Assessment of Aquifer Vulnerability to Contamination in Khanyounis Governorate, Gaza Strip - Palestine, Using the DRASTIC Model within GIS Environment

تقييم حساسية الخزان الجوفي للتلوث في محافظة خان يونس – قطاع غزة/ فلسطين باستخدام "نموذج دراستيك DRASTIC Model" ضمن بيئة نظم المعلومات الجغرافية

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Abstract

This study aims to: 1) assess the vulnerability of the aquifer to contamination in Khanyounis governorate, 2) find out the groundwater vulnerable zones to contamination in the aquifer of the study area, and 3) provide a spatial analysis of the parameters and conditions under which groundwater may become contaminated by applying the DRASTIC model within GIS environment. The model uses seven environmental parameters: **D**epth of water table, net **R**echarge, **A**quifer media, **S**oil media, **T**opography, **I**mpact of vadose zone, and hydraulic **C**onductivity to evaluate aquifer vulnerability. Based on this model and by using ArcGIS 9.3 software, an attempt was made to create vulnerability maps for the study area. According to the DRASTIC model index and pesticide DRASTIC index, the study has shown that in the western part of the study area the vulnerability to contamination ranges between high and very high due to the shallowness of water table with moderate to high recharge potential, and permeable soils. To the east of the previous part and in the south-eastern part, vulnerability to contamination is moderate.

In the central and the eastern part, vulnerability to contamination is low due to depth of water table. Vulnerability Analysis of the DRASTIC Model indicates that the highest risk of contamination of groundwater in the study area originates from the soil media. The impact of vadose zone, depth to water level, and hydraulic conductivity imply moderate risks of contamination, while net recharge, aquifer media, and topography impose a low risk of aquifer contamination. The coefficient of variation (CV) indicates that a high contribution to the variation of vulnerability index is made by the topography. Moderate contribution is made by the depth to water level, and net recharge, while impact of vadose zone, hydraulic conductivity, soil media, and Aquifer media are the least variable parameters. The low variability of the parameters implies a smaller contribution to the variation of the vulnerability index across the study area. Moreover, the "effective" weights of the DRASTIC parameters obtained in this study exhibited some deviation from that of the "theoretical" weights. Soil media and the impact of vadose zone were the most effective parameters in the vulnerability assessment because their mean "effective" weight was higher than their respective "theoretical" weight.. This explains the importance of soil media and vadose layers in the DRASTIC model. However, it is advised to get the accurate and detailed information on these two specific parameters. The GIS technique has provided efficient environment for analyses and high capabilities of handling large spatial data. Given these results, this model highlights as a tool can be used by national authorities, and decision makers especially in the agricultural areas that use chemicals and pesticides which are most likely to contaminate groundwater resources.

Keywords: Groundwater vulnerability to Contamination, DRASTIC model, GIS, Khanyounis Governorate

ملخص

تهدف هذه الدراسة إلى: ١) تقييم حساسية الخزان الجوفي للتلوث بمحافظة خان يونس (منطقة الدراسة)، ٢) تحديد المناطق الأكثر عرضة للتلوث، ٣) تقدم تحليلاً مكانياً للعوامل، والظروف التي يمكن بموجبها أن تصبح المياه الجوفية ملوثة من خلال تطبيق نموذج "دراستيك DRASTIC" ضمن بيئة نظم المعلومات الجغرافية. ويستخدم هذا النموذج سبعة عوامل

هيدروجيولوجية بيئية هي: عمق مستوى الماء الجوفي، التغذية الصافية، بيئة الخزان الجوفي (جيولوجية الخزان الجوفي)، بيئة التربة، طبوغرافية المنطقة (انحدار السطح)، تأثير المنطقة غير المشبعة بالمياه، ومعامل التوصيل الهيدروليكي، وذلك لتقييم مدى تعرض الخزان الجوفي للتلوث. على أساس هذا النموذج، وباستخدام برنامج ArcGIS 9.3، جرت محاولة لخلق خرائط تبين مواطن حساسية الخزان الجوفي للتلوث بمنطقة الدراسة، ووفقاً لقيم مؤشر نموذج "دراستيك"، أظهرت الدراسة أنه في الجزء الغربي من منطقة الدراسة يتراوح التعرض للتلوث بين المرتفع والمرتفع جداً نظراً لضحالة عمق المياه الجوفية، ومسامية التربة، وإمكانية التغذية العالية نسبياً. أما إلى الشرق من الجزء السابق، وفي الجزء الجنوبي الشرقي، يكون التعرض للتلوث متوسطاً، ومنخفضاً في المنطقة الوسطى، والشرقية نظراً لعمق مستوى المياه الجوفية. ويتبين من تحليل الحساسية لنموذج دراستيك بمنطقة الدراسة، ومن خلال فحص متوسطات تصنيفات العوامل، أن الخطر الأعلى لتلوث المياه الجوفية في منطقة الدراسة ينشأ من عامل بيئة التربة، ويتضمن كل من عامل المنطقة غير المشبعة بالمياه، وعمق مستوى المياه، ومعامل التوصيل الهيدروليكي مخاطر تلوث متوسطة، بينما يفرض كل من عامل التغذية الصافية، وبيئة الخزان الجوفي، والطبوغرافيا خطورة منخفضة على تلوث المياه الجوفية. ويُشير معامل الاختلاف إلى أن المساهمة العالية في تباين مؤشر الحساسية بمنطقة الدراسة كانت من قبل عامل الطبوغرافيا، وكانت المساهمة المعتدلة، أو المتوسطة من قِبل عامل عمق مستوى المياه، والتغذية الصافية، بينما كانت المساهمة الأقل من جانب عامل المنطقة غير المشبعة بالمياه، ومعامل التوصيل الهيدروليكي، وبيئة التربة، وبيئة الخزان الجوفي. وقد أظهرت الأوزان الفعلية لنموذج دراستيك بعض الاختلافات أو الانحرافات عن الأوزان النظرية، فقد كانت بيئة التربة، والمنطقة غير المشبعة بالمياه من أكثر العوامل تأثيراً في تقييم الحساسية لأن متوسط أوزانها الفعلية أعلى من أوزانها النظرية، وهذا يفسر مدى أهمية هاتين الطبقتين في نموذج دراستيك، ولكن يُنصح بالحصول على المعلومات المفصلة والدقيقة لهذين العاملين. لقد وفرت تقنية نظم المعلومات الجغرافية بيئة فعالة للتحليل، والقدرات العالية في التعامل مع الكم الكبير من البيانات المكانية، وبالنظر إلى هذه النتائج، يبرز هذا النموذج كأداة يمكن استخدامها من قبل السلطات الوطنية، وصانعي القرار خاصة في المناطق الزراعية التي تستخدم المواد الكيميائية التي تمثل الاحتمال الأكثر لتلوث موارد المياه الجوفية.

كلمات مفتاحية: حساسية الخزان الجوفي للتلوث، نموذج "دراستيك DRASTIC"، نظم المعلومات الجغرافية، محافظة خان يونس.

1. Introduction

In general in the Gaza Strip, and in particular in Khanyounis governorate, groundwater is a very important source for water supply and development. The quality of groundwater plays an important role in the scarcity problem, especially for drinking water supply. So, it has to be protected from the increasing threat of subsurface contamination. Furthermore, the quality of groundwater is generally under a considerable potential of contamination especially in agriculture-dominated areas with intense activities that involve the use of fertilizers and pesticides (Lake et al., 2003, p.316; Thapinta and Hudak, 2003, p.87; Chae et al., 2004, p.369).

The growth of Khanyounis population has doubled about four times since 1960s. Therefore, the demand of high-quality drinking water is increasing, while the average domestic water consumption is less than 25 cubic meter/capita/year which is one of the lowest rates in the world (Al Hallaq, A. H., 2002, p.153). The intensive utilization of aquifers has changed the groundwater chemical quality. The study of these changes requires the design of monitoring networks. One of the most successful tools for monitoring system has been the use of vulnerability maps. Vulnerability maps have become an ever more essential tool for groundwater protection and environmental management (Vias *et al*., 2005, p.587). These maps could be used for activities such as land use planning, decision making, groundwater resources management and groundwater quality maintenance (Samey, Amina A., and Gang, Chen, 2008, p.502). Maps of aquifer vulnerability to contamination are becoming more in demand because on the one hand groundwater represents the main source of drinking water, and on the other hand high concentrations of human/economic activities, e.g. industrial, agricultural, and household represent real or potential sources of groundwater contamination (Kebera, T., and Zhaohui, L., 2008, p.195).

2. Concept of Groundwater Vulnerability

The concept of groundwater vulnerability to contamination is based on the assumption that the physical environment may provide some degree of protection to groundwater against natural and human impacts with respect to contaminants in the groundwater. The vulnerability of a certain area can be described by the degree of susceptibility of that area to groundwater pollution (Baalousha, H. 2006, p.405).

In 1968 the French Margat was the first one who used the term vulnerability in Hydrogeology, thereafter, the concept was adopted worldwide (Albinet, M. and Margat, J. 1970, p.15). Recently, several propositions have been given by scientists to define groundwater vulnerability, many are quite similar, however, there is not any recognized and accepted common definition that has been developed.

Groundwater vulnerability to contamination is defined in agreement with the conclusion and recommendations of the international conference on " Vulnerability of Soil and Groundwater to Pollution", held in 1987, as "The sensitivity of groundwater quality to an imposed contaminant load, which is determined by the intrinsic characteristics of the aquifer" (Duijvenbooden and Waegening, 1987, p.3).

According to USA National Research Council (NRC), groundwater vulnerability to contamination is the tendency or likelihood for contaminants to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer (NRC, 1993, p.16). As can be inferred from the above definition, groundwater vulnerability is not an absolute or measurable property, but an indication of the relative possibility with which contamination of groundwater resources will occur. This understanding implies a very basic vulnerability concept that all groundwater is vulnerable.

3. DRASTIC Model

DRASTIC model of groundwater vulnerability falls into the category of overlay and an index method, which is one of the most commonly used categorical rating methods and was among the earliest methods used. It was developed by US Environmental Protection Agency (USEPA) which standardized a system for evaluating groundwater pollution potential of hydro-geologic setting (Aller, et. al, 1987, p.43; USEPA, 1993, p.27; Vrba and Zaporozec, 1994, p. 46).

