

Groundwater Quality Assessment Using Water Quality Index (WQI) Approach: Gaza Coastal Aquifer Case Study

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Abstract—Water resources in arid and semi-arid regions, such as the Gaza Strip (GS), are generally under increasing stresses in terms of water quality and quantity. Therefore management of these valuable resources is one of the crucial concerns and challenges facing researchers and specialists worldwide. In these areas, there is a pressing need to evaluate the water situation in terms of its quality using the available limited data. The Water Quality Index (WQI) helps managers and planners working in the water sector to qualitatively map water quality; which in turn enables them to propose the possible management options, and to prioritize the capital investment for the water sector. Being the only source of water for the GS population of more than 1.8 million, the Gaza Coastal Aquifer (GCA) is in a disastrous quality situation. It represents an extreme prototype model on how several negative factors (unstable political environment, disastrous economic situation, decaying environmental conditions, unplanned & disorganized human activities), are combined together to further deteriorate the groundwater quality. The objective of this paper is to assess and map the spatial distribution of groundwater quality of the GCA using the WQI approach. Research results indicate that severe water quality deterioration has occurred in the GS. The area fraction that is classified as "not good" based on the WQI jumped from about 30% to 55% over 10 years (between 2000 and 2010). The WQI maps developed in this research work assisted in forming a simple yet comprehensive view about groundwater quality in the GS. This, in turn, helps spotting critical locations in terms of water quality, and setting management priorities accordingly. In summary, the space-time analyses of WQI provide support for the decision making process, i.e., for drawing policies and proposing remediation measures to restore and maintain water resources.

Index Terms—Coastal aquifers, Contour maps, Gaza strip, Groundwater, Water Quality Index (WQI).

I INTRODUCTION

Groundwater (GW) constitutes about 89% of the freshwater on the earth, and it is considered as an important source for sustainable economic growth in any community especially in arid and semi-arid regions [1]. GW is the unique source of freshwater for more than one third of the world's population, for whom there is a limited or contaminated surface water resource. Worldwide, the demand on GW is continuously increasing to meet water demand [2, 3]. However, this valuable resource is not completely isolated from the surrounding environment. It is affected by both natural and anthropogenic contamination sources. Therefore an assessment of GW quality is of great importance for society, and particularly, in consideration of public health aspects [4, 5].

The Water Quality Index (WQI) is frequently used to assess the suitability of surface water as well as groundwater for drinking and agriculture purposes. The construction of the WQIs for different purposes has been described in the literature by various authors. Singh and Khan [6] used the WQI and Geographic Information System (GIS) to assess and map the spatial distribution of ground water quality of the

Dhankawadi ward of Pune, India. Ganeshkumar and Jaideep [7] emphasized the use of the WQI approach in the assessment of groundwater quality of Vedaranyam Taluk, India. Adhikari et al. [8] created WQI iso-maps to evaluate water quality parameters with respect to irrigation potential and to mark differences in water quality between seasons. Stigter et al. [9] created a GroundWater Quality Index (GWQI) with the aim of monitoring the influence of agriculture practices on several key parameters of groundwater chemistry and potability. Ramakrishnaiah et al. [4] evaluated the suitability of groundwater for human consumption in Tumkur Taluk, Karnataka State (India) based on computed WQI values. Srinivas et al. [10] analyzed groundwater samples from twenty-five locations in Kurmapalli Vagu basin, India for various physico-chemical parameters in terms of WQI to determine its suitability for drinking purposes. Gebrehiwot et al. [11] investigated the groundwater quality of the Hantebet watershed (Ethiopia) for human consumption through WQI investigation of the different hand dug wells in the watershed.

This paper aims at assessing and mapping the spatial and temporal distribution of ground water quality (for drinking purposes) in the Gaza Strip using the WQI method.

I. STUDY AREA

The Gaza Strip area is a part of the Palestinian occupied territories as shown in Figure 1. It is a narrow and low-lying stretch of sand dunes located at the eastern coast of the Mediterranean Sea between longitudes 34°2 " and 34°25 " east, and latitudes 31°16 " and 31°45 " north [12]. The GS is one of the most densely populated areas in the world, with an average density of about 4400 inhabitants/km² [13].

