Determination of Groundwater Vulnerability Zones to Contamination in Khanyounis Governorate, Gaza Strip, Using the DRASTIC Model within GIS

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Abstract

This study aims to provide a spatial analysis of the parameters and conditions under which groundwater may become contaminated, and to find out the groundwater vulnerable zones to contamination in the aquifer of Khanyounis governorate (The study area) by applying the DRASTIC model within GIS technique. The model uses seven environmental parameters: Depth of water table, net Recharge, Aquifer media, Soil media, Topography, Impact of vadose zone, and hydraulic Conductivity 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. Given these results, the model that has emerged can be used as a tool for national authorities and making decisions on where agricultural chemical applications pose the greatest potential for contaminating groundwater resources. 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.

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

تحديد مناطق المياه الجوفية المعرضة للتلوث في محافظة خان يونس بقطاع غزة باستخدام نموذج "دراستيك" من خلال نظم المعلومات الجغرافية

د. أكرم حسن الحلاق / د. بشير سفيان أبو العيش

الملخص :

تهدف هذه الدراسة إلى تقديم تحليل مكاني للمتغيرات والظروف التي يمكن بموجبها أن تصبح المياه الجوفية ملوثة، والوقوف على مناطق المياه الجوفية المعرضة للتلوث في محافظة خان يونس (منطقة الدراسة)، من خلال تطبيق نموذج "دراستيك DRASTIC" ضمن تقنية نظم المعلومات الجغرافية. ويستخدم هذا النموذج سبعة متغيرات بيئية: عمق مستوى الماء الجوفي، التغذية الصافية، جيولوجية الخزان الجوفي ، نوع التربة، طبوغرافية المنطقة، تأثير المنطقة غير المشبعة بالمياه، والتوصيل الهيدروليكي وذلك لتقييم مدى تعرض الخزان الجوفي للتلوث. على أساس هذا النموذج، جرت محاولة خلق خرائط تبين مواطن الضعف في منطقة الدراسة. ووفقاُ لقيم مؤشر نموذج "دراستيك"، والقيم الخاصة بالمبيدات، أظهرت الدراسة أنه في الجزء الغربي من منطقة الدراسة يتراوح التعرض للتلوث بين المرتفع والمرتفع جداً نظراً لضحالة عمق المياه الجوفية، وإمكانية التغذية العالية، ومسامية التربة. أما إلى الشرق من الجزء السابق، وكذلك في الجزء الجنوبي الشرقي، يكون التعرض للتلوث متوسطاً، ومنخفضاً في المنطقة الوسطى والشرقية نظراً لعمق المياه الجوفية. وبالنظر إلى هذه النتائج، برز هذا النموذج كأداة يمكن استخدامها من قبل السلطات الوطنية، وصانعي القرار في المناطق الزراعية التي تستخدم المواد الكيميائية التي تمثل الأكثر احتمالا لتلوث موارد المياه الجوفية. إن أكثر المتغيرات الهيدروجيولوجية خطورة والتي تسهم في تعرض المياه الجوفية للتلوث في منطقة الدراسة تتمثل في ضحالة عمق المياه، والتغذية العالية، ونوع التربة، وطبوغرافية المنطقة ذات الانحدار الهين.

كلمات مفتاحية: تعرض المياه الجوفية 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 (Rahman, A., 2008, p.51)

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 one the first used the term vulnerability in Hydrogeology, thereafter the concept was adopted worldwide (Albinet, M. and Margat, J. 1970, p.15). Up to date, several proposition 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 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 (ed), 1987, p.3).

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

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

- (**D**) Depth 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 Recharge: 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**) **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.
- (**S**) **S**oil media (texture): Soil of different types 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**) Impact 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.

- (**C**) 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.

3.1 Pesticide DRASTIC Model

The Pesticide DRASTIC methodology is identical to the DRASTIC methodology with the exception of the assignment of weighting values. This is a specific case analysis for evaluating groundwater vulnerability to agrochemical applications. Specifically, the modified Pesticide DRASTIC weights for soil media and topography are elevated over the unmodified DRASTIC values and the Pesticide DRASTIC weights for impact of the vadose zone media and hydraulic conductivity are less than the DRASTIC values, indicating the differences in relative importance of pesticides (agrochemicals) in the Pesticide DRASTIC model (Table 1). The modifications for the Pesticide DRASTIC index are meant to reflect the mobility of pesticides and therefore should not be used as a comparison to the general DRASTIC index (Aller *et al*. 1987, p.46).

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 have 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 have 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 DRASTIC factor has been divided into either ranges or significant media types that have an impact on contamination potential.

- ***Ratings:*** Ratings reflect the relative significance of classes (1 to 10) within each of the seven parameters. Ratings are taken from U.S. Environmental Protection Agency (USPEA, 1993, p. 127) since the ratings depend on 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, the DRASTIC INDEX can be calculated as: (Hammouri, N. and El-Naqa A., 2008, p.92).

DRASTIC Index = $D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w$

where: r = Rating for area being evaluated. (1-10), w = Importance weight for the factor (1-5).

4. Objective of Study

The main objective of this study is to provide a spatial analysis of the elements and conditions under which groundwater of the Khanyounis Governorate may become contaminated, and to find out the groundwater vulnerable zones to contamination in the aquifer of study area using the DRASTIC model.

5. Area of Study

Khanyounis Governorate is a part of the Gaza Strip. It is located in the south of the Gaza Strip, (Figure 1), bound by Deir al Balah to the north and Rafah in the south. It covers an area of about 111 km^2 (about 31% of the Gaza Strip total area). According to the Palestinian Central Bureau of Statistics (PCBS, 2008, 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 km^2, while the agricultural lands cover an area of about 63 km^2. 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 more than 300 mm. On an average there are less than 30 rainy days in the year (Ministry of Agriculture, 2008, Unpublished data).

