwater Wells of the North Governorate

Source: by researcher

Inadequate disposal of waste matter has also contributed to the contamination of the Governorate's aquifer. About 1.5% of occupied housing units are not served by any wastewater management systems, and are simply dumping raw sewage onto the sand dunes. What systems are in place remain inadequate, particularly in the refugee camps. Public latrines are still in use, and about 28% of occupied housing units throughout the North Governorate rely on septic tanks and soaking pits (Palestinian Central Bureau of Statistics, 1999). The quantities of sewage that may be infiltrating through the sewage collection network, cesspits, and septic tanks are significant. Wastewater return flow in the North

Governorate was estimated to be about 1.67 Mm^3 in 1998 *(PWA, 2000)*. Those activities within the Governorate are the primary cause of the elevated levels of NO_3.

NO_3 concentrations in the North Governorate aquifer ranged from 29 to 212 mg/L. In Beit Hanoun, Beit Lahia and Jabaliah, they ranged from 29 to 121 mg/L, 57 to 189 mg/L, and 55 to 212 mg/L, respectively (Table 3). Almost 94% of the sampled wells had levels of NO_3 above the WHO standard of 50 mg/L and only 4 of the 63 sampled wells were at or below the WHO standard (Figure 9). The highest levels of NO_3 were in Beit Lahia (in the west of the Governorate) and Jabaliah (in the middle). These areas showed average NO_3 concentrations of 123.9 mg/L and 121.6 mg/L, respectively.

Table (3)
Nitrate Concentration (mg/L) in the North Governorate

NO_3 Mg/L	Wells No.	Area	NO_3 Mg/L	Wells No.	Area	NO_3 Mg/L	Wells No.	Area
145	**E/85**	**B. Lahia**	91	**A/131**	B. Lahia	53	B/12	**B. Hanoun**
134	A/150	**Jabaliya**	125	**A/175**		121	**A/17**	
164	**A/153**		98	**A/181**		60	**B/20**	
139	**A/26**		135	**A/68**		114	**B/4**	
115	**A/28**		57	**A/74**		50	**B/7**	
203	**A/46**		155	**A/81**		93	**C/106**	
102	**A/48**		136	**A/86**		88	**C/111**	
76	**A/63**		189	**A/95**		76	**C/12A**	
108	**A/64**		108	**A/96**		58	**C/24**	
134	**D/20**		110	**A/169**		66	**C/33**	
134	**D/4**		88	**D/26**		58	**C/34**	
167	**E/113**		62	**D/30**		71	**C/56B**	
93	**E/127**		136	**D/34**		60	**C/53**	
88	**E/25**		139	**E/37**		56	**Q/10**	
60	**E/47**		133	**E/43**		74	**Q/15**	
212	**E/94**		182	**E/63**		29	**Q/21**	
66	**Q/1**		128	**E/68**		44	**Q/5**	
86	**Q/3**		124	**E/73**		47	**Q/8**	
101	**Q/41**		149	**E/79**		123	A/107	**B. Lahia**
195	**Q/48**		121	**A/76**		167	**A/112**	
55	**R/13**		86	**A/121**		111	**A/115**	

Source: by researcher

The average NO_3 concentrations in Beit Hanoun in the east was 67.6 mg/L. The distribution pattern seems to be a general tendency for NO_3 to increase from east to west. This is due to the increasing amount of sandy soil in the same direction (Figure 10).

