JOURNAL OF ENGINEERING RESEARCH AND TECHNOLOGY, VOLUME 7, ISSUE 1, APRIL, 2020

# Health Risk Assessment of Groundwater Contamination Case Study: Gaza Strip

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**https://doi.org/10.33976/JERT.7.1/2020/2**

**Abstract**—Gaza Governorates are suffering from shortage problems and poor quality of groundwater that is being pumped from 281 municipal wells. According to the latest data available at the Palestinian Water Authority (PWA), the water consumption can be distributed on municipal consumption 96.428 MCM and agricultural sector consumption 95.3 MCM. The annual recharge is less than the pumping rate with more than 90 MCM; resulting in declining water level, sea water intrusion and hence high chloride concentrations. Nitrate levels are increasing due to the improper systems of wastewater disposal, excess use of fertilizers and landfill leachate. The nitrate level exceeds the WHO limit in more than 90.6 % of Gaza Governorates municipal wells for the year 2018 (223 wells from a total of 245 wells. Due to the health impacts of nitrate, health risk assessment was conducted based upon the available quality data of 245 municipal wells. The risk assessment method adopted by the United States Environmental Protection Agency was utilized in this study. Three categories of receptors were assessed; infants, children and adults. The study revealed that the health risk values for adults is acceptable in 22 wells only while it is unacceptable in the other 223 wells. For children and small infants, the situation was riskier and the study outlined that none of the municipal wells in Gaza Governorates was suitable for drinking purposes for these two categories of people. The study recommended that actions should be taken to minimize the risk associated with drinking groundwater, looking for alternative water resources is to be seriously considered, community participation should be encouraged, people should know that their source of water is unsuitable and further studies that consider the impact of nitrate in groundwater on the public health in Gaza Strip should be performed.

**Index Terms**— Gaza Governorates, nitrate, municipal wells, health risk assessment, groundwater, public health.

## I. INTRODUCTION

Gaza Strip is a narrow area located along the coastal southwestern zone of the occupied Palestine just near the Mediterranean Sea. It is divided into five governorates with a total are of about 365 $km^2$ and a population of about 2 million. High current and expected future population growth rates will undoubtly lead to greater impacts on natural resources, especially the water. The over pumping of the Gaza groundwater aquifer (the only source of water) has resulted in continuous declining of the local groundwater levels and degrading its quality. Seawater intrusion and up-coning of deep brine water are considered as the major challenges impacting the existing groundwater in Gaza Strip. As Gaza strip is located in an arid area with an unsustainable water resource, it faces serious problems of water in terms of quantity and quality. According to the water budget components of Gaza Strip, it can be realized that the water resources in Gaza are usually fluctuating around a stationary average, while the population is increasing continuously. The higher natural population growth rate of Gaza Strip (as indicated by many organizations as the highest rate in the world) has transformed water to a chronic and worsening imbalance in the population – water resources equation (Qrenawi, 2007, Eldadah et al., 2007, Qrenawi et al., 2002).

The present state of the water sector in Gaza is distressing and has been described by many organizations as a humanitarian crisis. The main source of domestic and agricultural water is the groundwater, which is almost totally polluted and at the present yields a flow of unacceptable quality for domestic usage. The amount of water available to the people of Gaza is also insufficient, while its deteriorated quality causes large adverse public health impacts. According to the latest data available at the Palestinian Water Authority (PWA) database, the water consumption can be distributed on the different sectors as follows: municipal consumption 96.428 MCM (52%); of which 13 MCM is suitable for drinking purposes and agricultural sector consumption 95.3 MCM (48%) (WRD-PWA, 2014, WRD-PWA, 2018). The annual net deficit in the groundwater aquifer in 2016 is about 90 MCM and predicted to reach 180 MCM by 2035; indicating that the only source of fresh water in Gaza Strip is

being drastically over pumped and hence the aquifer is showing clear signs of irreversible failure or collapse, with quickly advancing the deterioration of the Gaza water resources in terms of both quality and quantity (Aiash and Mogheir, 2017, Eldadah, 2013).
The water municipal consumption varies slightly according to the time of the year; August is the month having the maximum consumption while February has the minimum consumption. Figure 1 outlines the annual municipal water consumption for Gaza Strip Governorates in 2018. According to the data available at PWA, this amount of water was extracted from 281 municipal wells distributed all over the Gaza Strip; as shown in Figure 2 (Eldadah et al., 2007, WRD-PWA, 2018).