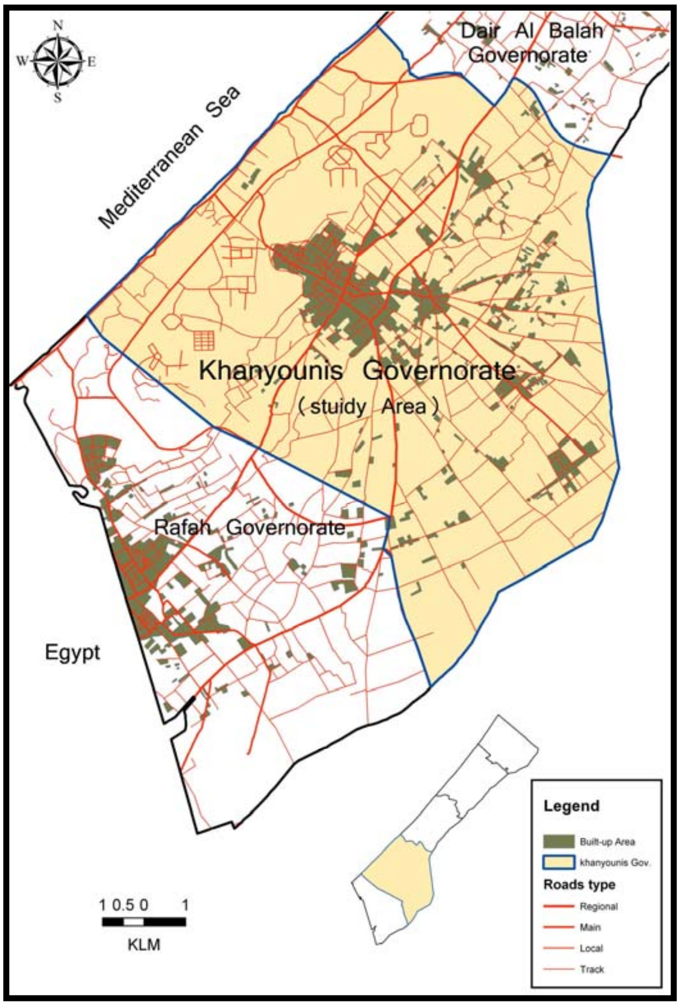

Figure (1) Location map of Khanyounis Governorate

(The Study Area)

Source: by researchers

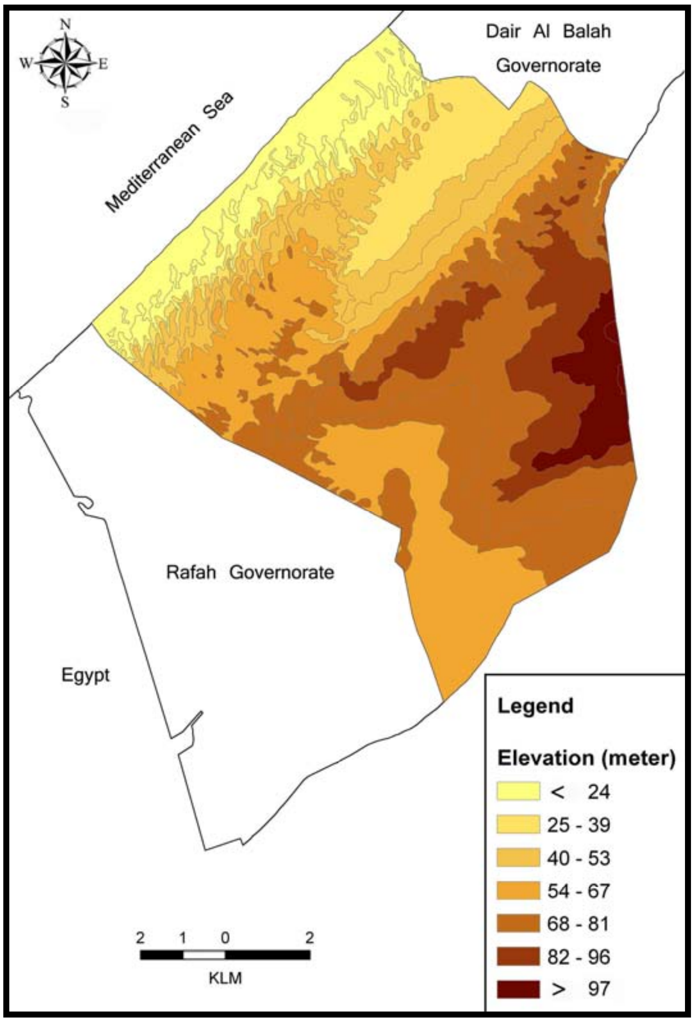

Figure (2) Topography of the Study Area

Source: by researchers

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 (sand dunes). Near the coast, coastal clays extend about 2-4 km inland, and divide the aquifer sequence into three sub-aquifers (Figure 3). Towards the east, the clay pinch out and the aquifer is largely unconfined (Palestinian Water Authority (PWA), 2000, 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.