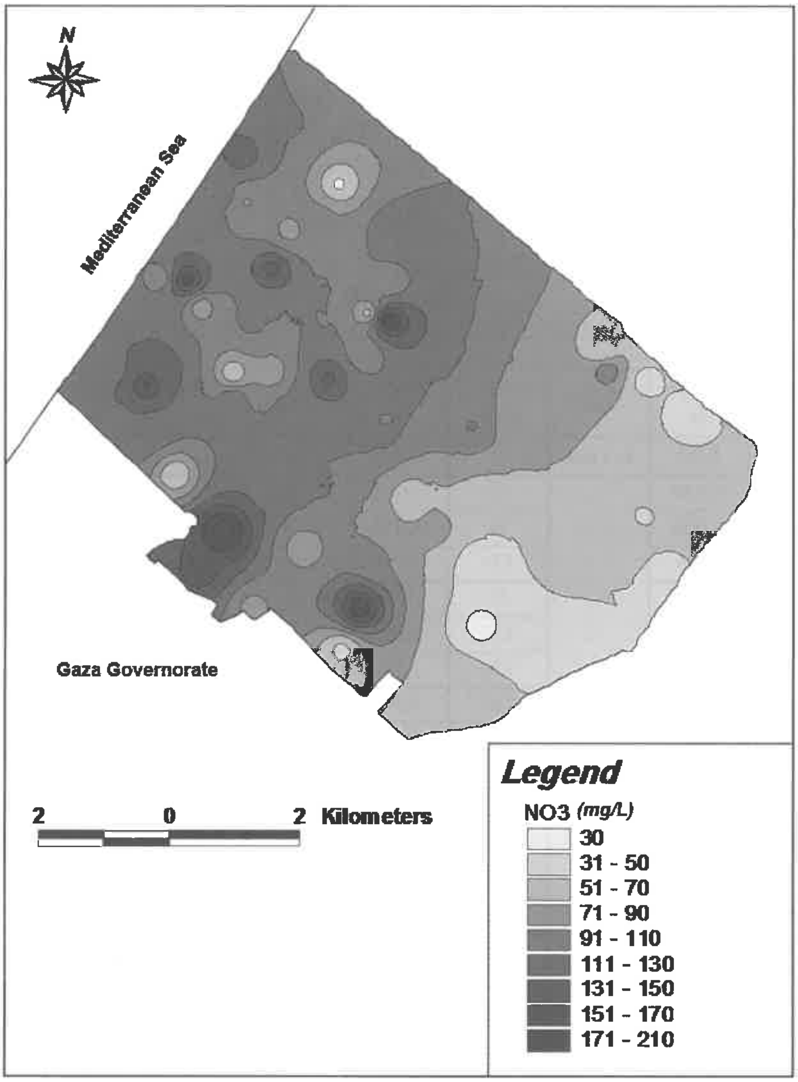

Figure (10) Distribution of NO_3 Concentrations in Groundwater of the North Governorate.

Source: by researcher

6. Soil Texture and $N0_3$ Concentration

Soil properties that affect NO_3 movement include texture and permeability. This is determined by the relative proportions of sand, silt, and clay. Texture affects movement of water through soil, and therefore also movement of dissolved chemicals, such as NO_3. The coarser the soil, like sands, the faster the movement of percolating water. Contaminants move into surface water and groundwater. Dissolved compounds can leach into groundwater supplies. The risks of any of these events occurring are highly dependent on soil texture.

Sandy soils have relatively large spaces among particles, which provide for rapid downward water movement. Substances dissolved in leaching waters are readily transported deep into the soil and potentially to groundwater. Agricultural activities such as fertilizer and pesticide may pose particular risks on sandy soils. Contamination of groundwater may also have long-term impacts on many users of the aquifer. Over-fertilization of sandy crop land with nitrogen may lead to contamination of groundwater by leaching nitrogen. High concentrations of NO_3 in drinking water are known to pose a health risk to infants and immune-suppressed individuals.

NO_3 leaches faster through sands than through soils that have an appreciable amount of silt and clay, such as loamy sands, sandy loams, and sandy clay loams. There is a positive relationship between the percentage of sands (in two Horizons "A" and "B") and NO_3 concentration in groundwater (r= 0.78, and 0.76 respectively), but there is a negative correlation between the percentage of clay and silt, and NO_3 (r= -0.77, and -0.75 for Horizon "A", r= -0.73 and -0.73 for Horizon "B" respectively (Table 4)). It is clear from this correlation that the proportion of sand has a positive effect on the leaching of nitrate in groundwater wells, while the proportions of clay and silt have a negative effect. This means also that No_3 leaches faster through sands than through soils that have an appreciable amount of silt and clay, such as loamy sands, sandy loams, and sandy clay loams.