The climate of the GS is semiarid; the mean annual rainfall ranges between 400 mm/year in the north to about 200 mm/year in the south [12, 14]. The annual average of relative humidity is about 72%, and the average mean daily temperature ranges from 25°C in summer to 13°C in winter [15]. Regarding land use, heavy agricultural activities take place in the GS, where agricultural land occupies about 65% of the land surface and it is the dominant economic sector [12].



Figure 1. Location of Gaza Strip [16]

The Gaza Coastal Aquifer (GCA) is the only natural water resource for different purposes in the GS, and is extensively utilized to satisfy agricultural, domestic, and industrial water demands [14, 17]. Water is pumped from the GCA by more than 4000 municipal and agricultural wells [15]. The GCA is a part of the coastal aquifer that extends from the GS in the south to about 120 km in the north along the Mediterranean coastal line as shown in Figure 2. The GCA thickness varies from about 120 m in the west (at the shoreline) to a few meters in the east [18]. On the other hand, the depth of water of the GCA ranges from about 60 m below ground surface in

the east to a few meters near the coastline in the west [14]. The GCA is composed of layers of sand dunes, sandstone, calcareous sandstone, and silt. It also contains several silty-clayey impermeable layers that partially intercalate and subdivide it into sub-aquifers as shown in Figure 2, section A-A [18, 19].

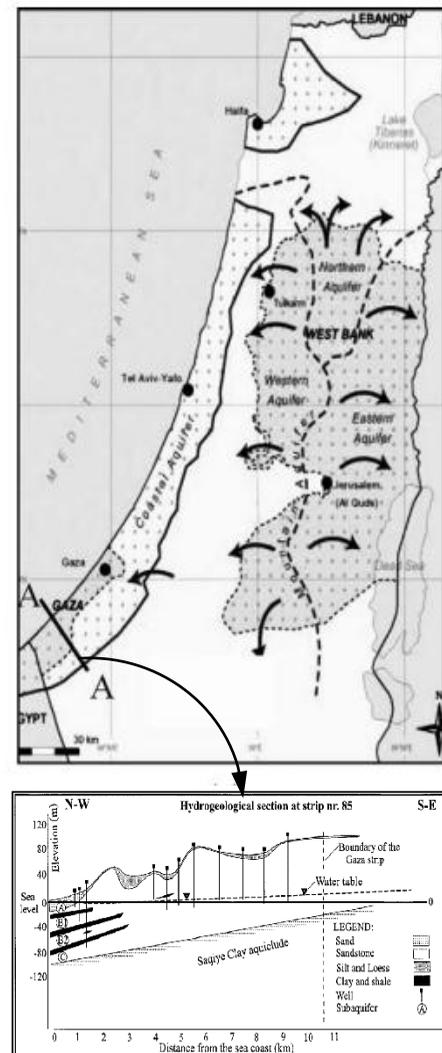


Figure 2. Layout of Gaza Coastal Aquifers showing a typical geological cross-section (section A-A) [14].

Regional groundwater flow in GCA is from east to west toward the Mediterranean Sea. However, intense pumping (abstraction) disturbs the regional natural flow patterns. Consequently, large cones of depression have formed over the past years within the major highly populated urban centers within the GS [12].

The GCA experiences such severe water quality deterioration that, as a consequence, up to 90% of the GW in the GS is currently not safe for drinking purposes without adequate treatment. Furthermore, it is reported that based on the current water and sanitation situation, the GW in the GS could

become unusable as early as 2016, and moreover, the damage of the GW in GS would become irreversible by 2020 [20]. The concentrations of many chemical parameters, particularly nitrate (NO_3^-) and chloride (Cl^-), have reached dangerous levels in many locations within the GS [21].