The DRASTIC model is used to prepare a vulnerability map for the area of study. The name DRASTIC is taken from initial letters of seven environmental parameters, (Table 1), used to evaluate intrinsic vulnerability of aquifer systems. These seven parameters are stated in:

(Aller, et al, 1987, p.46; Babiker, I. et Al 2005, p.130; and Baalousha, H., 2010, p. 242).

Table (1): Weights of DRASTIC Parameters

Parameters	DRASTIC Weight
Depth to water table	5
Net Recharge	4
Aquifer Media	3
Soil Media	2
Topography	1
Impact of Vadose Zone	5
Hydraulic Conductivity	3

Source: (Aller, et. Al, 1987, p.46).

- (**D**) **D**epth to water table: The more depth to water, the lesser the chance for the contaminant to reach it as compared to shallow water table.
- (**R**) Net **R**echarge: It represents the total quantity of water that reaches the water table. It is the process through which the contaminants are transported to the aquifer. The more the recharge is, the more vulnerable the aquifer is (Aller et al., 1987, p.44).
- **A**quifer media (geology): It reflects the attenuation characteristic of the aquifer material reflecting the mobility of the contaminants through the aquifer material. For example, the larger the grain size is and more fractures or openings within the aquifer are, the higher the permeability, and thus vulnerability, of the aquifer is.
- (**S**) **S**oil media (texture): Different types of soil have differing water holding capacity and influence the travel time of the contaminants.
- (**T**) **T**opography (slope): It refers to the slope of the land surface. High degree of slope increase runoff and erosion which is composed of the contaminants.

- **I**mpact of vadose zone: It is unsaturated zone above the water table. It reflects the texture of the vadose zone. The texture determines the time of travel of the contaminants through it.
- Hydraulic **C**onductivity: The amount of water percolating to reach the groundwater through the aquifer is influenced by the hydraulic conductivity of the soil media. The higher the conductivity is, the more vulnerable the aquifer is.

This model produces a numerical value called DRASTIC INDEX which is derived from the rating and weights assigned to the parameters used in the model. Using the seven DRASTIC parameters, a numerical ranking system of weights, ranges, and ratings has been devised to evaluate the potential of groundwater contamination (Aller, et. Al, 1987, p.46).

- ***Weights***: A relative parameter value ranging from 1 to 5, where 1 represents the least significant factor and 5 represents the most significant factor (Samey, Amina A., and Gang, Chen, 2008, p.504). DRASTIC model assumes that all the contaminants move vertically downwards with the water and are introduced at the soil surface. A combination of variable weights has been evaluated and based on the results obtained a specific weight has been assigned to each DRASTIC parameter on the basis that each weight determines the relative significance with respect to pollution potential (Table 1).
- ***Ranges:*** Each of the DRASTIC parameter has been divided into either ranges or significant media types that have an impact on contamination potential.
- ***Ratings:*** Each of the DRASTIC parameter is assigned a rating from 1 – 10 based on a range of values, and based on its relative effect on the aquifer vulnerability (Lobo-Ferreira, J. P., 2000, P. 77; and Almasri, 2008, p.580). Ratings are taken from USPEA, 1993 since the ratings depend on the physical character of the parameters which are more or less constant.

Determination of the DRASTIC INDEX value (pollution potential) for a given area involves multiplying each factor rating by its weight and adding together the resulting values. Higher sum values represent a greater potential for pollution or greater vulnerability of the aquifer to contamination. The total impact factor score of the DRASTIC INDEX can be calculated as: (Hammouri, N. and El-Naqa A., 2008, p. 92).

$$\text{DRASTIC Index} = D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w$$

where: D,R,A,S,T,I, and C are the seven hydrogeologic parameters, r = Rating for area being evaluated. (1-10), w = Importance weight for the factor (1-5). The resulting DRASTIC index represents a relative measure of groundwater vulnerability. The higher the DRASTIC index is the greater the vulnerability of the aquifer to contamination is. A site with a low DRASTIC index is not free from groundwater contamination, but it is less susceptible to contamination compared with the sites with high DRASTIC indices. The DRASTIC index can be converted into qualitative risk categories of low, moderate, high, and very high.

4. Objective of Study

This study aims to: 1) assess the vulnerability of the aquifer to contamination in Khanyounis Governorate, 2) find out the groundwater vulnerable zones to contamination in the aquifer of study area, and 3) provide a spatial analysis of the parameters and conditions under which groundwater may become contaminated by applying the DRASTIC model within GIS environment. The model uses seven environmental parameters. Though DRASTIC model was not originally designed as a GIS-based tool, but it can be utilized for such analysis. In this study, an attempt was made to create a vulnerability map for Khanyounis Governorate area in the Gaza Strip, Palestine, based on the DRASTIC model.

5. Area of Study

Khanyounis Governorate is a part of the Gaza Strip, located in the south of the Gaza Strip, (Figure 1), bound by Deir al Balah to the north (9 km distance between Khanyunis and Deir al Balah cities) and Rafah in the south (9 km distance between Khanyunis and Rafah cities). It covers an area of about 111 km2 (about 31% of the Gaza Strip total area). According to the Palestinian Central Bureau of Statistics (PCBS, 2007, Table 2, p.17), the population of Khanyounis in 2007 was 270,979 inhabitants (about 19.1% of the Gaza Strip total population).

The built-up area occupies an area of about 17.57 km2, while the agricultural lands cover an area of about 63 km2. The area is generally flat with topographic elevation ranging from mean sea level (MSL) in the west to about 100 m above MSL in the east (Figure 2). There is a five month period in winter (November-March) with a rainfall surplus. The rest of the year, evaporation greatly exceeds the rainfall. The annual average rainfall in the Governorate is about 300 mm. On an average there are less than 30 rainy days in the year.

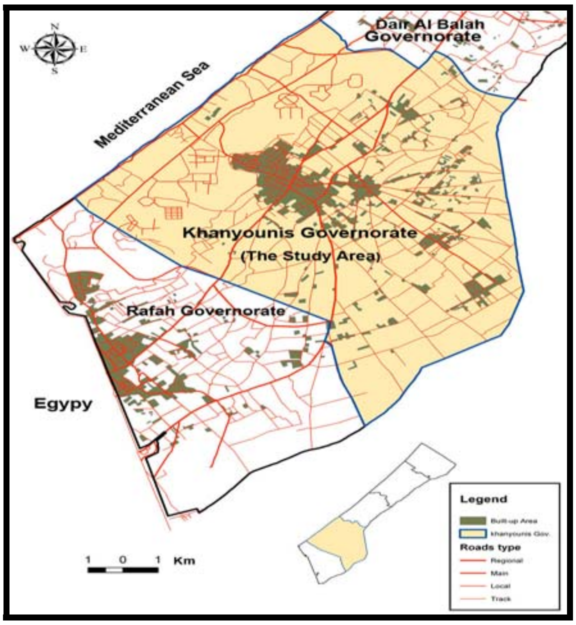

Figure (1) Khanyounis Governorate and its Location in the Gaza Strip (The Study Area). (**Source:** by researchers according to Ministry of Planning unpublished Data).

The aquifer of Khanyounis is a part of the Gaza Strip Pleistocene coastal aquifer. Its average thickness ranges from 60 m in the east to about 140 m at the coastline. The aquifer is mainly composed of gravel, calcareous sandstone, clay and unconsolidated sands (old sand dunes). Near the coast, coastal clays extend about 2-4 km inland, and divide the aquifer sequence into three subaquifers (A, B and C). Towards the east, the clay pinch out and the aquifer is largely unconfined (Palestinian Water Authority (PWA), 2001, p.7). In fact, the natural conditions (Unconfined condition and shallow water table near the coast) allow the entry of contaminants through the surface. So, the groundwater vulnerability will be evaluated for the Pleistocene aquifer. This aquifer represents the most important water bearing formation.

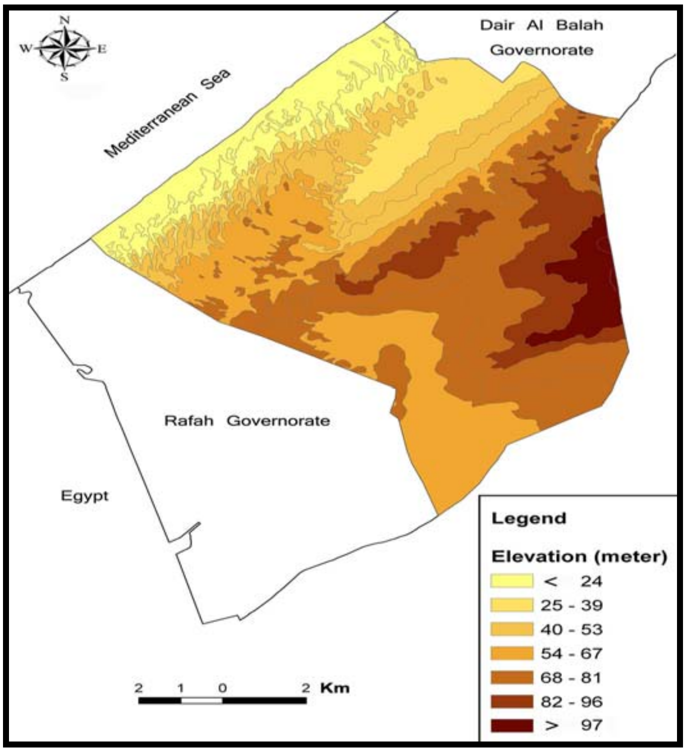

Figure (2): Topography of the Study Area. (**Source:** by researchers according to Ministry of Planning unpublished Data).

6. Methodology and Data

Groundwater vulnerability maps are designed to show areas of greatest potential for groundwater contamination on the basis of hydro-geologic and anthropogenic (human) factors. The maps are developed by using computer mapping hardware and software called a Geographic Information System (GIS) to combine data layers such as soils and depth of water table. Usually, groundwater vulnerability is determined by assigning point ratings to the individual data layers and then adding the point ratings together when those layers are combined into a vulnerability map. The seven maps needed for the DRASTIC model were prepared and built using available hydro-geological data with the help of ArcGIS 9.3. The methodology flow chart is shown in Figure (3).