The average NO_3 concentration in water wells which are located in areas of surface sandy soil is about 128 mg/L. In areas of loamy sand, sandy loam, sandy clay loam, loam, and clay loam, the average is immediately reduced to about 94, 70, 58, 52 and 29 mg/L respectively as a result of decreasing soil permeability, which is responsible for the leaching of water and the leaching of NO_3 to the underground reservoir (Table 5).

Table (4)
Correlation between NO_3 Concentration in Water Wells and Soil Texture

NO_3 Pearson Correlation	Horizon "A"			Horizon "B"		
	Sand	Clay	Silt	Sand	Clay	Silt
	0.783*	- 0.766*	- 0.747*	0.755*	- 0.734*	- 0.727*

* Correlation is significant at the 0.01 level (2 - tailed). *Source: by researcher.*

Table (5)
Averages of NO_3 Concentration in Water Wells and Permeability of Soil Classes

Soil Class	Sand	Loamy Sand	Sandy Loam	Sandy Clay Loam	Loam	Clay Loam
Average of NO_3 (mg/L)	128	94	70	58	52	29
Average of Permeability (cm/h)	12	3.4	1.7	1.2	0.65	0.22

Source: by researcher.

There is also a relationship between the texture of the soil and permeability. A linear regression analysis found a correlation coefficient of $r = 0.75$ between the ratio of sands (in Horizon "A") and permeability. This means that it is quite easy for nitrates to leach into groundwater through soil with a high proportion of sand, while there is less leaching through soil with a low proportion of sand or a high proportion of clay and silt.

7. Conclusions

Based on the results of the study, the following conclusions can be drawn:

- There is considerable variation in the soils in the North Governorate. The major part consists of light or coarse textured soil. Seven different types of soil were recognized and mapped. These vary in texture from sand to clay. Light-textured soils in Horizon "A" (sands, loamy sands, and sandy loams) make up about 67% of the total area, and, in Horizon "B", about 76%. Medium-textured soils (loams and sandy clay loams) in Horizon "A" and Horizon "B" comprise about 33% and 23%, respectively, of the total area. The remainder consists of heavy-textured soils (clay loams and clays) that occur less widely.

- On average, 71.5% of the soils of the two Horizons (A and B) have a relatively high permeability; 28% have low or moderate permeability; and 0.5% have low permeability.
- Almost 94% of the groundwater wells of the North Governorate sampled between 2007 and 2008 showed a NO_3 concentration one to four times higher than WHO standards. Only 6% of the 63 sampled wells were at or below the WHO standard. The highest levels of NO_3 were in Beit Lahia (in the west) and Jabaliah (in the middle). These areas showed average NO_3 concentrations of 123.9 mg/L and 121.6 mg/L, respectively.
- NO_3 can be an environmental pollutant if it is not controlled. Because of the potential for NO_3 in groundwater to cause methemoglobinemia in babies younger than six months, governmental and non-governmental sectors should take immediate actions to solve the nitrate problem by groundwater quality management and to offer the greatest protection to infants. Babies younger than six months should not drink water that exceeds the WHO NO_3 standard.
- There is a positive relationship between the percentage of sands (in two Horizons "A" and "B") and NO_3 concentration in groundwater ($r = 0.78$, and 0.76 respectively). This shows that the proportion of sand has a positive impact on the concentration of nitrate in groundwater wells and there is a correlation between them.
- There is also a relationship between the texture of the soil and permeability ($r = 0.75$ between the ratio of sands, in Horizon "A", and permeability). NO_3 can be a significant groundwater contaminant when applied to a sandy soil rather than when applied to a loamy soil, since $N0_3$ will leach from the soil into the groundwater at a faster rate. This means that it is quite easy for nitrates to leach into groundwater through soil with a high proportion of sand, while there is less

leaching through the soil with a low proportion of sand or a high proportion of clay and silt.