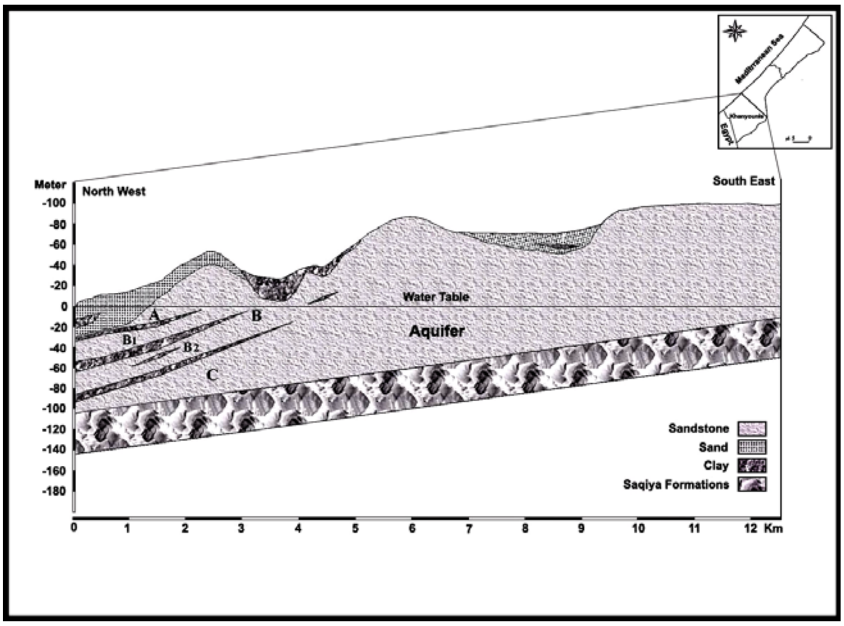

Figure (3) Hydrological Cross-Section of Khanyounis Governorate Aquifer.

Source: PWA, 2001

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 (4).

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).

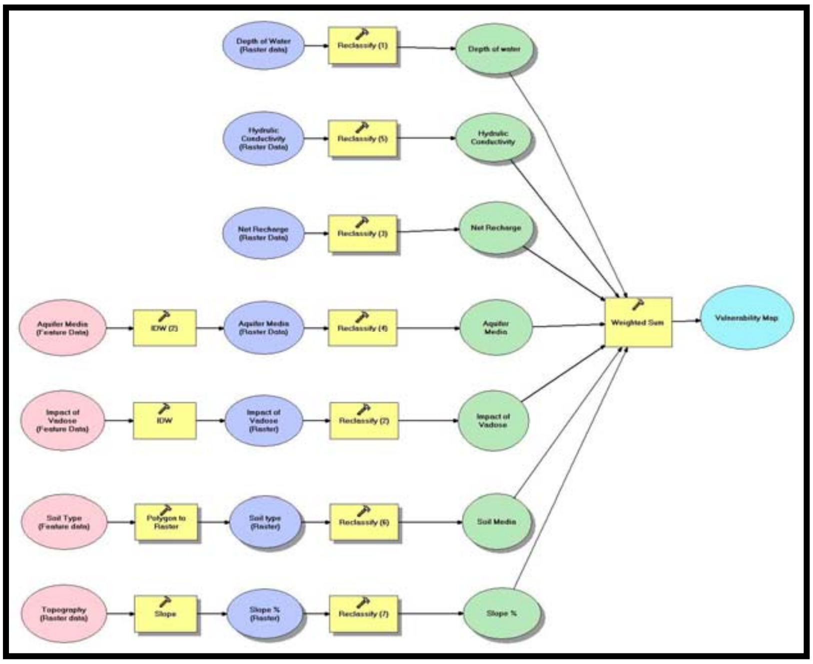

Figure (4) Flow chart for groundwater vulnerability analysis using DRASTIC model

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 higher vulnerability rating.

Depth to water data (for 199 drinking and agricultural water wells) was obtained from summary of Palestinian hydrologic data report; 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. 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 (D_r D_w) is at a value of 5 indicating the relative importance of this model element (Table 2).

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

Range	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		**Pesticide DRASTIC Weight = 5**		

Divided into ten categories based on the depth to water element within the DRASTIC model, statistical data shows that the majority of wells are at a depth greater than 22 m. This accounts for 74% of the total wells considered in the analysis. The highest percentage of wells, at about 25%, falls within the <12 m range. These wells are located in the west of governorate where the sand dunes layer sequences with a layer of sandstone. Wells that are in excess of 92 m account for 1.5% of all wells. These wells are located in the east of the governorate where the sandstone layer is prevailed.

The points of well location are converted to create a continuous depth to water surface by using the Inverse Distance Weighting (IDW) function within the ArcGIS Spatial Analyst extension for spatial interpolation in the representation of depth to water areas in Figure (5).

The depth to water table index value (D_r D_w) 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 fall within < 12 m range, water depth in the range 63 to 72 m below the surface accounts for more than 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 level makes 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 5).