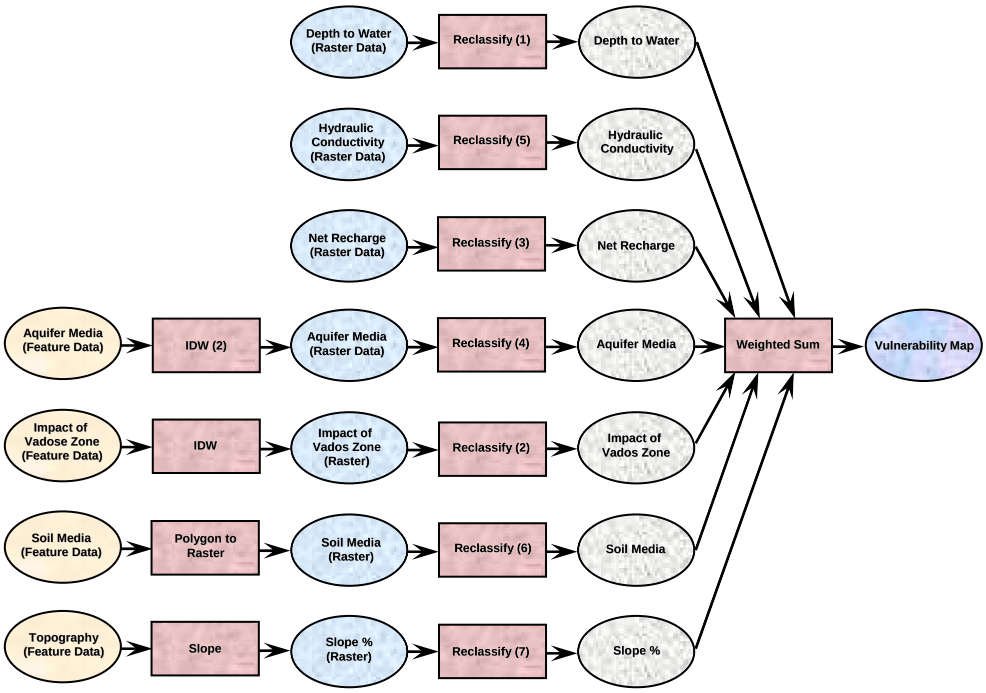

Figure (3) Flow chart for groundwater vulnerability analysis using DRASTIC model in GIS. (**Source:** by researchers).

The required data were obtained from different sources, including the Palestinian Water Authority (PWA), contour map for the study area, Ministry of Agriculture (MOA), and Ministry of Planning and International Cooperation (MOPIC).

7. Results and Discussion

7.1 Depth to Water Table

Depth to water table is a significant parameter of the DRASTIC model controlling the ability of contaminants to reach the groundwater or aquifer. A shallow depth to water table will lead to a higher vulnerability rating.

Depth to water data (for 210 drinking and agricultural water wells) was obtained from a summary of Palestinian hydrologic data report (Appendix 1); vol. 2 Gaza (PWA, 2000, pp.69-474). Depth to water table in the study area varies between 3 m in the west to 96 m in the east. Range values of depth to water table are divided into ten levels from <12 m to depth of >92 m (Table 2 and Figure 4).

Table (2): Range, Rating and Weight for Depth of Water in Khanyounis Aquifer

Range (m)	Percent of Wells	Rating	Index	Area (%)
< 12	24.62	10	50	14.89
13 – 22	1.51	9	45	3.88
23 – 32	11.06	8	40	3.35
33 – 42	11.06	7	35	9.49
43 – 52	11.06	6	30	4.96
53 – 62	14.57	5	25	8.79
63 – 72	10.05	4	20	22.18
73 – 82	9.05	3	15	15.41
83 – 92	5.53	2	10	12.19
> 92	1.51	1	5	4.85
DRASTIC Weight = 5				

Source: by researchers.

The highest rating values are assigned to depth to water levels that are nearer to the surface and more vulnerable to contamination. The weight of depth to water table index (Dr Dw) is at a value of 5 indicating the relative importance of this model element.

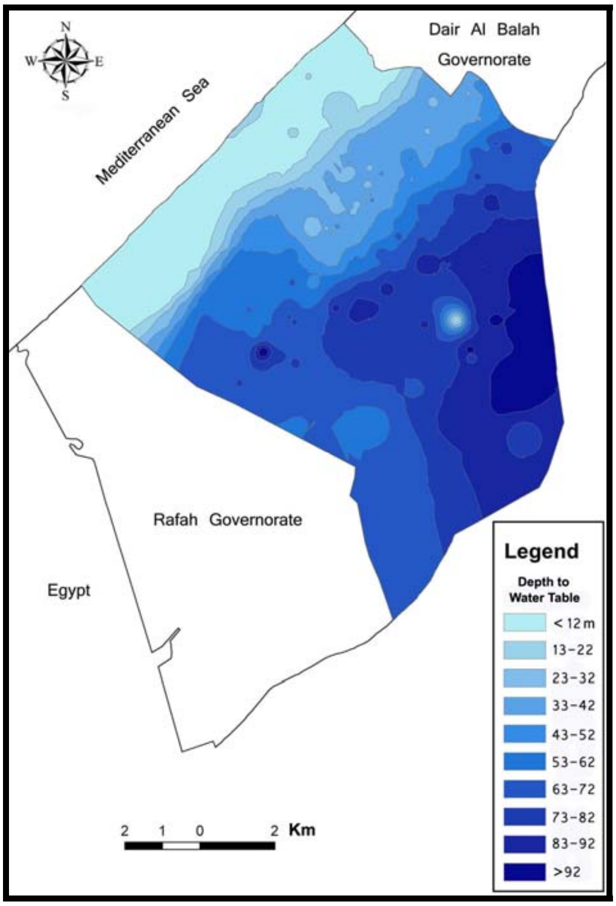

Figure (4): Depth to Water Table Map of the Study Area. (**Source:** by researchers according to PWA data).

The depth to water table index value (Dr Dw) ranges from a value of 5, representing the deepest and least vulnerable water level, to 50, where the water table is near the surface. Whereas the greatest percentage of wells (24.6%) falls within <12 m range and makes up about 15% of the total area, water that is from 63 to 72 m below the surface accounts for over 22% of the total area and the predominant depth to water index value (20) impacting the DRASTIC model. Overall, about 95% of the area has water levels less than 92 m. The deepest water levels, those over 92 m, make up the remaining 5% of the study area. The greatest depth to water values is predominantly found in the east of Khanyouns. In general, the aquifer potential protection increases with depth to water. Piezometric map of the Khanyounis Governorate was used to provide the depth to water map (Figure 4).

7.2 Net Recharge

Net recharge is the total amount of water reaching the land surface that infiltrates into the soil and then continues to percolate through the vadose zone (unsaturated zone) into the groundwater (Ckakraborty, S., et. al, 2007, P. 111), measured in centimeters or inches per year. Recharge represents the primary contaminant transport mechanism into the aquifer and depends on the soil characteristics. A sand or loamy sand will have the maximum infiltration capacity, while clay or clay loam may allow a very small amount of infiltration. The prevailing soils in the study area are sand, sandy loam and loamy sand.

The primary source of groundwater recharge in the study area is rainfall. Rainfall data are derived from Khanyounis climatic station with 27 years records (1980-2007), and they were used for computing net recharge (Ministry of Agriculture, 2008, without page). The annual average rainfall of the study area is 310 mm/year (12.2 inch/year). According to the Isohyetal map of the study area, the average rate of rainfall varies in its value during this period from 295 mm/year in the South to 335 mm/year in the North. Estimation of annual recharge (Appendix 2) was accomplished by using Williams and Kissel's equation (Jha, M. K. and Sebastain, J., 2005, p. 3):

PI = (P – 10.28)2/(P + 15.43) for hydrologic soil gravel and sand.

PI = (P – 15.05)2/(P + 22.57) for hydrologic soil sandy loam and loamy sand.

Where: PI = Percolation index, and P = Annual average rainfall.

As mentioned above, the amount of rainfall that contributes to the net recharge value for the study area is between 295-335 mm. According to the rainfall values, and by using these equations which allow for a minimum and maximum recharge value, the rate of recharge of the study area is ranging between 1.7 mm per year in the south of the study area and 8.8 mm per year in the north. Combining rainfall with soil permeability, rating values are created and used to compute the recharge index value (Rr Rw), and they show recharge variation over the study area using the above recharge equations. An ascending range and rating scale is devised from which an index value can be assigned. The net recharge index is weighted at a value of 4. Table (3) and Figure (5) illustrate the recharge values.

Table (3): Range, Rating and Weight for Net Recharge in Khanyounis Governorate

Range (mm)	Rating	Index	Area (%)
< 2	1	4	13.54
3 – 4	3	12	32.94
5 – 6	5	20	28.98
7 – 8	7	28	17.91
> 8	10	40	6.63
DRASTIC Weight = 4			

Source: by researchers.

The areas of vulnerability for this parameter are identified by recharge index values (Rr Rw) 4 through 40, representing the ranges of recharge vulnerability from lowest to highest respectively. The vulnerability index value 12 represents about 33% of the study area, distributed across all directions of the study area (Figure 5). The higher and the lowest recharge values are mostly associated with soil type and with amount of rainfall. In general, the greater recharge, the greater the potential for groundwater contamination (Piscopo, G. 2001, p.5). These higher recharge areas combined are, nearly, 25% of the total area.