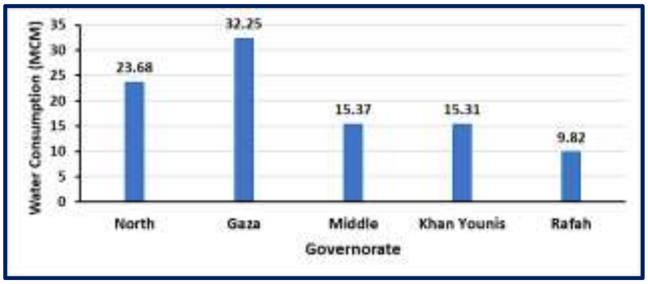


Figure 1 Municipal Water Consumption in Gaza Governorates (WRD-PWA, 2018)

Currently, groundwater extraction is far exceeding the rate of aquifer recharge. The level of groundwater is declining and the chloride concentrations are increasing, these results are expected; rendering the water unsuitable either for drinking or irrigation purposes. The random disposal of raw wastewater and solid waste to the ground surface and the uncontrolled use of fertilizers have also contaminated groundwater and raise the nitrate levels in certain areas to unacceptable concentrations (Eldadah et al., 2007).
Recently, and due to the continuous degradation of groundwater quality in Gaza Strip, public attention has significantly grown and has concentrated on anthropogenic causing of the problem. The Gaza Strip Aquifer is the most important source of water to agricultural, domestic, and industrial demands (Lubbad and Al-Yaqoubi, 2007).
The nitrate concentration in groundwater has increased in the last years; this phenomenon has primarily taken place in the coastal area, where the water sources are close to population clusters and to industrial and agricultural regions. The increased accumulation of nitrates in groundwater is responsible for creating health dangers to the population who are using this contaminated water (Lubbad and Al-Yaqoubi, 2007). In this paper, health risk assessment – a decision support tool – of groundwater contamination by nitrate will be presented; risk management will also be outlined.

## II. Literature Review

### Sources of Nitrate:

Nitrate is considered as a stable oxidized form of the combined nitrogen in the majority of environmental media. Different sources of the combined organic or ammonia nitrogen can be considered as the main source of nitrate, this is due to the fact that most of nitrogenous compounds in water tends to be transformed with a certain means to nitrate. Nitrates exists naturally in mineral stores including sodium or potassium nitrate, in soils, seawater, freshwater sources, the atmosphere, and in the animal and plant life. Main nitrate sources include, but not limited to, agricultural fertilizers, wastewater, landfill leachate, and livestock waste (Shelton and Lance, 1999).
For the case of Gaza Governorates, nitrate is commonly incorporated into groundwater source through widespread or diffuse sources, normally known as non-point sources, which can't be easily identified. Point source contaminants are also a major cause of contamination. By looking at the land use map of Gaza Strip, one can conclude that the agricultural activities are mainly located in the eastern part which has a thick unsaturated zone with very low permeable layers, while the urban areas are located mainly in the western part which has a relatively thin unsaturated zone with high permeable sandy soil.

Figure 2 Location Map of Municipal Wells in Gaza Strip (PWA, 2018)

The routine analysis results of nitrate for different wells located in different agricultural and urban locations showed that the problem is particularly serious in public water supply wells as these are mainly located in un-sewered urban areas. These areas rely on cesspits for wastewater disposal which is basically not an efficient system of disposal. Wastewater infiltrates into the soil, which is mostly sandy of high permeability to the groundwater leading to the high levels of nitrate. Main causes of high nitrate in groundwater of Gaza are:

- Infiltration of untreated wastewater in cesspits, septic and sewage discharges.
- Leaching of chemical fertilizers.
- Landfills' leachate (Lubbad and Al-Yaqoubi, 2007).

#### HEALTH IMPACTS OF NITRATE:

Nitrate is an inorganic dissolved substance that may generally found in groundwater samples. Nitrate is naturally an occurring chemical in the environment as a component of the nitrogen cycle. Relatively, the small amount of the nitrate found in natural waters is of mineral origin, most of it is coming from organic (solid waste and wastewater discharges) and inorganic sources (artificial agricultural fertilizers). However, oxidation by bacteria and nitrogen fixation by plants can both result in the formation of nitrate. High levels of nitrate and nitrite can cause dangerous illness due to acute exposure. High concentrations of nitrate in drinking water cause both environmental and health concerns due to its toxicity. Methaemoglobinaemia, or known as blue baby syndrome, is the major health concern attacking infants that are bottle fed with formula prepared with drinking water (CAWST, 2009, Shelton and Lance, 1999, EPA, 2001).