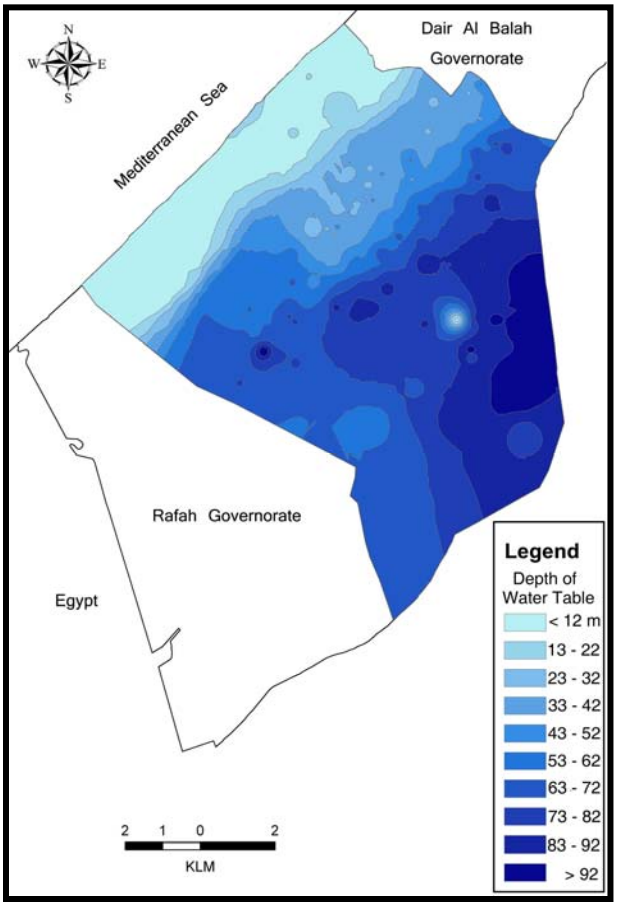

Figure (5) Depth to Water Table Map of the Study Area

Source: by researchers based upon data of water table (PWA, 2000).

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, 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 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 is derived from Khanyounis climatic station with 27 years records (1980-2007), and were used for computing net recharge (Ministry of Agriculture, 2008). 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 (Figure 6), 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.

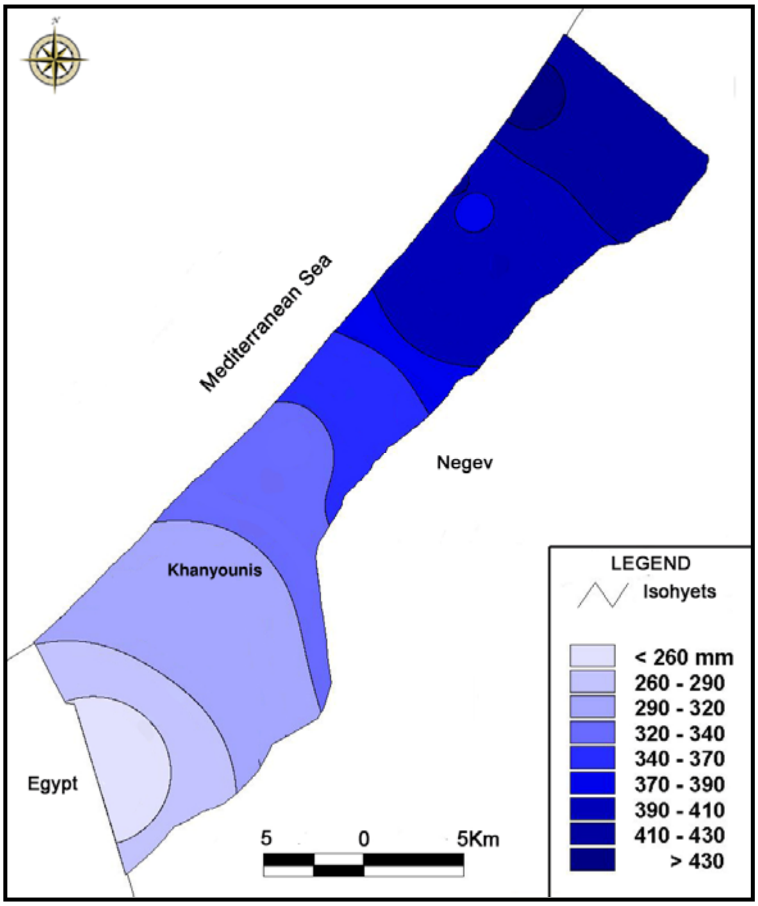

Figure (6) Distribution of annual rainfall for the Gaza Strip

Source: Al Hallaq, A., & Abu Elaish, B., (2008) Estimation of annual recharge was accomplished by using Williams and Kissel's equation (Jha, M. K. and Sebastain, J., 2005, p.3):

$\boldsymbol{PI = (P - 10.28)^2/(P + 15.43)}$ for hydrologic soil gravel and sand.

$\boldsymbol{PI = (P - 15.05)^2/(P + 22.57)}$ for hydrologic soil sandy loam and loamy sand.

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

According to the rainfall values, and by using these equations, which allows 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 that are used to compute the recharge index value (R_r R_w) and 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		**Pesticide DRASTIC Weight = 4**	

The areas of vulnerability for this parameter are identified by recharge index values (R_r R_w) 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 7). 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 about 25% of the total area.