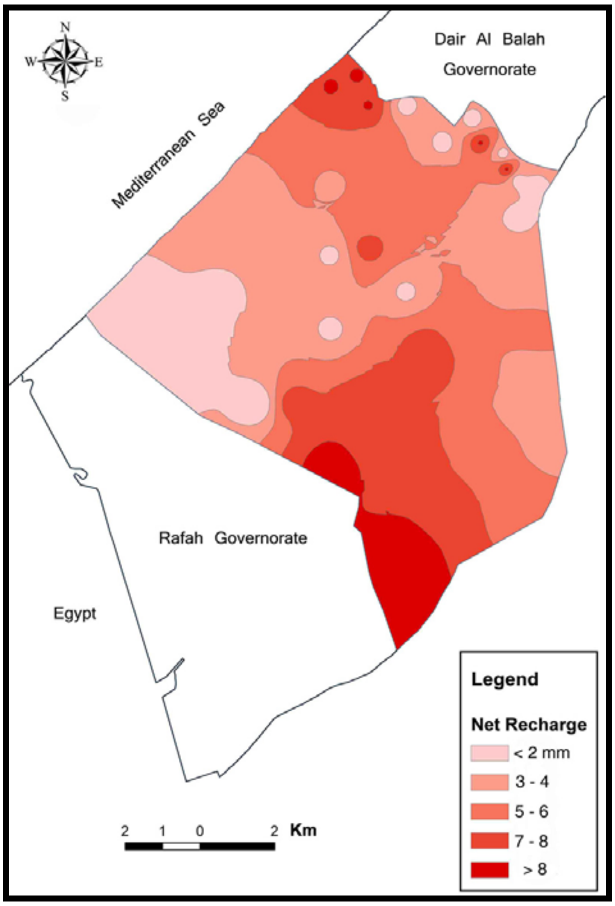

Figure (5): Spatial Distribution of Net Recharge Rate (mm) of the Study Area. (**Source:** by researchers according rainfall and soil texture unpublished data).

7.3 Aquifer Media

The aquifer media has been identified from available geological map and cross-sections of the study area (Appendix 3). The aquifer media refers to the portion of ground capable to yield water in pores or to the saturated zone material properties. Therefore, the aquifer media affect the flow within aquifer which controls the rate of contaminant contact within the aquifer. The higher larger grain size and the more porosity within the aquifer are the higher the permeability is, and thus vulnerability of the aquifer. The aquifer media in the study area comprised mainly of unconsolidated formations such as sand, and consolidated rock such as sandstone (Kurkar). According to DRASTIC standards, the rating of aquifer media in the study area varies between 4 for clay and sandstone, and 5 for sand, sandstone and clay (Table 4). The weight assigned for aquifer media is 3.

Table (4): Range, Rating and Weight for Aquifer Media in Khanyounis Governorate.

Range	Rating	Index	Area (%)
Clay and Sandston	4	12	62.64
Sand, Sandstone and Clay	5	15	37.36
DRASTIC Weight = 3			

Source: by researchers.

The aquifer media index value (Ar Aw) is moderately low (12) in areas comprised of clay and sandstone, and is moderate (15) in the areas with sand, sandstone and clay. The lowest percent of the study area where the aquifer media is partially exposed at the surface consists of sand, sandstone and clay at 37%. Clay and sandstone predominate within the study area and make up about 63% of it (Figure 6). In general, as the index value increases, vulnerability increases.

7.4 Soil Media

Soil media is the upper and weathered portion of the unsaturated zone. The characteristics of the soil influence the amount of recharge infiltrating into the aquifer, the amount of pollutant dispersion and purifying process of contaminant. A number of soil characteristics controls the capacity of contaminants to move into the groundwater. The thickness of soils determines the length of time contaminants reside within the media. The texture and structure influence the rate at which water percolates through the soil profile.

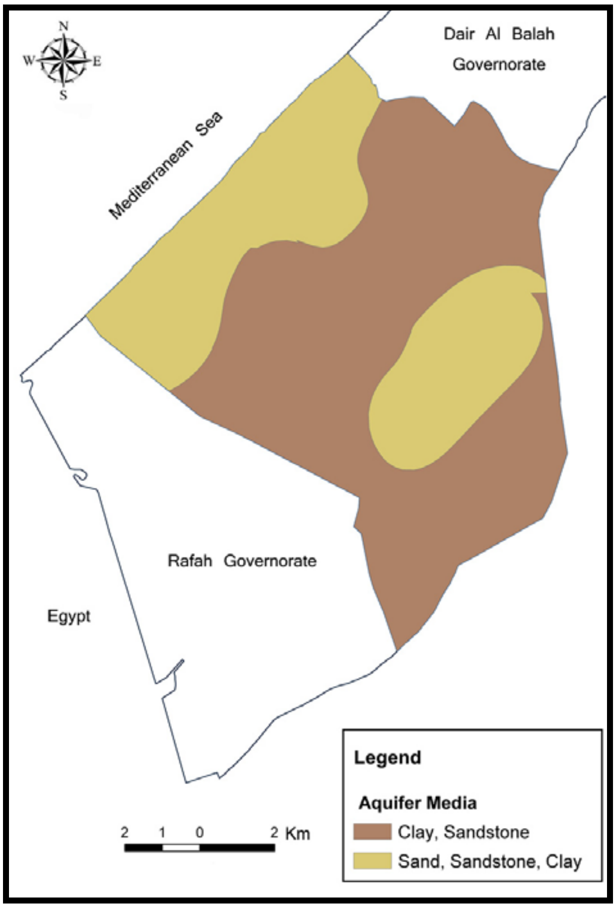

Figure (6): Aquifer Media (Geology) of the Study Area. (**Source:** by researchers according to the data derived from the geological map and hydrological cross-section of the study area).

The soil data of the study area were derived from the results of the mechanical analysis of soil which was done by the central laboratory for soil (Appendix 4) which belongs to the Ministry of Agriculture (Ministry of Agriculture, 2000, without page). This study depended on the results of 36 samples of soil distributed within the study area. Textural classification of a soil type provides the necessary information for evaluating the rating value that is assigned for the range of soil media, reflecting the greatest impact to vulnerability. Referring to soil data for the study area, and according to the United States Department of Agriculture (USDA) texture triangle software which is used to obtain the soil texture class (*USDA, 2008, http://soil.usda.gov/technical/aids/ investigations/texture*), there are three types of soil: sand, sandy loam and loamy sand. The ratings, and DRASTIC weight (2), are used to determine the final index value (Sr Sw). The rating values of soil vary from 9 for sand to 6 for sandy loam and loamy sand (Table 5).

Table (5): Range, Rating and Weight for Soil Media in the Study Area.

Range	Rating	Index	Area (%)
Sand	9	18	54.25
Loamy Sand	7	14	35.13
Sandy Loam	6	12	10.62
DRASTIC Weight = 2			

Source: by researchers.

Sand soil, rated high (18) in terms of the soil media index value is the predominant textural type comprising about 54% of the study area. This soil type can be found along the study area from west to east, but it is particularly prevalent west of it in form of sand dunes. Loamy sand and sandy loam follow at about 35 and 11% respectively with moderate index value (7 and 6). These soil types spread east and southeast of the study area (Figure 7).

7.5 Topography

Topography refers to the slope of the land surface. Topography indicates whether a contaminant will run off or remains on the surface long enough to infiltrate into the groundwater (Aller, L., *et al.*, 1987). Areas with low slope tend to retain water for a longer period of time. This allows greater infiltration or recharge of water and a greater potential for contaminant migration.

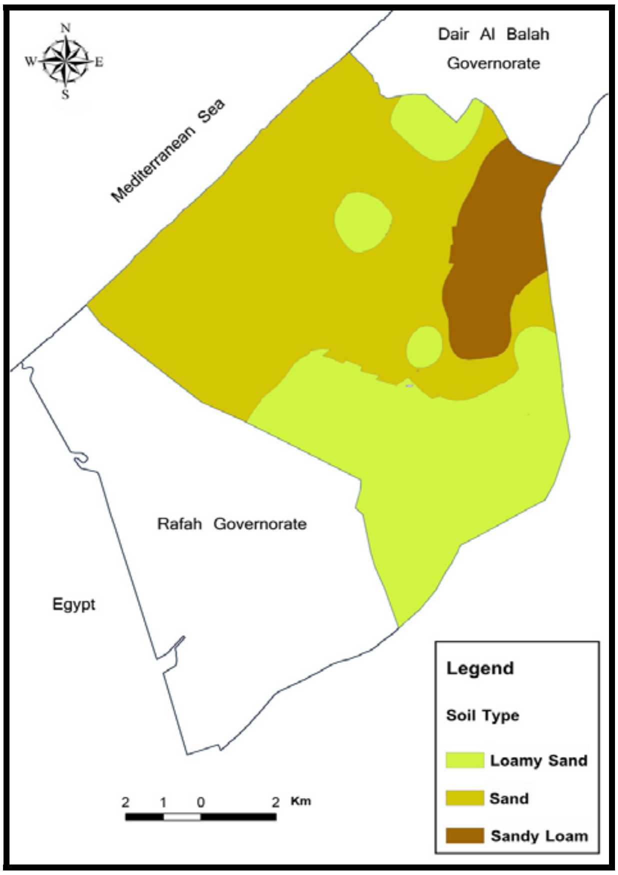

Figure (7): Soil Media of the Study Area. (**Source:** by researchers).

To obtain the slope map, the study used a contour map of the study area, using ArcGIS 9.3 options to obtain the percentage slope map. As mentioned above, the study area is generally flat with topographic elevation ranging from mean sea level (MSL) in the west to about 100 m above MSL in the east. The slope variation in the study is moderate (< 4% to more than 32%), but most of the study area has a gentle slope (Table 6). Flat area was assigned high rate because in flat area the run off rate is less, so there is more percolation of contaminants to the groundwater.

Table (6): Range, Rating and Weight for Topography in the Study Area .

Range (Slope %)	Rating	Index	Area (%)
< 4	10	10	87.860
4 – 7	9	9	3.391
7 – 11	8	8	0.137
11 – 14	7	7	0.015
14 – 18	6	6	2.339
18 - 21	5	5	6.245
21 – 25	4	4	0.003
25 – 28	3	3	0.005
28 – 32	2	2	0.002
> 32	1	1	0.002
DRASTIC Weight = 1			

Source: by researchers.

Ratings corresponding to >32% slope have a value of 1, and for < 4% slope, a value of 10. The DRASTIC weight assigned for topography is (1). At < 4% slope, the greatest potential exists for contaminant infiltration. At > 32% slope, little potential exists for infiltration. Distribution of categories across the study area is divided nearly equally. It is noticed that the < 4% slope range represents about 88% of the study area, while the remaining range categories make up 12% of the area (Figure 8).