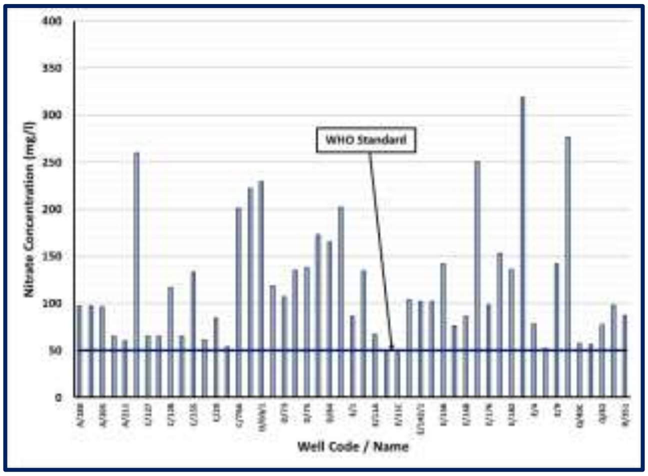
Nitrate toxicity results since the human's body reduces nitrate to nitrite. This reaction occurs in human saliva at all ages and in the infants' gastrointestinal tract within the first three months of life. Nitrite toxicity is demonstrated by vasodilatory/cardiovascular impacts at high dose levels and methemoglobinemia at lower dose levels. Methemoglobinemia is an impact in which oxidation of hemoglobin to methemoglobin takes place; and hence asphyxia results. Infants up to the age of three months, the most sensitive population to nitrate. This can be figured out by the fact that; in the case of adult and child, approximately 10 % of the taken in nitrate is converted to nitrite, while 100 % of taken in nitrate by the infant can be converted to nitrite. The impacts of methemoglobinemia are quickly reversible, and there are, therefore, no accumulation of these impacts. It results in the difficulty of breathing and turning skin to blue due to the absence of oxygen. It is a dangerous case that can sometimes cause death (CAWST, 2009, Shelton and Lance, 1999).

Due to the insufficient data of animal and humans, the EPA classifies both nitrate and nitrite as Group D contaminant. For the case of infants, nitrate compounds tend to demonstrate adverse toxic impacts. Because of the widespread occurrence of this toxicity in water, nitrate has been regulated.

Recent advances in research have proved that nitrate of high concentrations may cause cancer for adults. The World Health Organization (WHO) stated that the concentration of nitrate in drinking water should be < 50 mg/L. This regulation is set to protect the bottle-fed infants, in the short-term exposure, from methaemoglobinaemia illness. (Shelton and Lance, 1999, Qrenawi, 2006, CAWST, 2009).

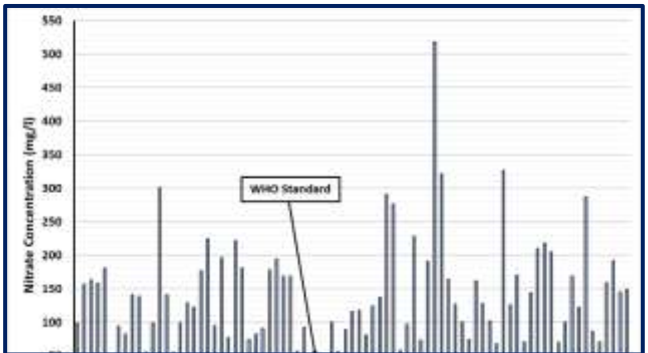
## III. SIGNIFICANCE OF THE RESEARCH

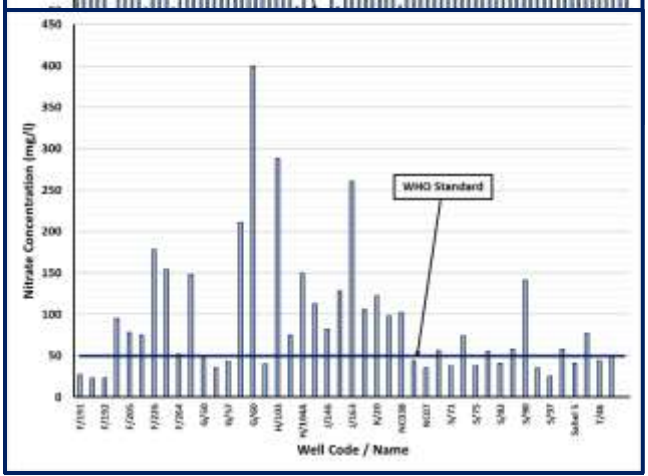
While the guideline stated by the WHO for nitrate is 50 mg/l, and it exceeds 300 mg/l in some areas of Gaza Strip. Since groundwater is the most important potable water source in Gaza strip; this encourages the researchers to be care of performing health risk assessment of groundwater contamination in Gaza Strip. Figures 3 to 7 outline the nitrate concentration in Gaza Governorates in the year 2018




for 243 municipal wells.