- The average amount of NO_3 concentration in water wells which are located in areas of surface sandy soil was about 128 mg/L. In areas of loamy sand, sandy loam, sandy clay loam, loam, and clay loam, the average is immediately reduced to about 94, 70, 58, 52 and 29 mg/L respectively as a result of the decrease in soil permeability which is responsible for the leaching of water and then the leaching of NO_3 to the underground reservoir.

References

Abu Maila, Y. El-Nahal, I, and Al-Agha, M.. (2004). Seasonal variations and mechanisms of groundwater nitrate pollution in the Gaza Strip. *Environmental Geology*. Springer-Verlag, 47: 84-90.

Aish, A.. (2000). Nitrate pollution and contaminant transport to groundwater resources in Beit Lahia Area, Gaza, Palestine. Unpublished Master's Thesis. Brussels: University of Lueven-Vriji.

Al Hallaq, A. H. and Abu Elaish, B. S.. (2008). Determination of mean areal rainfall in the gaza strip using geographic information system (GIS) Technique. *University of Sharjah Journal of Pure & Applies Sciences*, 5, (2), 105-126.

Al Hallaq, A. H.. (2002). Groundwater resources depletion in Gaza Strip: Causes and effects. (In Arabic). Unpublished Ph.D. dissertation. Cairo: Ain Shams University.

Al Hallaq, A. H.. (2004). Israeli policies in depleting Gaza Strip fresh groundwater. *The Journal of Human Sciences*. University of Bahrain (in press).

Cepuder, P., and Shukla, M.K.. (2002). *Groundwater nitrate in Austria: a Case study in Tullnerfeld" Nutrient Cycling in Agro-ecosystems*, 64: 301-315.

Christopherson, R.. (1992). *Geosystems, An introduction to physical geography*. New York: Macmillan Publishing Company.

De Blij, H. J. and Muller, P. O.. (1993). *Physical geography of the global environment*. New York: John Wiley & Sons.

De Blij, H. J.. (1987). *The Earth, a Physical and human geography*. New York: John Wiley & Sons.

Federal Register, (1975). *National interim primary drinking water standards, Federal Register* 40:59, 566588.

Fernandez-Illescas, C. P., Porporato A., Laio, F., and Rodriguez-Iturbe, I.. (2001). The eco-hydrological role of soil texture in a water-limited ecosystem. *Water Resources Research*, 37, (12), 2863-2872.

Grot, K. R. and Anger, C.. (2005). *Estimation of soil texture using ground penetrating radar ground wave techniques*. American Geophysical Union, Fall Meeting 2005, abstract #H41F-0480, American Geophysical Union (AGU).

Laegreid, M., Bockman, O.C., and Kaarstad, O.. (1999). *Agriculture, Fertilizers and the environment*. Norsk Hydro ASA, Porsgrunn, Norway: CABI Publishing.

Palestinian Central Bureau of Statistics. (1999). *Population, Housing and establishment Census - 1997, Final Results, Housing Report, Governorates of Gaza Strip*. Ramallah: Palestinian Central Bureau of Statistics.

Palestinian Central Bureau of Statistics. (2008). *Population and housing establishment census 2007*. Press Conference on the Preliminary Findings (Population, Buildings, Housing Units and Establishments). Ramallah: Palestinian Central Bureau of Statistics.

Palestinian Central Bureau. (2007). *Agricultural Statistics 2005/2006*. Ramallah: Palestinian Central Bureau of Statistics.

Palestinian Water Authority (PWA). (1999). *Evaluation of monitoring results for the treatment plant in Beit Lahia, Gaza Strip. Palestine*, Gaza: PWA.

Palestinian Water Authority (PWA). (2000). *Coastal aquifer management program: Integrated aquifer management*. 1, Gaza: PWA.

Sharif, F. A.. (2003). Impact of a wastewater treatment facility on well waters in Beit Lahia, Gaza Strip. *Journal of the Islamic University of Gaza*, Gaza: 11, (1), 15-25.