The topography index value (Tr Tw) in this case is just as prevalent as the value for less than 4%. So, this area which represents 88% of the study area has more potential for contaminant retention and in turn infiltration of contaminants. The nine categories that comprise the >4 through >32% slope range are distributed throughout the remaining of the study area.

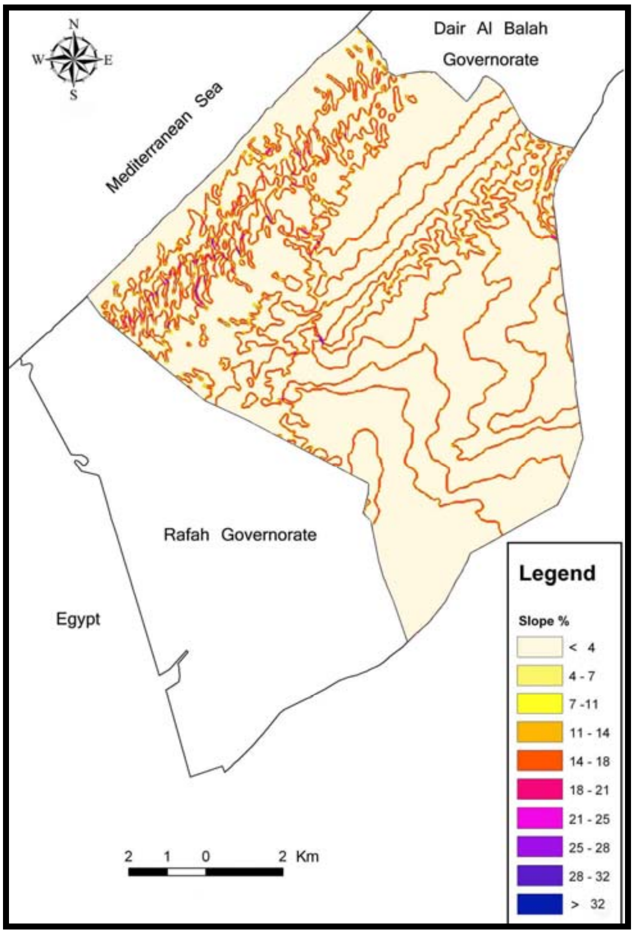

Figure (8): Slope of the Study Area. (**Source:** by researchers according to Ministry of Planning unpublished data).

7.6 Impact of the Vadose Zone Media

Vadose zone is defined as that zone above the water table which is unsaturated or discontinuously saturated, lying between soil layer and water table (Kabera, T. and Zhaohui, L., 2008, p.201). The vadose zone influences aquifer contamination potential; it is essentially similar to that of aquifer media, depending on its permeability and on the attenuation characteristics of the media (Added and Hamza, 2000, p. 9). If vadose zone is highly permeable, then this leads to a high vulnerable rating (Corwin, et al., 1997, p. 2166). The vadose zone has been identified from available geological map and cross-sections of the study area (Appendix 3). The vadose zone is composed of sand, sandstone (Kurkar), and clay (Figure 9). From table (7) the typical ratings, DRASTIC weight (5) is used to determine the final index value (Ir Iw)

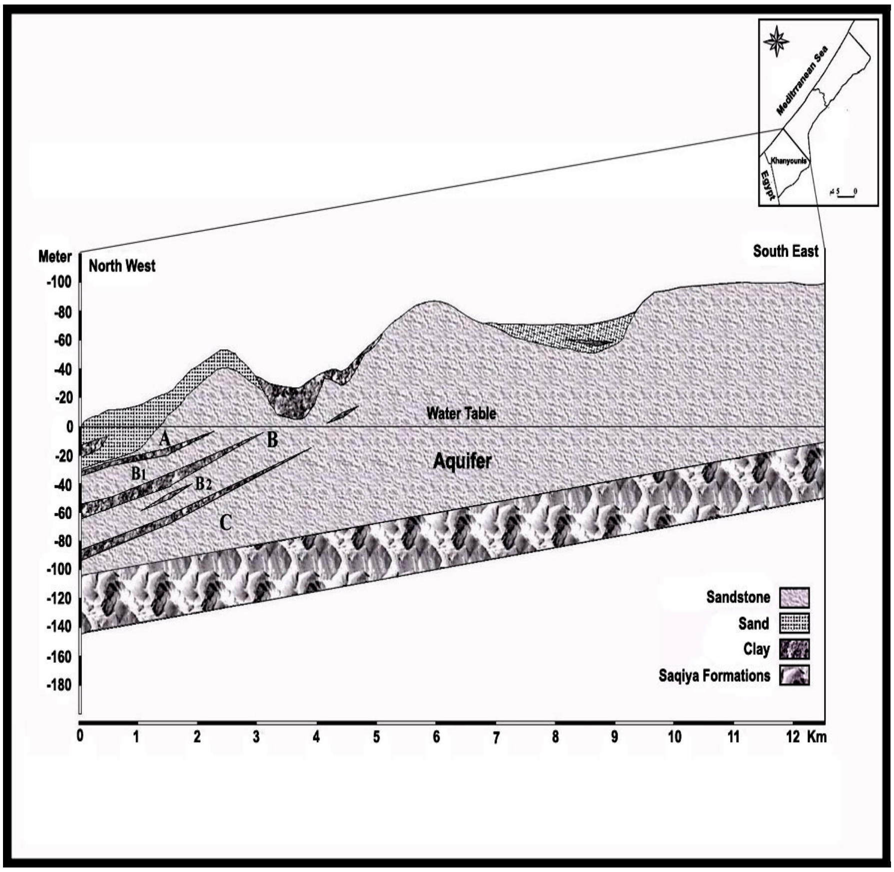

Figure (9): Hydrological Cross-Section of Khanyounis Governorate Aquifer. (**Source:** PWA, 2001, p. 81).

Table (7): Range, Rating and Weight for Vadose Zone in Khanyounis Governorate.

Range	Rating	Index	Area (%)
Clay and Sandstone	4	20	18.51
Sandstone	6	30	49.91
Sand and Sandstone	7	35	31.58
DRASTIC Weight = 5			

Source: by researchers.

The vadose zone media is evaluated with about 50% of the study area controlled by sandstone layer. The sand and sandstone account about 32% of the study area. Clay and sandstone make up the remaining area (about 19%). The sandstone (rating =6), and clay and sandstone (rating =4) are moderate vulnerability index value (Ir Iw) and present the two-thirds of the study area, while the sand and sandstone formations (rating =7) are relatively high vulnerability index value and present about the remaining one-third of the area (Figure 10).

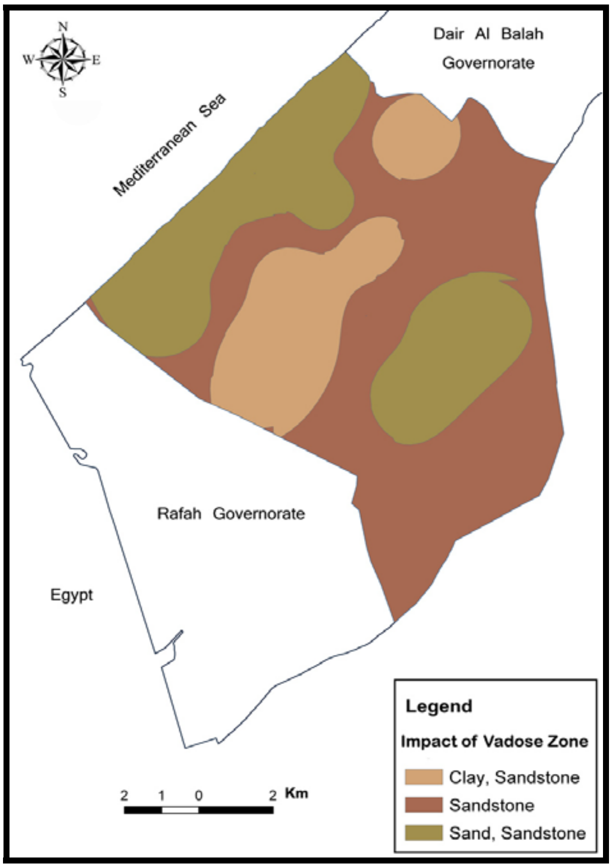

Figure (10): Vadose Zone of the Study Area. (**Source:** by researchers according to the data derived from the geological map and hydrological cross-section of the study area).

7.7 Hydraulic Conductivity

The Hydraulic Conductivity is described in terms of aquifer material and its ability to transmit water for a given hydraulic gradient. The rate of groundwater flow within the aquifer media also controls the rate of contaminant movement. Based on PWA data of coastal aquifer hydraulic properties from existing aquifer test in the Gaza Strip (Appendix 5), the hydraulic conductivity in the study area varies between 40 and 51 m/day

(PWA, 2001, p.9-10). According to DRASTIC standard rating (Aller et al., 1987, p.46), these values fall in the same category and have the same rating. Therefore, a local scale was assigned for the rating as shown in Table (8). A higher rating is indicative of higher hydraulic conductivity. Weighting criteria is 3 for the regular DRASTIC model. The product of rating and weight are the final index value (Cr Cw).

Data show that there are four categories of hydraulic conductivity index values (Cr Cw) for all aquifers. A range of 45-48 (rating =5 and 15) is the most prevalent value covering more than a half of the study area (Figure 11). This is followed by 23.7% of the area ranging from 43-45 m/day (rating =4 and 12). According to the DRASTIC model, high hydraulic conductivity is associated with high contamination potential (Aller, et al., 1987, p.46). In the study area, the hydraulic conductivity index value is moderate (9 and 18)

Table (8): Range, Rating and Weight for Hydraulic Conductivity in Khanyounis Governorate.

Range (m/day)	Rating	Index	Area (%)
40 – 43	3	9	3.06
43– 45	4	12	23.76
45 – 48	5	15	56.76
48 – 51	6	18	16.42
DRASTIC Weight = 3			

Source: by researchers.