Thus, Cl^- concentration is continually increasing, such that less than 5% of water wells in the GS meet the Cl^- standards of the World Health Organization (WHO): this is due to seawater intrusion and excessive water withdrawals [16, 21]. Similarly, NO_3^- concentrations also reach levels that threaten public health. The primary sources and causes of NO_3^- elevated levels are septic effluents, followed by agricultural applications of sludge and synthetic fertilizers [22]. The concentrations of other physico-chemical parameters such as TDS, EC, Ca and Mg, also reach elevated levels.

II. METHODOLOGY

Water quality data for GS Strip municipal wells between 2000 and 2010 were collected from the database of the related institutions working in the water sector, particularly the Palestinian Water Authority (PWA) and Ministry of Health (MoH).

In this study, the WQI was calculated based on 6 water quality parameters, namely; Chloride (Cl^-), Nitrate (NO_3^-), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sulphate (SO_4^{2-}), and Alkalinity.

The selection of these parameters depends on several factors, such as the purpose of the index, the importance of the parameter, and the availability of data [9]. The selection of Chloride (Cl^-) is referred to the fact that the majority of the GW in GS suffers from high levels of (Cl^-). Additionally, chloride is an indicator of salinity, and it has direct effects on human health. As for Nitrate (NO_3^-), it constitutes the main problem in the study area due to its direct effects on human health [23]. Finally, Ca, Mg and SO_4 are typically associated to agricultural activities. The Ca and Mg cations are indicators of GW hardness, and high concentrations of these cations in water may affect its acceptability to the consumers in terms of taste and scale deposition. High levels of SO_4^{2-} can cause dehydration and gastrointestinal irritation, and may also contribute to the corrosion of distribution systems. Alkalinity is introduced into the water by dissolving carbonate-containing minerals [24]. The high concentration of sewage and industrial waste may be the cause of high alkalinity in polluted water [25]. Alkalinity control is important in boiler feed water, cooling tower water, and in the beverage industry [24]. Excessive alkalinity may cause eye irritation in human and chlorosis in plants [26].

Other parameters are voluntarily left out of this analysis, such as TDS, EC, PO_4 , NO_2 , and hardness, because these may be indirectly included due to their correlation with the other included parameters. For example, the parameters

TDS, EC and (Cl^-) are all indicators of water salinity. Therefore, to avoid redundancy, only (Cl^-) was retained for constructing the quality index. The same justification holds concerning hardness, which is strongly correlated with Mg and Ca.

The Palestinian standards for drinking purposes (Table 1) were considered for the calculation of the WQI, which was based on a procedure presented in details in the next section (see steps A, B, ..., G).

After computing the WQI, groundwater quality maps were created based on a geostatistical, kriging interpolation algorithm using the SURFER 12 software (Golden).

TABLE 1

Palestinian drinking water standards, and weights, for the selected parameters

Parameter	Palestinian Standard, mg/l	Weight
Cl	600	4
NO_3	70	5
Ca	200	2
Mg	150	2
SO_4	400	3
Alkalinity	400	2

III. WATER QUALITY INDEX

The Water Quality Index is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. It becomes an important parameter for the assessment and management of groundwater [4].

Traditionally, water resource professionals communicated drinking water quality status by comparing the individual parameters with guideline values. However, this language is too technical, and it would not provide a global picture of drinking water quality. To resolve this decision-making problem, Horton (1965) made a pioneering attempt to describe the water quality as an index, the WQI [27]. Horton defined the Water Quality Index as a reflection of composite influences of individual quality characteristics on the overall quality of water [10].

The WQI concept is based on the comparison of the water quality parameter with respective regulatory standards and provides a single number that express overall water quality at certain location based on several water quality parameters [6]. The WQI summarizes large amount of water quality data into simple terms, i.e., excellent, good, bad, etc., which are easily understandable and usable by the public [25].

Therefore, by combining multiple parameters into a single index, a more comprehensive picture of the pollution state is provided. When mapping the index, the areas of high and low water quality can easily be distinguished [9].

The advantages of a WQI include its ability to represent measurements of a variety of variables in a single number, its ability to combine into a single metric various measurements having different physical dimensions (units), and also, its effectiveness as a communication tool [28].