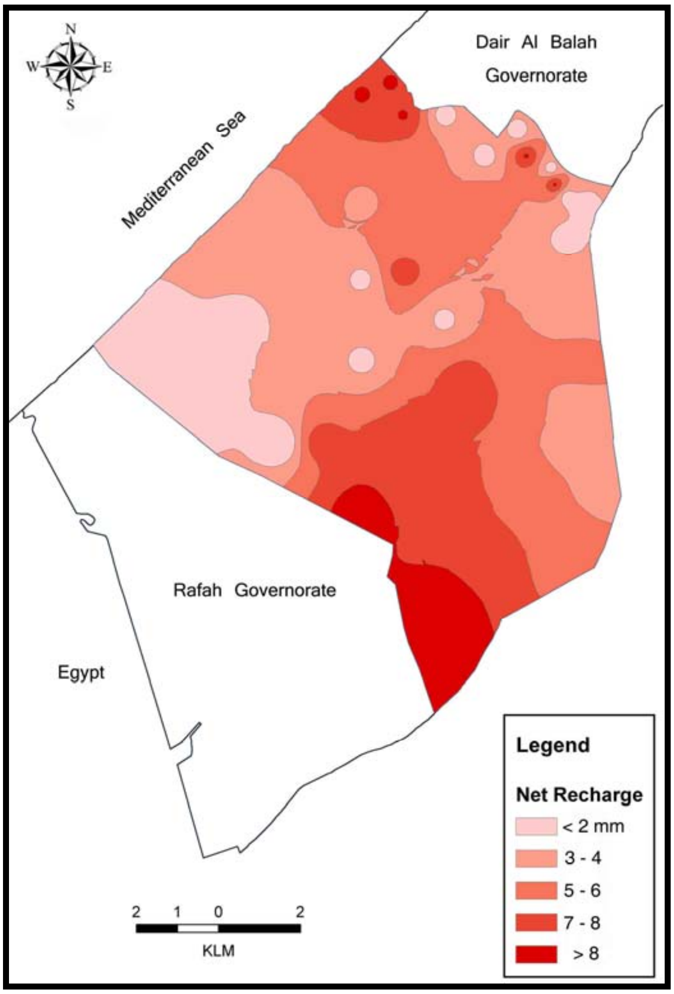

Figure (7) Spatial Distribution of Net Recharge Rate (mm) of the Study Area

Source: by researchers

The aquifer media has been identified from available geological map and cross-sections of the study area. 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, and thus vulnerability of the aquifer. The aquifer media in the study area comprised mainly of unconsolidated formations such as gravel and sand, and consolidated rock such as sandstone (Kurkar). According to DRASTIC standards, the rating of aquifer media in the study area varies between 6 for gravel, clay and sandstone, and 7 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 (%)
Gravel, Clay and	6	18	62.64
Sand, Sandstone and	7	21	37.36
DRASTIC Weight = 3	**Pesticide DRASTIC Weight = 3**		

The aquifer media index value (A_r A_w) is moderately low (18) in areas comprised of gravel, clay and sandstone, and is moderate (21) 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%. Gravel, clay and sandstone predominate within the study area and make up about 63% of it (Figure 8). In general, as the index value increase, vulnerability increase.

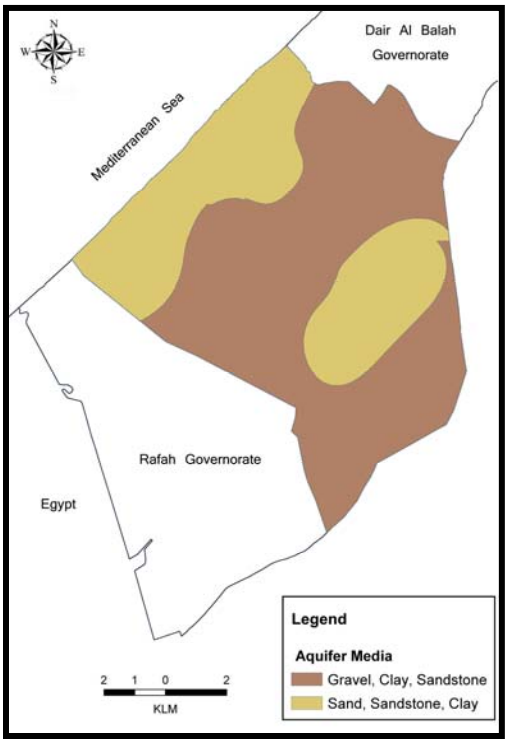

Figure (8) Aquifer Media (Geology) of the Study Area

Source: by researchers based upon hydrogeologic cross-section of the study area.

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 control 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.

The soil data of the study area was 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 (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, DRASTIC weight (2), and Pesticide DRASTIC weight (5) are used to determine the final index value (S_r S_w). 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 Area Soil Media in the Study

Range	Rating	Index		Area (%)
Sand	9	18	45	54.25
Sandy Loam	6	12	30	10.62
Loamy Sand	6	12	30	35.13
DRASTIC Weight = 2		**Pesticide DRASTIC Weight = 5**		

Sand soil, rated high (18 and 45) 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 is particularly prevalent west of it in form of sand dunes. Loamy sand and sandy loam follows at about 35 and 11% respectively, with moderate index value (6). These soil types spread east and southeast of the study area (Figure 9).