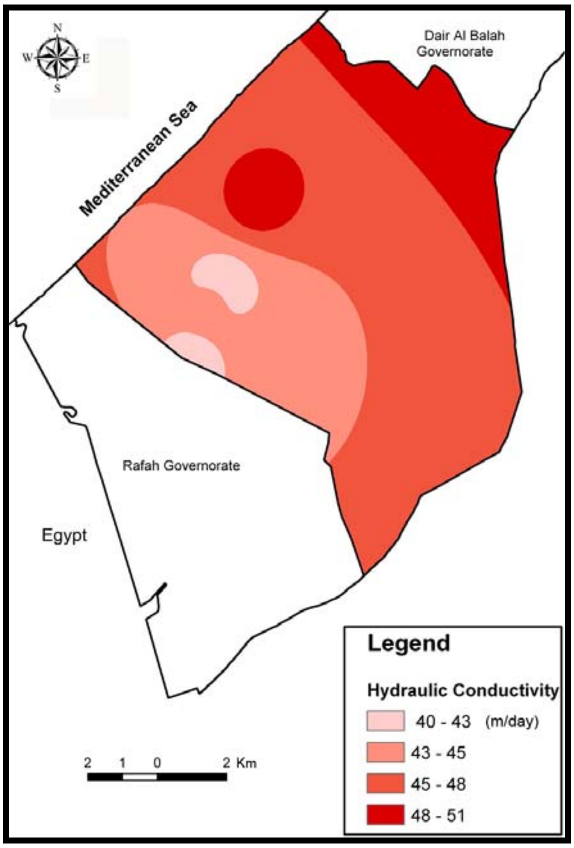

Figure (11): Hydraulic Conductivity of the Study Area. (**Source:** by researchers according to PWA data, 2001 p. 9-10).

8. Aquifer Vulnerability

Aquifer vulnerability analysis was carried out as described in DRASTIC model section. Combining the hydro-geological setting parameters results in a range of numerical values termed the DRASTIC index. Derived by combining the seven DRASTIC parameters index values, a range of values are developed that have been classified to present groundwater vulnerability. Using the DRASTIC model index, a composite layer representing the study area has been created combining the grid files described in Figures 4 through 11 and in Tables 2 through 8.

According to the DRASTIC model index, the aquifer vulnerability ranges from 88 to 190. The values were categorized into four classes. They are low (77-104), moderate (105-130), high (131-156), and very high (157-182) groundwater vulnerability. Table (9) shows the total area covered by each of the class.

Table (9): DRASTIC Index values in Khanyounis Governorate.

DRASTIC Index Value	Area (%)	Vulnerability Zone
77 – 104	27.24	Low
105 – 130	43.44	Moderate
131 –156	26.16	High
157 – 182	3.14	Very High

Source: by researchers.

Figure (12) indicates that in the western part of the study area, the vulnerability to contamination ranges between high (26.16%) and very high (3.14% of the total area). These classes are found in the sand dunes area with moderate-high recharge potential, shallow water table and permeable soils. These areas require a particular attention in regard to future land use decisions. To the east of the previous part and in the south-eastern part, vulnerability to contamination is moderate (43.44%). In the central and the eastern part, vulnerability to contamination is low (27.24% of the total area).

Figure (13) shows the distribution of the nitrate concentration in the study area. Recent monitoring in 51 wells in the study area indicates that nitrates level in about 85% of the total wells exceeded the permissible limit of the WHO Standard (50 mg/l). By comparing DRASTIC map (Figure 12) with nitrate distribution map (Figure 13), it is also found that areas with high nitrate concentration are correlated with high vulnerability areas. It is also clear that the aquifer in the western area is located under the high-risk because of high pollution resulting from: 1) intensive agricultural operations (cultivation of vegetables), in areas of sandy soil where there is an implementing use of large quantities of chemical fertilizers, and 2) extensive use of the septic tanks in the urban area, while the eastern part of the aquifer is less vulnerable to nitrate contamination due to height above sea level, and the depth of the groundwater level, in addition to a lack of intensive agriculture.

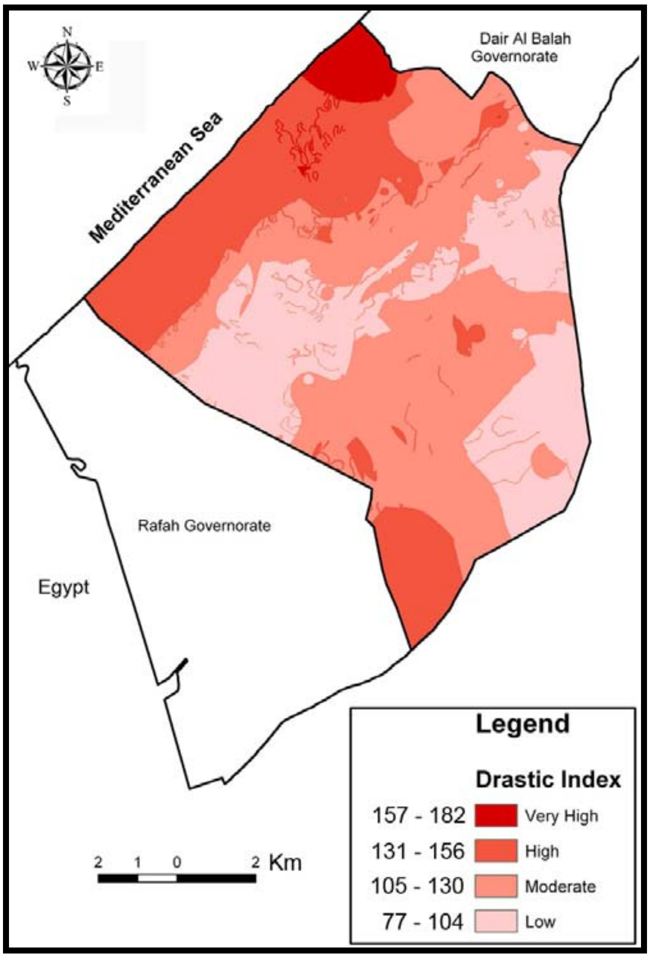

Figure (12): The Map of Vulnerability to Contamination for Khanyounis Governorate. (**Source:** by researchers).

Given these results, the model that has emerged can be used as a tool for making decisions on where agricultural chemical applications pose the greatest potential for contaminating groundwater resources. For example, in these regions, pesticides which might have heavy metals or nitrate-rich groundwater should not be used in the agricultural fields and orchards, since the contaminants may easily leach into the aquifer through the vadose zone. The most critical hydro-geologic parameters that contribute to groundwater vulnerability in this study are a combination of shallow depth to water, high net recharge, soil type and topography with low percent slope.

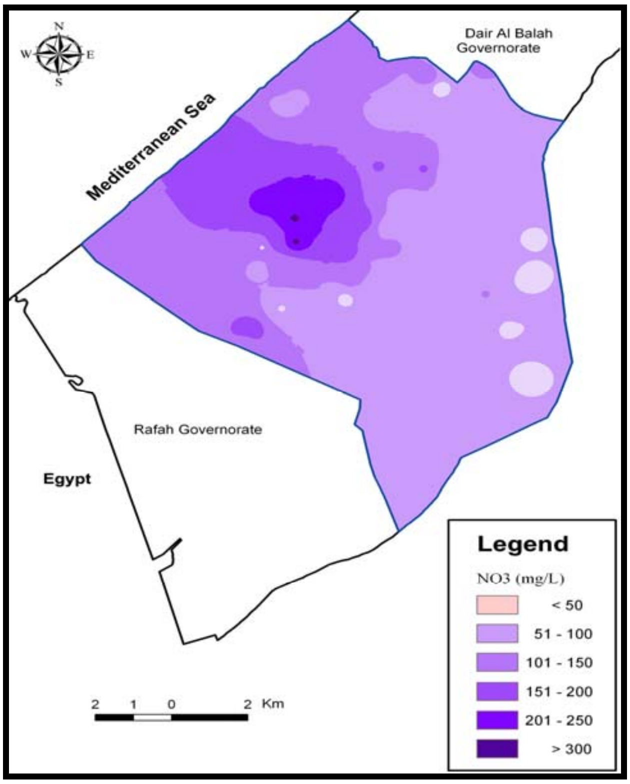

Figure (13): Distribution of the Nitrate Concentration Levels in the Study Area. (**Source:** Drawn by researchers according to PWA and Ministry of Agriculture, unpublished Data).

9. Sensitivity Analysis of the DRASTIC Model

Table (10) presents a statistical summary of the seven rated parameters of the DRASTIC model to workout the vulnerability of groundwater in Khanyounis Governorate. An examination of the means of the parameters reveals that the highest risk of contamination of groundwater in the study area originates from the soil media (mean value is 7.98). The impact of vadose zone, depth to water level, and hydraulic conductivity imply moderate risks of contamination (mean values are 5.95, 5.15, and 4.87 respectively), while net recharge, aquifer media, and topography impose a low risk of aquifer contamination (mean values are 4.49, 4.37, and 1.44 respectively).

Table (10): A statistical summary of the DRASTIC parameter maps.

	D	R	A	S	T	I	C
Minimum	1	1	4	6	1	4	3
Maximum	10	10	5	9	10	7	6
Mean	5.15	4.49	4.37	7.98	1.44	5.95	4.87
SD	2.79	2.37	0.48	1.15	1.33	1.03	0.71
CV (%)	54.17	52.78	10.98	14.41	92.63	17.31	14.58

Source: by researchers.

The coefficient of variation (CV) indicates that a high contribution to the variation of vulnerability index is made by the topography (92.63%). Moderate contribution is made by the depth to water level (54.17%), and net recharge (52.78%), while impact of vadose zone (17.31%), hydraulic conductivity (14.58%), soil media (14.41%), and Aquifer media (10.98%) are the least variable parameters. The low variability of the parameters implies a smaller contribution to the variation of the vulnerability index across the study area.

10. Single Parameter Sensitivity Analysis

The single parameter sensitivity measure was developed to evaluate the impact of each of the DRASTIC parameter on the vulnerability index. The single parameter sensitivity analysis is normally used to compare the "theoretical" weight of each input parameter in each polygon with their "effective" weight assigned by the analytical model. The "effective" weight is a function of the value of the single parameter with regard to the other six parameters as well as the weight assigned to it by the DRASTIC model (Rahman, 2007, p. 51). The "effective" weight of each polygon is obtained using the following formula (Hasiniaina, F., et al., 2010, p. 75):

$$W = 100 * (PrPw / V)$$

Where W refers to the "effective" weight of each parameter, Pr and Pw are the rating value and weight of each parameter, and V is the overall vulnerability index.