Generally, the construction of the WQI involves three steps: (1) selection; (2) standardization and (3) aggregation of the parameters to be included [9]. In the standardization step, the raw analytical results for selected water quality parameters, having different units of measurement, are transformed into unitless sub-index values [27]. The resulting values are then aggregated using some type of sum or mean (e.g. arithmetic, harmonic, geometric) [9, 27, 29].

In what follows, the methodology used to calculate the WQI is developed step by step.

A Parameter selection:

The selection of the parameters that will make up the index depends on several factors, such as the purpose of the index, the importance of the parameter, and the availability of data [9].

In drinking water quality assessment, priority should be given to those substances which are known to be important to health (potability) and which are known to be present in significant concentrations in the water source (World Health Organization [27]).

As stated previously in the methodology section, the WQI in this paper is calculated based on six water quality parameters: Chloride, Nitrate, Calcium, Magnesium, Sulphate, and Alkalinity.

B Weight assignment:

The purpose of an assignment of weights to water quality parameters is to denote each parameter's importance to the overall water quality. A larger weight value implies greater importance of the variable with respect to public health [29]. Therefore, each of the selected parameters has been assigned a weight (w_i) based on a scale of 1 to 5, where 5 mean high importance. The chosen weights are shown in Table 1. These weights are based on the prevailing weights used in previous studies [4, 11, 12, 24].

C Relative weight calculation

Relative weight (W_{Ri}) can be determined by dividing the individual weight of each parameter (w_i) by the sum of weight of all selected parameters (W):

$$W_{Ri} = \frac{w_i}{W} \quad (1)$$

where W_{Ri} is the relative weight, w_i is the weight of the parameter under consideration.

D Quality rating calculation

The fourth step is the calculation of a quality rating scale (Q_i) for each parameter, as follows:

$$Q_i = \frac{C_i}{S_i} \times 100 \quad (2)$$

where Q_i is the quality rating, C_i (mg/l) is the concentration of each parameter in each water sample in, and S_i (mg/l) is the Palestinian drinking water standard for each chemical parameter.

E Sub-index calculation

The sub-index SI_i for each chemical parameter is determined using the following equation:

$$SI_i = W_{Ri} \times Q_i \quad (3)$$

SI_i is the sub-index of the i^{th} parameter. It combines its quality rating as well as its assigned weight.

F Calculation of the Water Quality Index WQI (Sub-Index aggregation)

Aggregation is a most important aspect of the WQI concept, and an important step in its construction. The sub-index aggregation of a WQI mathematically combines sub-indices into an overall index [29]. The multiplicative and additive aggregation functions are the popular aggregation techniques in the WQI approach. Besides, some researchers have also adopted some other aggregation techniques [27].

In the present study, additive aggregation was applied. Accordingly, we aggregate the index as follows, which leads finally to the WQI:

$$WQI = \sum_{i=1}^{i=n} SI_i \quad (4)$$

G Classification of Water Quality Index Scores

The aggregation equations generate a WQI score, higher WQI scores indicating worse water quality, and lower scores indicating excellent water quality. The computed WQI values are classified into five types, "excellent water" to "water unsuitable for drinking", according to Table 2.

TABLE 2
Classification of WQI Scores

WQI value	Water quality
<50	Excellent water
50-100	Good water
100-200	Poor water
200-300	Very poor water
>300	Water unsuitable for drinking

IV. RESULTS AND DISCUSSION

The WQI contour maps for the GS area are presented in Figures 4, 5, 6, for the years 2000, 2005, 2010, respectively. In the year 2000, it can be observed that the area classified as “excellent” and “good” occupied 70.4% of the overall GS area. A slight decline of the area belonging to the same category was noticed in the year 2005 (68.5% classified as “excellent” and “good”). However, between 2005 and 2010, a steep deterioration occurred in water quality: the area of “excellent” and “good” water quality dropped to only 45.2%. Equivalently, this also indicates that the areas which are “not good” based on the WQI jumped from 29.6% to 54.8% within 10 years. In other words, the bad quality areas increased by 80 % from 2000 to 2010, as depicted in Figure 3.