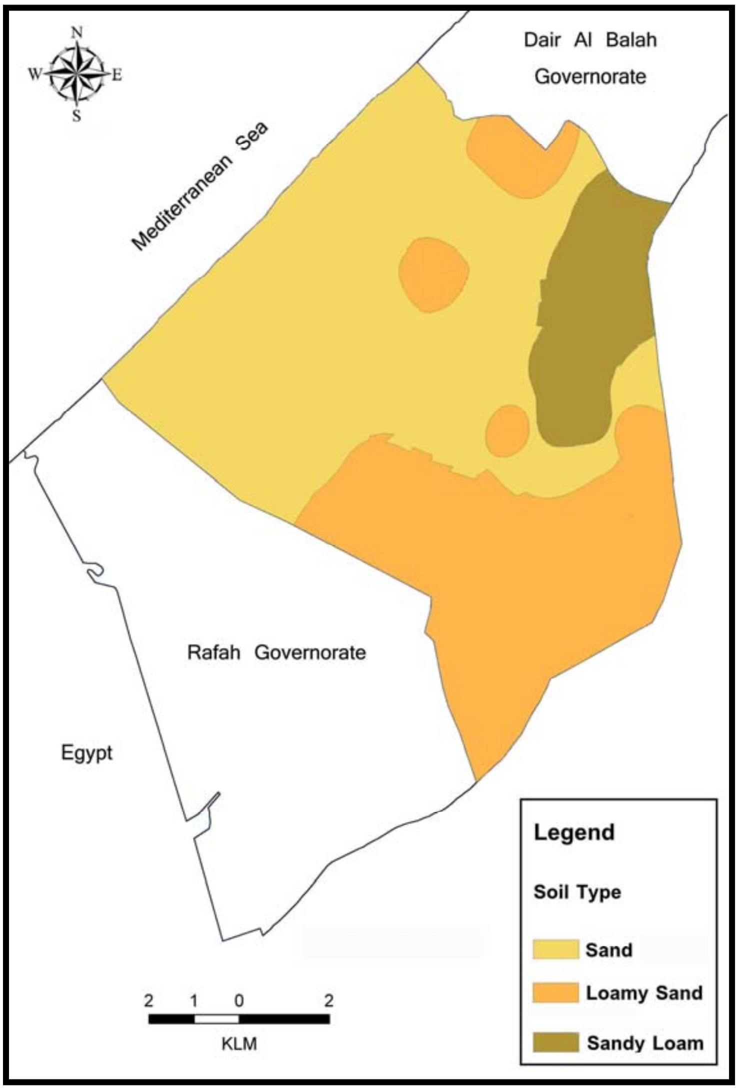

Figure (9) Soil Media of the Study Area

Source: by researchers

7.5 Topography

Topography in DRASTIC model 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, p.45). 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.

To obtain the slope map, it used a contour map of the study area, and 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 runoff rate is less, so 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	30	87.860
4 – 7	9	9	27	3.391
7 – 11	8	8	24	0.137
11 – 14	7	7	21	0.015
14 – 18	6	6	18	2.339
18 - 21	5	5	15	6.245
21 – 25	4	4	12	0.003
25 – 28	3	3	9	0.005
28 – 32	2	2	6	0.002
> 32	1	1	3	0.002
DRASTIC Weight = 1		**Pesticide DRASTIC Weight = 3**		

Ratings corresponding to >32% slope have a value of 1, and for < 4% slope, a value of 10. The DRASTIC weight and pesticide DRASTIC weight assigned for topography are 1 and 3 respectively. 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 10).

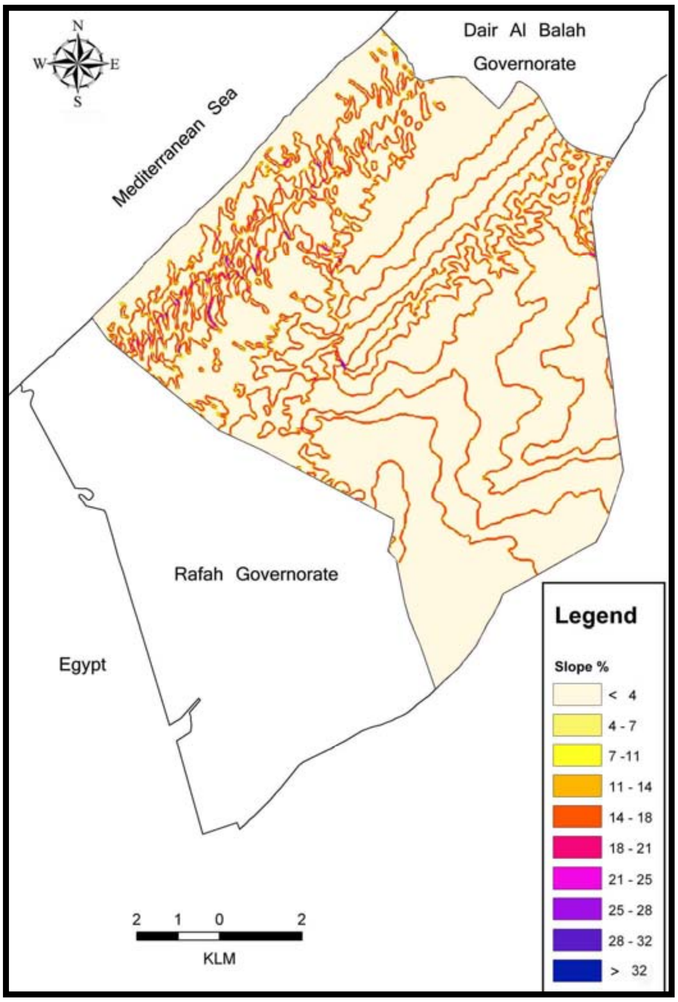

Figure (10) Slope of the Study Area

Source: by researchers

The topography index value (T_r T_w) 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.

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 on 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 lead 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. The vadose zone is composed of sand, sandstone (Kurkar), and clay. From table (7) the typical ratings, DRASTIC weight (5) and pesticide DRASTIC weight (4) are used to determine the final index value (I_r I_w)

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

Range	Rating	Index		Area (%)
Clay and Sandstone	5	25	20	28.08
Sandstone	6	30	24	38.99
Sand and Sandstone	8	40	32	32.93
DRASTIC Weight = 5		**Pesticide DRASTIC Weight = 4**		

The vadose zone media is evaluated with 39% of the study area controlled by sandstone layer. The sand and sandstone account about 33% of the study area. Clay and sandstone make up the remaining area (about 28%). The sandstone (rating =6), and clay and sandstone (rating =5) are moderate vulnerability index value (I_r I_w) and present the two-thirds of the study area, while the sand and sandstone formations (rating =8) are high vulnerability index value and present the remaining one-third of the area (Figure 11).