Figure 3 Nitrate Concentration in Northern Governorate



Municipal Wells (PWA, 2018)

Figure 4 Nitrate Concentration in Gaza Governorate Municipal Wells (PWA, 2018)

Figure 5 Nitrate Concentration in the Middle Governorate Municipal Wells (PWA, 2018)

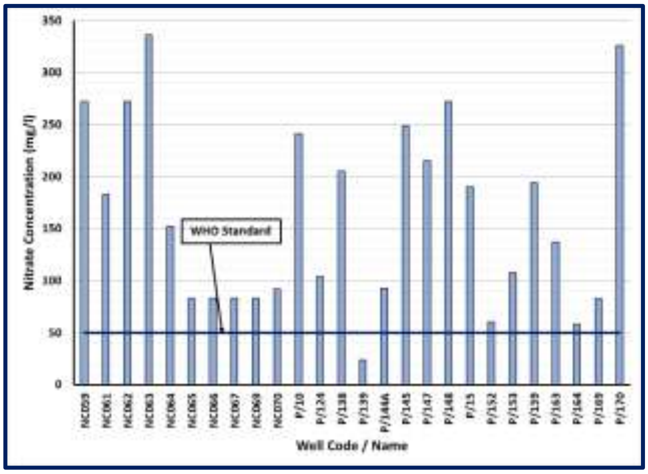



Figure 6 Nitrate Concentration in Khan-Younis Governorate Municipal Wells (PWA, 2018)

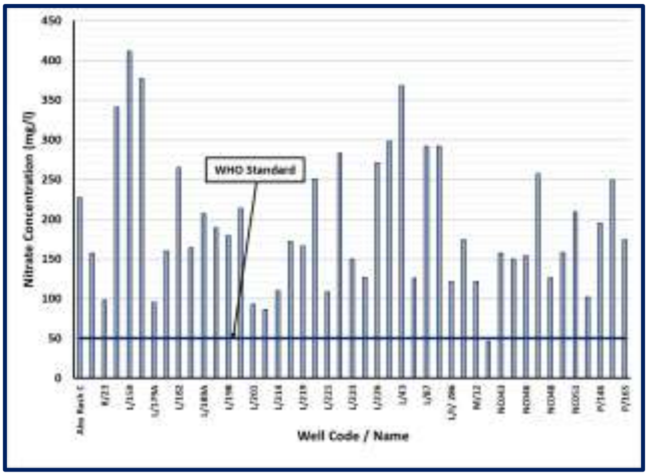



Figure 7 Nitrate Concentration in Rafah Governorate Municipal Wells (PWA, 2018)

Due to the unstable political issue in the Palestinian territories and its negative impacts on the security and socio-economics, the water situation in Gaza Strip became worse in terms of water quality deterioration, water depletion and water supply system efficiency. By referring to the previous figures, one can conclude that nitrate level exceeds the WHO limit in more than 90.6 % of Gaza Governorates municipal wells for the year 2018 (222 wells from a total of 245 wells); indicating that the problem of water is not only a quantity problem but also a quality one.

A WHO study found a high concentration of nitrates in the water supply from wells in different localities within the Gaza Strip, and this nitrate contamination was found to be the cause of the incidence of "blue-baby syndrome" among infants in the Gaza Strip (IBRD, 2009). Whilst this disease primarily affects young children, nitrate contamination can also affect pregnant women and might increase the risk of certain types of cancer (Abu Naser et al., 2007).

(Shomar et al., 2008) stated that recent observations revealed a high positive correlation between the concentrations of nitrate in groundwater of the Gaza Strip and the occurrence of methemoglobinemia in babies younger than 6 months. Among 640 babies tested in Gaza, 50% showed signs of methemoglobinemia in their blood samples.