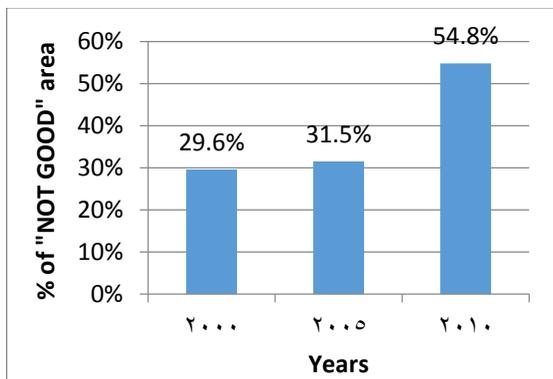


Figure 3. Percentage of GS areas (relative to total GS area) that is classified as “Not Good” for GW quality according to the WQI: evolution over ten years.

With regards to the spatial distribution of the WQI, and particularly, the geographical locations of low quality zones. In 2000, the zones classified as “not good” in terms of the WQI were limited to two main regions: the first one located in Gaza city (area A in Figure 4) which is the central and most highly populated city of GS, and is characterized by large commercial and economic activities. The poor water quality in this area is mainly due to elevated concentrations of nitrate and chloride; the former is due to deficiency of wastewater collection and treatment system, while the latter is due to seawater intrusion resulted from high GW abstraction rates.

The second area of high WQI was located beneath the south eastern part of GS (area B in Figure 4), whose poor WQI is also related to elevated concentrations of nitrate and chloride. Being the main economical and dominant activity in this area, agricultural activities including excessive use of fertilizers and manures are the main source of the elevated nitrate. As for chloride, lateral flow from the neighboring eastern Eocene aquifer (characterized by high chloride levels) is the main source of high chloride concentrations in that area [30-32].

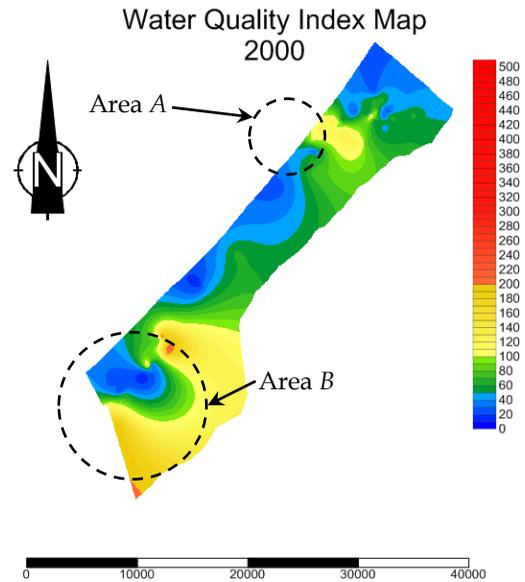


Figure 4. Water Quality Index contour map for the year 2000

In 2005, a new major zone of low quality GW (“not good” according to WQI) appeared in the middle region of the GS (area C in Figure 5). This low quality resulted from the same reasons as for the city of Gaza (Area A). However, there is an unexpected improvement of WQI in the south eastern part of the GS (area D in Figure 5). This unexpected trend resulted from improvement of various water quality parameters namely, nitrate, calcium, sulfate and magnesium. This trend is actually due to a decline of agricultural activities as a result of continuous Israeli military incursions in the Gaza Strip between 2001 and 2005 on agricultural lands. For example, one of the effects is the uprooting of plants, especially near the eastern borders of the GS [33].