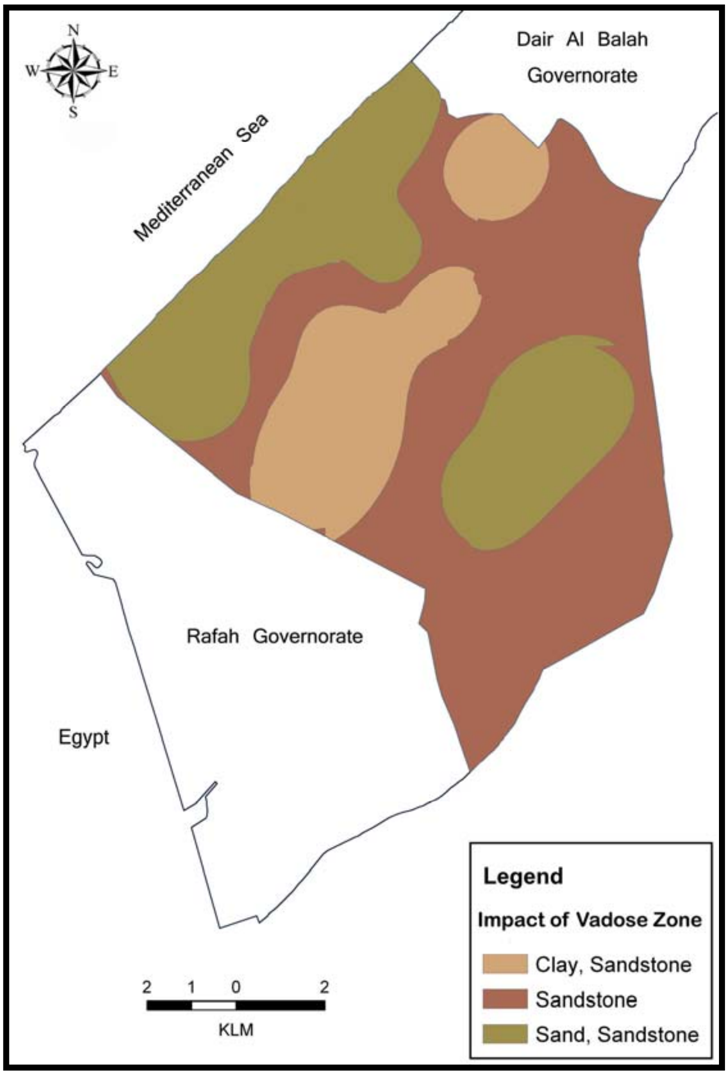

Figure (11) Vadose Zone of the Study Area

Source: by researchers

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, the hydraulic conductivity in the study area varies between 40 and 48 m/day (PWA, 2000, 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 are reduces from 3 for the regular DRASTIC model to 2 for the pesticide DRASTIC model. The product of rating and weight are the final index value (C_r C_w).

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

Range (m/day)	Rating	Index		Area (%)
40 – 42	4	12	8	13.55
42 – 44	4	12	8	32.24
45 – 46	5	15	10	45.63
46 – 48	5	15	10	8.58
DRASTIC Weight = 3		**Pesticide DRASTIC Weight = 2**		

Data shows that there are four categories of hydraulic conductivity index values (C_r C_w) for all aquifers. A range of 45-46 and 46-48 m/day (rating =5 and 15) is the most prevalent value covering more than a half of the study area (Figure 12). This is followed by 46% of the area ranging from 40-42 and 42-44 m/day (rating =4 and 12). According 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 (12 and 15).

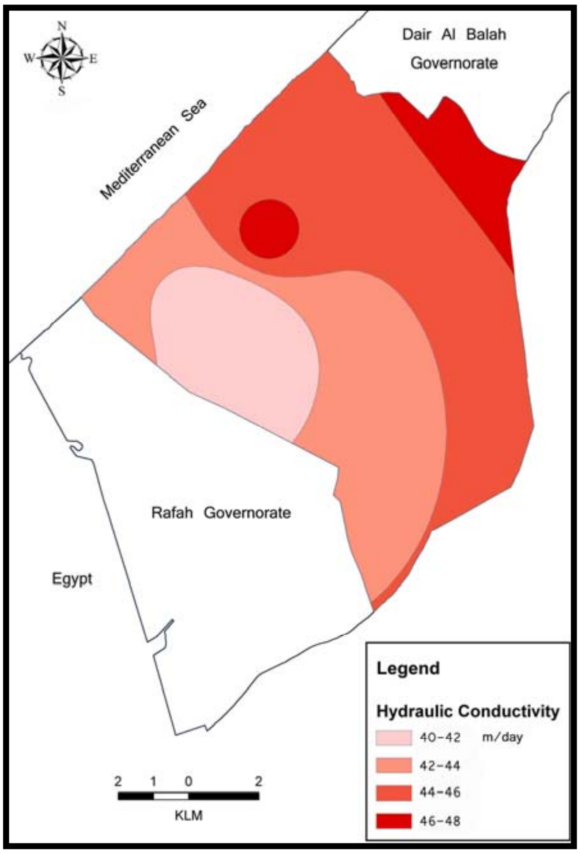

Figure (12) Hydraulic Conductivity of the Study Area

Source: (PWA, 2000).

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 and the pesticide DRASTIC index a composite layer representing the study area has been created combining the grid files described in Figures 4 through 10 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 (Almasri, M., 2007, P. 580). They are low (88-114), moderate (115-139), high (140-165), and very high (166-190) 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
88 – 114	29.74	Low
115 – 139	48.90	Moderate
140 –165	16.19	High
166 – 190	5.17	Very High

Figure (13) indicates that western part of the study area, the vulnerability to contamination ranges between high and very high. 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. In the central and the eastern part, vulnerability to contamination is low.

In terms of the pesticide DRASTIC index, statistical data grouping has been implemented in order to differentiate four categorical index ranges. Index values for this integrated model range from 102 to 216. The distribution of the data in this model indicates that over 20% of the study area has high and very high vulnerability. Moderately vulnerable areas comprise about 45% of the area, and the least vulnerable areas make up the remaining 35% of the total area (Table 10 and Figure 12).