Shomar B, Yahya A, and Müller G.. (2005). *Geochemical characterization of soil and water from a wastewater treatment plant in Gaza. Soil and Sediment Contamination*, 14, 309-327.

Shomar B.. (2006). *Groundwater of the Gaza Strip: Is it drinkable? Environmental Geology*. Springer-Verlag, 50, 743-51.

Skinner, B. J. and Porter, S. C.. (1992). *The dynamic earth: An introduction to physical geology*. New York: John Wiley & Sons, 2nd Edition.

Soil Survey Division Staff. (1993). *Soil survey manual*. Soil Conservation Service, U.S. Department of Agriculture Handbook 18.

United States Department of Agriculture (USDA). (2008). Natural Resources Conservation Service (NRCS). *Soil texture calculator*. <http://soils.usda.-gov/technical/aids/investigations/texture>.

United States Department of Agriculture. (USDA). (1951). *Soil survey manual*. New York: U.S. Dept. Agric. Handbook.

WHO. (2004). *Guidelines for drinking water quality: Recommendations*. 1. Geneva: World Health Organization, 3rd Edition.

Submitted: February 2009
Approved: June 2009

أثر نسيج التربة على تسرب عنصر النترات للمياه الجوفية بمحافظة الشمال-قطاع غزة

أكرم حسن الحلاق*

ملخص: الهدف الرئيس من هذه الدراسة تحديد أثر نسيج التربة على خطورة تسرب النترات إلى آبار المياه الجوفية، وإقامة علاقة إحصائية بين نسيج التربة وتركيز عنصر النترات في مياه محافظة الشمال الجوفية. بينت الدراسة أن ثمة اختلافاً كبيراً في التربة بالمحافظة. الجزء الأكبر من محافظة الشمال يتألف من تربة ذات نسيج خشن أو خفيف. هناك سبعة أنواع مختلفة من التربة مميزة وُقعت على خريطة المحافظة، وتتباين هذه الأنواع في نسيجها من الرمل إلى الطين، وفي نفاذيتها من المعدلات العالية إلى المنخفضة. في المتوسط، 71,5% من التربة في الأفقين "أ" و "ب" لها نفاذية عالية نسبياً، و 28% لها نفاذية قليلة أو معتدلة، و0,5% منخفضة النفاذية. وفيما يتعلق بتركيز النترات، فإن 94% تقريباً من آبار المياه الجوفية بالمحافظة أظهرت تركيزاً للنترات يفوق معايير منظمة الصحة العالمية بمقدار الضعف إلى أربعة أضعاف. كذلك أظهرت الدراسة تأثيرات نسيج التربة على تسرب النترات، فالتربة ذات النسيج الخشن – مثل التربة الرملية – تسمح بتسرب النترات إلى المياه الجوفية بصورة أسرع من التربة ذات النسيج الناعم مثل التربة اللومية الطينية الرملية والتربة اللومية الطينية والتربة الطينية. وهناك علاقة موجبة بين النسبة المئوية للرمل وتركيز النترات في آبار المياه الجوفية؛ حيث بلغ معامل الارتباط 0,78

* قسم الجغرافيا، جامعة الأقصى، غزة، فلسطين.

و 0,76 على التوالي في الأفقين "أ" و "ب". وقد بلغ معدل تركيز النترات في آبار المياه التي تقع بمناطق التربة الرملية السطحية نحو 128 مليجرام/لتر. أما في مناطق التربة الرملية اللومية، والتربة اللومية الرملية، والتربة اللومية الطينية الرملية، والتربة اللومية، والتربة اللومية الطينية، فقد تناقص المعدل إلى نحو 94، 70، 58، 52 و29 مليجرام/لتر على التوالي؛ نتيجة لانخفاض نفاذية التربة المسؤولة عن تسرب المياه، ومن ثم تسرب النترات إلى الخزان الجوفي.

المصطلحات الأساسية: نسيج التربة، نترات، نفاذية، تسرب، محافظة الشمال.