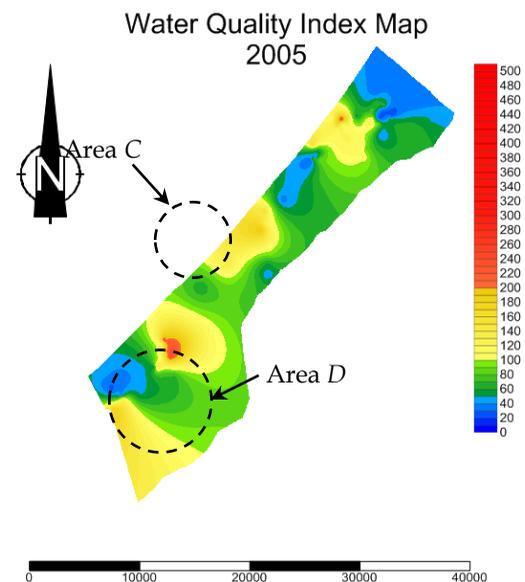


Figure 5. Water Quality Index contour map for the year 2005

Another potential reason of the above-mentioned WQI positive trend may be related to an artefact in the processing of data: the wells used to develop the WQI contour maps (2000, 2005, 2010) were different from one map to another (i.e. the wells change over the years). Only those wells having data records were utilized for developing the maps. This will in turn affect to some degree the interpolation accuracy of WQI contour maps and their evolution with time.

In the year 2010, it can be seen that the southern and the middle "not good" WQI areas have extended and merged together, now forming a very large zone (area E in Figure 6). This low quality zone, in 2010, includes the major part of the southern and middle GS, except for a coastal portion in the south western coastal area. Elevated concentrations of several water quality parameters, notably chloride and nitrate, led to the observed deterioration in WQI in area A. It is also noticed that the effect of seawater intrusion is not clear in the south, compared with that in Gaza city. The lack of seawater intrusion effects there may be related to several factors: comparatively low GW abstraction; existence of sand dunes and open areas in the south western GS (these geologic features favor higher GW recharge, which in turn improves water quality by reducing seawater intrusion).

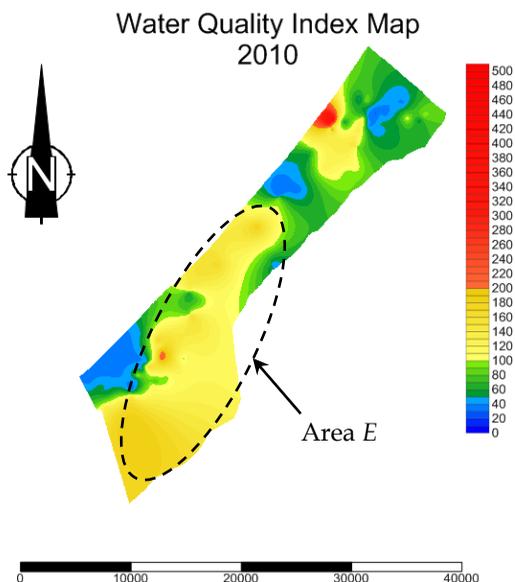


Figure 6. Water Quality Index contour map for the year 2010

V. CONCLUSION

Despite the simplicity of the WQI concept and its theoretical background, it is still widely utilized as a preliminary tool to give an overview about GW quality worldwide. In this study, six water quality parameters (chloride, nitrate, sulfate, calcium, magnesium, and alkalinity) were used to develop and map the WQI in the Gaza Coastal Aquifer, Gaza Strip,

Palestine. Although decision makers cannot depend only on WQI for groundwater management, nevertheless, this tool can help focus on the hot spots and the priority areas.

Tracking water quality situation in the GS with time using contour maps showed that the GCA is subjected to severe and rapid quality deterioration that threatens the sustainability of water supply and ecosystems. This deterioration is related to the fact that the aquifer is affected by multiple influencing variables such as seawater intrusion, lateral flow from adjacent aquifer, contamination from mixed and uncontrolled land use, and other factors. Deterioration of water quality in the GCA necessitates sustainable and wise management practices to alleviate stress on the aquifer and to improve water quality.

Developing contour maps for the WQI is an effective tool to present the situation and illustrate the extent of water quality problems to non-specialists and to the community. However, the study showed that using identical wells (the same group of wells) to develop WQI contour maps is one of the necessary measures to be considered. The fact that different wells appear in the dataset at different years, may significantly affect the accuracy of the developed WQI maps. On the one hand, the time evolution of the resulting WQI maps can be somewhat misleading if a different group of observation wells is used at each different time (or year). On the other hand, it would be better to use all the data available if possible. In future, new data processing procedures could be implemented in order to improve the resulting space-time maps, e.g., combining space-time interpolations, using inter-well correlations and augmenting the water quality datasets using hydrometeorological data.