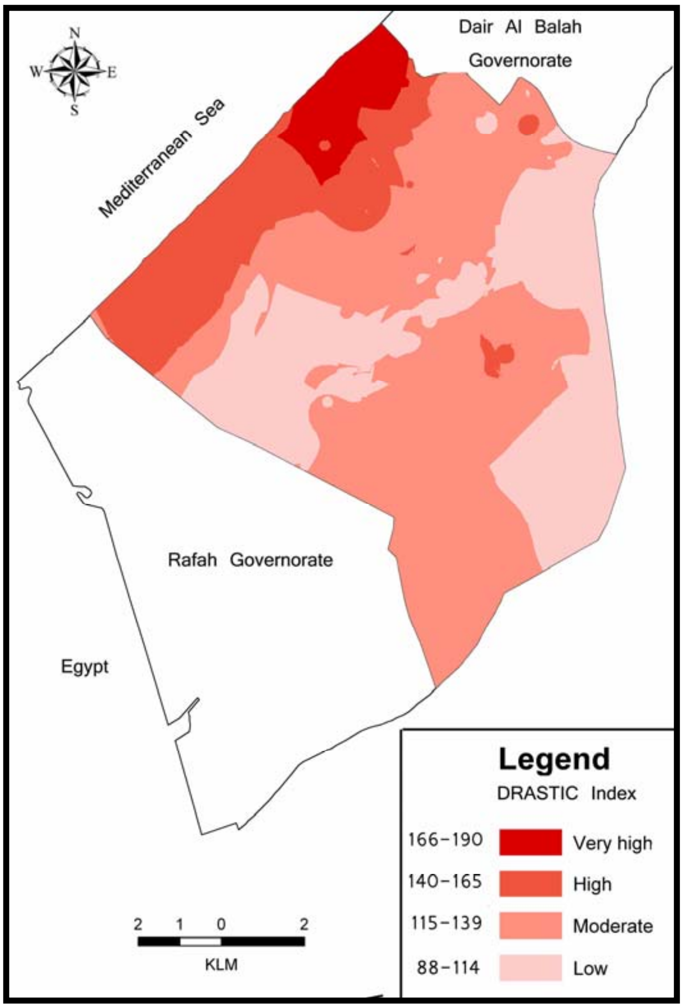

Figure (13) The Map of Vulnerability to Contamination for Khanyounis Governorate

Source: by researchers

Table (10) Pesticide DRASTIC Index Values in Khanyounis Governorate

Pesticide DRASTIC Index Value	Area (%)	Vulnerability Zone
102 – 131	35.09	Low
132 – 159	44.67	Moderate
160 –188	16.99	High
189 – 216	3.25	Very High

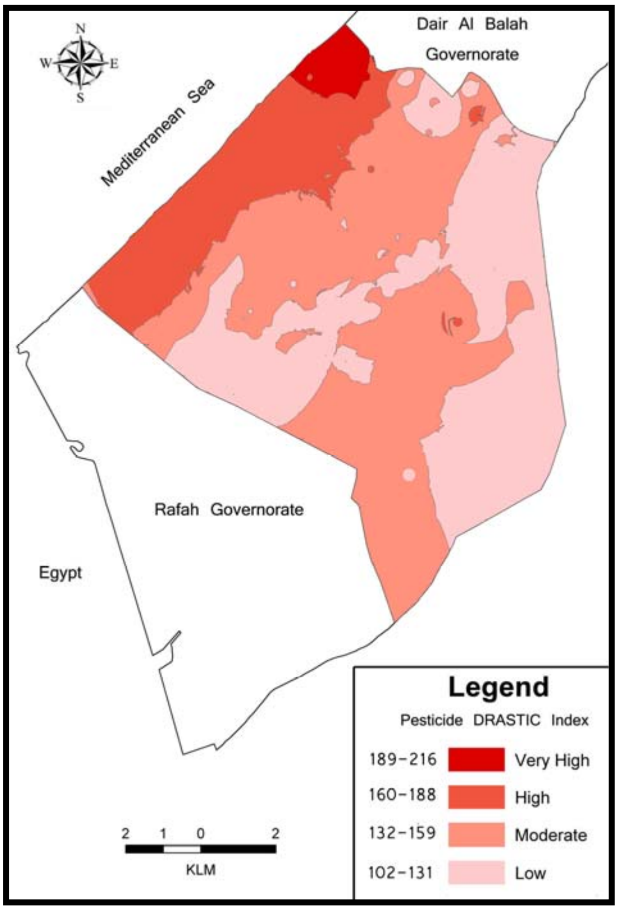

Figure (12) Vulnerability Zones According Pesticide DRASTIC Index for Khanyounis Governorate

Source: by researchers

From Figure (12), the areas with highest vulnerability are found also in the western part of the study area with moderate-high recharge potential, shallow water table and permeable soils. Moderate and low vulnerability areas can also be determined from this Figure.

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.

9. Conclusion

In this paper, an attempt has been made to determine groundwater vulnerability 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 16% and 5% of the study area is under high and very high vulnerability of groundwater contamination ,respectively, while more than 49% and 29% of the study area can be classified as an area of moderate and low, respectively, vulnerability of groundwater contamination. In the other hand, and according to pesticide DRASTIC index value, the distribution of the data in this model indicates that over 20% of the study area has high and very high vulnerability. Moderately vulnerable areas comprise about 45% of the area, and the least vulnerable areas make up 35% of the total area. 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 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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