The "effective" weights of the DRASTIC parameters obtained in this study exhibited some deviation from that of the "theoretical" weights. Table (11) reveals that the soil media and the impact of vadose zone were the most effective parameters in the vulnerability assessment because their mean "effective" weight, 13.5% and 25.1%, respectively, were higher than their respective "theoretical" weight.

Table (11): Statistics of the single parameter sensitivity analysis.

Parameter	Theoretical Weight	Theoretical Weight (%)	Effective Weight (%)	SD
			Mean	
D	5	21.7	21.7	13.93
R	4	17.4	15.1	9.46
A	3	13.0	11.1	1.45
S	2	8.7	13.5	2.30
T	1	4.3	1.2	1.33
I	5	21.7	25.1	5.13
C	3	13.0	12.3	2.13

Source: by researchers.

The depth to water table showed that its "effective" weight (21.7%) and its "theoretical" weight (21.7%) were equal. The rest of the parameters exhibit lower "effective" weights compared to the "theoretical" weights. The significance of soil media and vadose zone layers highlights the importance of obtaining accurate, detailed, and representative information about these factors.

11. Conclusion

In this paper, an attempt has been made to assess groundwater vulnerability to contamination in Khanyounis Governorate. This task was accomplished using DRASTIC model. Based on the vulnerability analysis and according to DRASTIC index values, it was found that about 26% and 3% of the study area is under high and very high vulnerability of groundwater contamination, respectively, while more than 43% and 27% of the study area can be classified as an area of moderate and low, respectively, vulnerability of groundwater contamination.

It is noticed that the western part of the study area was dominated by high and very high vulnerability classes, while the east of the previous part and in the south-eastern part, vulnerability to contamination is moderate. In the central and the eastern part, vulnerability to contamination is low. In these regions, pesticides which might have heavy metals or nitrate-rich groundwater should not be used in the agricultural fields and orchards, since the contaminants may easily leach into the aquifer through the vadose zone.

The study also showed that the highest risk of contamination of groundwater in the study area originates from the soil media (mean value is 7.98). The impact of vadose zone, depth to water level, and hydraulic conductivity imply moderate risks of contamination (mean values are 5.95, 5.15, and 4.87 respectively), while net recharge, aquifer media and topography impose a low risk of aquifer contamination (mean values are 4.49, 4.37, and 1.44 respectively).

The single parameter sensitivity analysis has indicated that the soil media and the impact of vadose zone were the most effective parameters in the vulnerability assessment. The significance of soil media and vadose zone layers highlights the importance of obtaining accurate, detailed, and representative information about these factors.

The GIS technique has provided an efficient tool for assessing and analyzing the vulnerability to groundwater contamination. The study suggests that this model can be an effective tool for local authorities, water authority and decision makers who are responsible for managing groundwater resources.

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Appendix (1)

Depth to Water Table in Khanyounis Governorate

Well ID	Well Coordinates		Depth (M)	Well No	Well Coordinates		Depth (M)
	E	N			E	N	
L/8	86254	86212	40.03	L/166	79800	85050	9.30
K/10	86850	88280	30.00	L/167	79900	85330	10.00
K/9	81624	88240	50.00	L/168	85120	89440	10.00
L/10	85660	85630	40.00	L/169	84300	88300	20.00
L/100	84140	89300	9.38	L/17	85100	86070	29.00
L/101	84806	89100	4.19	L/170	83080	82780	60.00
L/102	84870	89300	10.00	L/171	86340	80600	67.30
L/103	84630	89500	10.00	L/172	81570	81440	60.00
L/104	84670	89670	10.00	L/173	86680	87500	30.00
L/106	83370	82940	55.00	L/174	86570	86900	35.80
L/107	83620	83120	51.50	L/18	85277	85822	32.20
L/108	84600	86380	30.00	L/19	85190	85670	50.00
L/109	80540	86050	10.00	L/2	86670	86810	39.00
L/110	82650	88080	9.80	L/20	85050	85750	30.00
L/111	82690	88000	9.80	L/21	85050	85600	30.00
L/112	82720	87840	10.00	L/22	85090	85560	32.40
L/113	82920	87800	10.00	L/23	84820	85550	30.00
L/114	85160	85800	30.50	L/24	84260	85400	28.00
L/115	83200	82780	60.50	L/26	84250	84930	50.00
L/116	84220	89820	10.00	L/27	84230	84900	30.00
L/117	84380	89700	10.00	L/28	84180	84770	30.00
L/118	84700	89440	10.00	L/29	84560	84730	35.00
L/119	84460	89660	9.90	L/3	86100	87450	32.30
L/12	82800	81080	61.00	L/30	84700	84770	35.00
L/120	84560	89100	10.00	L/31	84210	84080	37.93
L/121	84520	88880	10.00	L/32	84780	84120	50.00
L/122	84040	89140	10.00	L/33	84690	83920	53.30

Well ID	Well Coordinates		Depth (M)	Well No	Well Coordinates		Depth (M)
	E	N			E	N	
L/124	83340	89000	8.80	L/34	84950	83360	70.00
L/125	84260	89030	10.10	L/35	85120	82780	80.00
L/126	83070	87520	14.60	L/37	84880	82890	80.00
L/128	84220	82780	80.00	L/39	84500	82250	76.00
L/13	85620	84900	40.00	L/4	86220	86760	50.00
L/130	86610	86580	40.00	L/42	83630	84900	25.00
L/131	84290	89360	10.00	L/43	83063	83461	59.87
L/132	83400	88660	10.00	L/44	83600	83420	45.00
L/133	84000	84900	30.00	L/45	82600	83450	50.00
L/134	84480	84580	40.20	L/46	82400	83050	50.00
L/135	84060	84530	33.80	L/47	82609	82590	63.02
L/136	84700	85340	30.00	L/48	82420	82650	50.00
L/137	82680	82620	58.80	L/49	81880	82560	50.00
L/139	81800	82000	60.00	L/50	81800	82540	60.00
L/14	85550	85150	49.00	L/51	82040	82140	55.00
L/140	81920	82720	60.00	L/52	82680	81960	59.50
L/141	83840	82720	61.30	L/53	82980	82550	70.00
L/142	83620	81080	62.50	L/54	83130	82400	70.00
L/143	82790	82270	61.90	L/57	84369	81663	70.28
L/144	83540	78990	60.00	L/59	83500	79220	60.00
L/145	83400	78560	60.00	L/6	85750	86630	35.00
L/15	85450	86370	41.00	L/61	83310	78720	58.74
L/150	84760	82580	80.00	L/62	83200	78700	60.00
L/161	84060	88900	10.00	L/63	83270	78850	60.00
L/162	83600	88860	10.00	L/65	82960	79350	50.00
L/163	83600	88840	10.00	L/66	82716	79914	61.71
L/164	85870	78800	60.00	L/67	83160	80900	60.00
L/165	85240	79700	54.50	L/68	83150	81250	70.00

Appendix (1) Continued

Well ID	Well Coordinates		Depth (M)	Well No	Well Coordinates		Depth (M)
	E	N			E	N	
L/69	82700	81380	70.00	N/7	89263	83503	93.19
L/7	85950	86420	40.00	N/9	87833	81624	96.00
L/70	82300	81600	96.10	O/1	89210	80320	90.00
L/71	81870	80730	60.00	O/3	89230	79400	70.00
L/72	81700	80750	70.00	P/28	78450	83160	10.00
L/73B	78400	83800	10.00	P/29	77860	83660	10.00
L/74	78885	83657	9.05	T/10	88480	87180	70.00
L/75	78860	84350	6.30	T/11	88330	87180	60.40
L/76	79320	84720	3.00	T/12	88250	87100	55.00
L/77	79500	84750	10.00	T/13	88080	86830	64.70
L/78	79250	84950	8.40	T/14	87740	87440	45.00
L/79	79440	85000	10.00	T/15	87279	87444	35.63
L/80	79740	84920	9.80	T/16	87360	86860	45.00
L/81	79750	85130	6.70	T/17	87350	86780	48.30
L/84	80630	85650	10.00	T/18	86940	86680	41.00
L/86	82244	84659	47.72	T/19	87300	86570	48.00
L/87	83040	84201	52.54	T/2	89000	88980	41.00
L/88	81404	86784	5.38	T/20	87470	86320	50.00
L/9	86420	85750	50.00	T/21	88000	86300	70.00
L/91	81910	87450	10.00	T/22	88338	85644	82.03
L/92	82200	87570	9.60	T/23	87560	85650	75.00
L/93	82650	88240	10.00	T/24	87500	84840	75.00
L/94	83066	88152	5.34	T/26	87081	85664	66.10
L/95	82810	87850	10.00	T/27	86600	85350	62.00
L/96	83030	87670	10.30	T/28	86470	85500	60.00
L/97	83500	88970	15.00	T/29	89300	89010	44.70
L/98	83825	89089	6.56	T/3	88000	89000	30.00
M/1	85440	84240	62.60	T/30	87910	86930	61.40
M/10	85880	84720	61.00	T/32	87400	87870	33.80

Well ID	Well Coordinates		Depth (M)	Well No	Well Coordinates		Depth (M)
	E	N			E	N	
M/3	85580	83300	80.00	T/33	87600	88140	33.30
M/4	85480	82120	70.00	T/34	87620	88040	34.80
M/5	86600	82340	78.80	T/35	87950	88050	40.10
M/7	86480	83000	69.50	T/36	88860	88840	41.30
M/8	86608	84010	85.58	T/38	87770	88530	30.20
M/9	86490	84540	70.00	T/39	87250	87560	36.70
N/1	88000	83950	80.00	T/4	88090	88780	50.00
N/10	87850	81500	70.00	T/6	88322	88117	44.16
N/11	88800	80730	90.41	T/7	89100	87950	61.00
N/12	88701	80357	92.48	T/8	88080	87840	40.00
N/13	88010	80490	82.00	T/9	88757	87070	72.78
N/14	87350	79750	80.00	N/21	87450	82450	10.00
N/15	88570	81850	80.00	N/22	88050	81820	79.97
N/16	88941	81123	91.62	N/23	86899	81551	71.77
N/17	89030	82150	91.00	N/24	88270	82900	85.70
N/18	89120	82270	91.00	N/3	88130	83950	88.00
N/19	88450	82450	90.30	N/5	87922	83467	77.68
N/2	88000	84050	80.30	N/6	88198	83205	84.20
N/20	88070	82520	80.00	L/157	85140	85680	32.30
L/151	85840	85020	51.50	L/16	85340	85850	32.37
L/156	85150	86520	30.00	L/160	84040	88900	10.00

Source: PWA, 2000, pp. 69-474.