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REFERENCES

- [1] Sheng, Z., "Impacts of groundwater pumping and climate variability on groundwater availability in the Rio Grande Basin". *Ecosphere*, 2013. **4**(1): p. art5.
- [2] Koundouri, P., "Current issues in the economics of groundwater resource management". *Journal of Economic Surveys*, 2004. **18**(5): p. 703-740.
- [3] Morris, B.L., A.R.L. Lawrence, P.J.C. Chilton, B. Adams, R.C. Calow, and B.A. Klinck, "Groundwater and its susceptibility to degradation: A global assessment of the problem and options for management", in *Early Warning and Assessment Report Series 2003*, United Nations Environment Programme (UNEP): Nairobi, Kenya.
- [4] Ramakrishnaiah, C.R., C. Sadashivaiah, and G. Ranganna, "Assessment of

- Water Quality Index for the Groundwater in Tumkur Taluk, Karnataka State, India". *E-Journal of Chemistry*, 2009. **6**(2): p. 523-530.
- [5] Sener, E., S. Sener, and A. Davraz, "Assessment of aquifer vulnerability based on GIS and DRASTIC methods: a case study of the Senirkent-Uluborlu Basin (Isparta, Turkey)". *Hydrogeology Journal*, 2009. **17**(8): p. 2023-2035.
- [6] Singh, P. and I.A. Khan, "Ground water quality assessment of Dhankawadi ward of Pune by using GIS". *International Journal of Geomatics and Geosciences*, 2011. **2**(2): p. 688-703.
- [7] Ganeshkumar, B. and C. Jaideep, "Groundwater quality assessment using Water Quality Index (WQI) approach - Case study in a coastal region of Tamil Nadu, India". *International Journal of Environmental Sciences and Research* 2011. **1**(2): p. 50-55.
- [8] Adhikari, K., B. Chakraborty, and A. Gangopadhyay, "Assessment of Irrigation Potential of Ground Water Using Water Quality Index Tool". *Asian Journal of Water, Environment and Pollution*, 2012. **10**(3): p. 11-21.
- [9] Stigter, T.Y., L. Ribeiro, and A.M.M. Carvalho Dill, "Application of a groundwater quality index as an assessment and communication tool in agro-environmental policies – Two Portuguese case studies". *Journal of Hydrology*, 2006. **327**(3-4): p. 578-591.
- [10] Srinivas, P., G.N. Pradeep Kumar, A. Srinivasa Prasad, and T. Hemalatha, "Generation of Groundwater Quality Index Map: A Case Study". *Civil and Environmental Research*, 2011. **1**(2): p. 9-20.
- [11] Gebrehiwot, A.B., N. Tadesse, and E. Jigar, "Application of water quality index to assess suitability of groundwater quality for drinking purposes in Hantebet watershed, Tigray, Northern Ethiopia". *ISABB Journal of Food and Agriculture Science*, 2011. **1**(1): p. 22-30.
- [12] Almasri, M.N. and S.M.S. Ghabayen, "Analysis of nitrate contamination of Gaza coastal aquifer, Palestine". *Journal of Hydrologic Engineering*, 2008. **13**: p. 132.
- [13] PCBS, "Statistical Yearbook of Palestine ", 2012, Palestinian Central Bureau of Statistics 2011: Ramalla- Palestine.
- [14] UNEP, "Desk Study on the Environment in the Occupied Palestinian Territories", 2003, United Nations Environment Programme: Geneva.
- [15] Qahman, K. and A. Larabi, "Evaluation and numerical modeling of seawater intrusion in the Gaza aquifer (Palestine)". *Hydrogeology Journal*, 2006. **14**(5): p. 713-728.
- [16] Al-Khatib, I.A. and H.A. Arafat, "Chemical and microbiological quality of desalinated water, groundwater and rain-fed cisterns in the Gaza strip, Palestine". *Desalination*, 2009. **249**(3): p. 1165-1170.
- [17] Metcalf and Eddy, "Coastal Aquifer Management Plan (CAMP). Final model report (task 7). ", 2000, USAID.
- [18] Baalousha, H., "Vulnerability assessment for the Gaza Strip, Palestine using DRASTIC". *Environmental Geology*, 2006. **50**(3): p. 405-414.
- [19] Melloul, A. and M. Collin, "Sustainable groundwater management of the stressed Coastal aquifer in the Gaza region". *Hydrological sciences journal*, 2000. **45**(1): p. 147-159.
- [20] UNCT, "Gaza in 2020 A liveable place?", 2012, Office of the United Nations Special Coordinator for the Middle East Peace Process (UNSCO) - A report by the United Nations Country Team in the occupied Palestinian territory: Jerusalem.
- [21] Shomar, B., S. Fkher, and A. Yahya, "Assessment of groundwater quality in the Gaza Strip, Palestine using GIS Mapping". *Journal of Water Resource and Protection*, 2010. **2**(2): p. 93-104.
- [22] Shomar, B., K. Osenbruck, and A. Yahya, "Elevated nitrate levels in the groundwater of the Gaza Strip: Distribution and sources". *Science of the Total Environment*, 2008. **398**(1-3): p. 164-174.
- [23] Cissé, I.A. and X. Mao, "Nitrate: Health effect in drinking water and management for water quality". *Environ. Res*, 2008. **2**: p. 311-316.
- [24] Kalpana, G.R., D.P. Nagarajappa, K.M. Sham Sundar, and B. Suresh, "Determination of Groundwater Quality Index in Vidyanagar, Davanagere City, Karnataka State, India". *International Journal of Engineering and Innovative Technology (IJEIT)*, 2014. **3**(12): p. 90-99.
- [25] Gangwar, R.K., J. Singh, A.P. Singh, and D.P. Singh, "Assessment of Water Quality Index: A Case Study of River Ramganga at Bareilly U.P. India". *International Journal of Scientific & Engineering Research - IJSER*, 2013. **4**(9): p. 2325-2329.
- [26] Sisodia, R. and C. Moundiotiya, "Assessment of the Water Quality Index of Wetland Kalakho Lake, Rajasthan, India". *Journal of Environmental Hydrology*, 2006. **14**(23): p. 1-11.
- [27] Ramesh, S., N. Sukumaran, A.G. Murugesan, and M.P. Rajan, "An innovative approach of Drinking Water Quality Index - A case study from Southern Tamil Nadu, India". *Ecological Indicators*, 2010. **10**(4): p. 857-868.
- [28] Tambekar, D.H. and B.B. Neware, "Water Quality Index and Multivariate Analysis for Groundwater Quality Assessment of Villages of Rural India". *Science Research Reporter*, 2012. **2**(3): p. 229-235.
- [29] Song, T. and K. Kim, "Development of a water quality loading index based on water quality modeling". *Journal of Environmental Management*, 2009. **90**(3): p. 1534-1543.
- [30] Yakirevich, A., A. Melloul, S. Sorek, S. Shaath, and V. Borisov, "Simulation of seawater intrusion into the Khan Yunis area of the Gaza Strip coastal aquifer". *Hydrogeology Journal*, 1998. **6**(4): p. 549-559.
- [31] Zoller, U., L.C. Goldenberg, and A.J. Melloul, "The "short-cut" enhanced contamination of the Gaza Strip coastal aquifer". *Water Research*, 1998. **32**(6): p. 1779-1788.
- [32] Al-Agha, M.R. and H.A. El-Nakhal, "Hydrochemical facies of groundwater in the Gaza Strip, Palestine/Faciès hydrochimiques de l'eau souterraine dans la Bande de Gaza, Palestine". *Hydrological sciences journal*, 2004. **49**(3).
- [33] PCHR, "The effects of Closure on the Agricultural Exports in Gaza Strip - Palestinian Center for Human Rights", 2011, Palestinian Center for Human Rights: Gaza.