Appendix (2)

Net Recharge in Khanyounis Governorate

No.	Point Coordinates		Rainfall (Inch)	Soil Texture	Recharge (mm/year)
	E	N			
1	83000	81000	12.00	Loamy Sand	6.835
2	85000	81000	12.00	Loamy Sand	6.835
3	84000	79300	11.61	Loamy Sand	8.794
4	85000	80000	12.00	Loamy Sand	6.835
5	86000	79000	12.00	Loamy Sand	6.835
6	87000	78000	12.00	Loamy Sand	6.835
7	86000	77000	11.61	Loamy Sand	8.794
8	86000	75000	11.61	Loamy Sand	8.794
9	89000	78000	12.40	Loamy Sand	5.101
10	88000	80000	12.40	Loamy Sand	5.101
11	86800	82100	12.00	Loamy Sand	6.835
12	86500	82500	12.00	Loamy Sand	6.835
13	85000	85200	12.00	Loamy Sand	6.835
14	85000	86000	12.40	Loamy Sand	5.101
15	90000	80000	12.80	Loamy Sand	3.635
16	89000	81000	12.80	Loamy Sand	3.635
17	89000	82000	12.80	Loamy Sand	3.635
18	86000	89000	13.19	Loamy Sand	2.457
19	87000	88000	13.19	Loamy Sand	2.457
20	87800	88600	13.19	Loamy Sand	2.457
21	82000	86900	12.40	Sand	4.102
22	81000	86000	12.40	Sand	4.102
23	79000	84000	12.00	Sand	2.739
24	81000	84000	12.00	Sand	2.739
25	80000	82000	11.61	Sand	1.662
26	82000	81000	11.61	Sand	1.662
27	84000	83000	12.00	Sand	2.739

No.	Point Coordinates		Rainfall (Inch)	Soil Texture	Recharge (mm/year)
	E	N			
28	86000	84000	12.00	Sand	2.739
29	84000	85000	12.00	Sand	2.739
30	84000	86900	12.40	Sand	4.102
31	87000	86900	12.80	Sand	5.714
32	89000	83000	12.80	Sand	5.714
33	82000	87000	12.40	Sand	4.102
34	83000	88000	12.80	Sand	5.714
35	85000	88000	12.80	Sand	5.714
36	84000	89500	13.19	Sand	7.515
37	84700	89800	13.19	Sand	7.515
38	85000	89000	13.19	Sand	7.515
39	88700	87300	13.19	Sand	7.515
40	88000	88000	13.19	Sand	7.515
41	88000	82000	12.40	Sandy Loam	5.101
42	88000	83000	12.40	Sandy Loam	5.101
43	88900	84000	12.80	Sandy Loam	3.635
44	89000	85000	12.80	Sandy Loam	3.635
45	89000	86000	13.19	Sandy Loam	2.457
46	89400	86800	13.19	Sandy Loam	2.457
47	89000	87000	13.19	Sandy Loam	2.457
48	88600	87700	13.19	Sandy Loam	2.457

Source: by researchers using Williams and Kissel's equation**.**

Appendix (3)

Formations of Aquifer Media and Vadose Zone in Khanyounis Governorate

No.	Point Coordinates		Aquifer Media	Vadose Zone
	E	N		
1	82000	87000	Sand, sandstone and clay	Sand and sandstone
2	84000	86000	Sand, sandstone and clay	Sand and sandstone
3	80000	85000	Sand, sandstone and clay	Sand and sandstone
4	84000	89000	Sand, sandstone and clay	Sand and sandstone
5	80000	83000	Sand, sandstone and clay	Sand and sandstone
6	85000	85000	Clay and sandstone	Clay and sandstone
7	83000	84000	Clay and sandstone	Clay and sandstone
8	82000	82000	Clay and sandstone	Clay and sandstone
9	86000	88000	Clay and sandstone	Clay and sandstone
10	83000	82000	Clay and sandstone	Clay and sandstone
11	86000	84000	sandstone	Sandstone
12	85000	83000	sandstone	Sandstone
13	84000	82000	sandstone	Sandstone
14	83000	81000	sandstone	Sandstone
15	87000	83000	Sand, sandstone and clay	Sand and sandstone
16	87000	82000	Sand, sandstone and clay	Sand and sandstone
17	86000	81000	Sand, sandstone and clay	Sand and sandstone
18	88300	81700	Sand, sandstone and clay	Sand and sandstone
19	89000	81000	sandstone	Sandstone
20	90000	80000	sandstone	Sandstone
21	89000	79000	sandstone	Sandstone

Source: Data of Formations Aquifer Media and Vadose Zone are derived by researcher through the use of the geological map and cross-sections of the study area.

Appendix (4)

Soil Texture in Khanyounis Governorate

No.	Sample Coordinates		Sand %	Clay %	Silt %	Soil Texture
	E	N				
1	89210	80320	90	6	4	Sand
2	87684	83506	75	10	15	Sandy Loam
3	85580	83300	88	4	8	Sand
4	85880	84720	93	4	3	Sand
5	89230	79400	83	7	10	Loamy Sand
6	89200	80310	87	7	6	Loamy Sand
7	89205	80300	84	8	8	Loamy Sand
8	89120	82270	84	8	8	Loamy Sand
9	88450	82450	77	13	10	Sandy Loam
10	84820	85550	86	5	9	Loamy Sand
11	82300	81600	94	2	4	Sand
12	83160	80900	88	6	6	Loamy Sand
13	83630	84900	91	4	5	Sand
14	85580	83000	93	5	2	Sand
15	86600	82340	82	9	9	Loamy Sand
16	85240	79700	85	8	7	Loamy Sand
17	87450	82450	76	14	10	Sandy Loam
18	85440	84240	90	6	4	Sand
19	86850	88280	90	3	7	Sand
20	85120	89440	85	1	14	Loamy Sand
21	85880	86900	89	1	10	Sand
22	85570	87460	89	5	6	Sand
23	86462	88592	90	5	5	Sand
24	84700	89440	84	7	9	Loamy Sand
25	83400	88600	92	4	4	Sand
26	83070	87520	93	4	3	Sand

No.	Sample Coordinates		Sand %	Clay %	Silt %	Soil Texture
	E	N				
27	82450	86250	93	3	4	Sand
28	81150	85100	94	4	2	Sand
29	78140	83440	93	5	2	Sand
30	79500	84750	92	4	4	Sand
31	81050	85770	88	4	8	Sand
32	80947	81867	93	4	3	Sand
33	82600	83450	91	4	5	Sand
34	85870	78800	92	5	3	Sand
35	88757	87070	85	6	9	Loamy Sand
36	88338	85644	78	12	10	Sandy Loam

Source: Soil data of the study area were derived from the results of the mechanical analysis of soil which was done by the central laboratory for soil which belongs to the Ministry of Agriculture**.**

Appendix (5)

Data of Hydraulic Conductivity Data in the Gaza Strip

Well ID	Well Coordinates		K (m/day)
	E	N	
L/159A	82678	85082	50
P/124	77598	79414	55
C/128	106477	104891	20
A/180	102459	107032	120
R/162L	98442	104037	70
A/188	104500	108400	38
C/79	105350	105200	30
D/73	101700	107130	20.5
E/1	103290	104970	47.5
R/162E	98300	104370	58.5

Well ID	Well Coordinates		K (m/day)
	E	N	
R/272B	98944	98747	75
R/272C	99045	99024	72
F/191	95100	98800	83
G/50	93150	98200	27
G/49	91500	96500	38
S/71	92350	91200	55.5
L/181	81400	82400	43.5
L/182	81700	82850	40
P/145	79400	80250	50
P/147	80100	80250	36

Source: PWA, 2001, P. 9-10

Appendix (6)

Nitrate Concentration in Water Wells in Khanyounis Governorate

Well ID	Well Coordinates		No3 (mg/l)	Well No	Well Coordinates		No3 (mg/l)
	E	N			E	N	
K/10	86850	88280	26	L/88	81404	86784	167
K/14	86560	88580	121	L/9	86420	85750	155
L/10	85660	85630	117	L/93	82650	88240	114
L/101	84806	89100	129	L/95	82810	87850	74
L/133	84000	84900	225	M/10	85880	84720	67
L/138	82160	82600	65	M/2A	85555	83909	56
L/176	82187	83277	97	M/3	85580	83300	112
L/179	85570	87460	80	M/4	85480	82120	57
L/18	85277	85822	156	M/7	86480	83000	59
L/32	84780	84120	186	M/8	86608	84010	53
L/35	85120	82780	99	N/11	88800	80730	33
L/39	84500	82250	111	N/16	88941	81123	60

Well ID	Well Coordinates		No3 (mg/l)	Well No	Well Coordinates		No3 (mg/l)
	E	N			E	N	
L/41	84346	83161	190	N/18	89120	82270	35
L/43	83063	83461	257	N/19	88450	82450	59
L/45	82600	83450	189	N/22	88050	81820	103
L/47	82609	82590	101	N/23	86899	81551	67
L/48	82420	82650	114	N/24	88270	82900	54
L/53	82980	82550	115	N/7	89263	83503	48
L/57	84369	81663	37	O/1	89210	80320	85
L/68	83150	81250	78	O/3	89230	79400	40
L/69	82700	81380	45	P/51	81750	80350	134
L/71	81870	80730	194	T/22	88338	85644	50
L/73B	78400	83800	114	T/26	87081	85664	59
L/84	80630	85650	150	T/3	88000	89000	112
L/86	82244	84659	217	T/6	88322	88117	96
L/87	83040	84201	255	--	--	--	--

Source: PWA and Ministry of Agriculture, unpublished Data.