A study into the relationship between the concentration of nitrates in drinking water and the disease of Methemoglobinemia in children under 6 months old was conducted in 2001. Twelve primary health care centers were involved in the study and results showed a strong positive relationship between levels of nitrates and contraction of the disease. The highest incidence of the disease was found in Khan Younis coinciding with the highest levels of water nitrates. Moreover, the proportion of Methemoglobinemia incidence was highest in children between 1 – 3 months old due to their dependence on milk and hence their higher intake of nitrates, while it decreased in those between 3 – 6 months old (Ramahi, 2013).

## IV. Risk Assessment

Using risk assessment as decision making process tool has given more importance in the last two decades, because it has become evident that different statuses cannot be easily referred to as either safe or unsafe (Langley et al., 2002). Risk does not have a specific and clear definition; everyday language uses the term risk to indicate a chance of danger or catastrophe. When used in the risk assessment theme, it has a concise definition; the combination of the probability or frequency of occurrence of a defined hazard and the magnitude of the consequences of the occurrence. Or it is the systematic steps that determine the potential effects of a chemical, physical, microbiological or psychosocial hazard on a certain human population or ecological system under a certain set of conditions and for a specified period of time. It is a set of logical, systemic and well defined activities that give comprehensive information to risk managers, specifically those who put policies and regulations and decision makers with a good identification, measurement, estimation and evaluation of the risk linked to specific natural incidents or man-made activities, so that the best possible decisions are made (Blumberga, 2001, Langley et al., 2002).

The risk assessment process can give a systematic concept for characterizing the nature and extent of the risks related with specific hazards. The main goal of risk assessment is to give the best available scientific, social and practical information concerning the risks, so that these information can be extensively studied and therefore the best alternatives can be formulated and hence the best decisions can be taken (Petts and Eduljee, 1994, Langley et al., 2002).

Tracking and following of risk needs an accident, pathway for transport and a receptor that could be impacted at the place of exposure. Basically, risk assessment gives a wellorganized concept for figuring out the nature and extent of the relationship between the cause and effect (Petts and Eduljee, 1994, Langley et al., 2002).

Good risk assessment needs a high level of scientific skill and objectivity and should be differentiated from the risk management process which chooses alternatives as a result of the health risk assessments process. Risk management needs scientific, social, financial and political data and also needs judgments to measure the degree of tolerance required of risk and reasonableness of expenses. Risk assessment should give a confidential, objective, applicable and equiponderant analysis (Langley et al., 2002).

#### Health Risk Assessment:

The process used to determine the potential effects of physical, biological, chemical or social agents on a certain human population under specified conditions within a certain time period is referred to as health risk assessment (Langley et al., 2002). It includes identifying, analyzing and presenting information in terms of risk to human health, to support planning and making decisions. In this process, facilitating all social and economic data concerning the decision making is not always required. Also, its approach is not intended to be a part of the planning and management processes (MOLEP., 2000).

In the past two decades, the public's consciousness of the health risks has been greatly raised despite the conducted limited risk assessment works. A great portion of the increased public awareness has raised because of the extensive risk associated with some wastes such as the nuclear waste, and the consequent dumping of such waste into the ground; this practice will transfer the toxic substances present in this waste to the groundwater and hence its contamination. The public generally do not have benchmarks for making a scientific comparison among the different threats to their health and the safety and the quality of the environment. The publics' increased awareness about the risks due to groundwater contamination has an impact not only on looking for clean and safe water, but also greatly contributed to searching for alternative safe water resources (Garrick, 2002).

#### Strengths of Risk Assessment:

- It is a mechanism that aids decision making especially the choice between options for risk reduction.
- It is a means of comparison between risks to determine whether there is equity of action or that the action is proportionate to the risk.
- It is a technique that can break down complex systems and identify areas of processes or plant where risk reduction options can be most effective.
- It clearly outlines the relationship that connects the natural environment and the human activities.
- It removes the doubt of stakeholders so that probable changes to the environment from human activities are being taken into account.
- It is valid scientifically, defensible and applicable (MOLEP., 2000).

#### Uncertainty of Risk Assessment:

Although risk assessment is a well-established scientific approach, it has some demerit. It must be recognized that the present state of knowledge concerning the impacts of specific constituent is incomplete. Thus, each step in the risk assessment involves uncertainty and the best possible utilization of available information must be ensured. In hazard identification, most assessments depend on animal tests and yet the biological systems of animal are different from those of humans. In dose response, it is often unknown whether safe levels or threshold exists for any toxic chemical. Exposure assessment usually involves modeling, with the attendant uncertainty as to substance release, release characteristics, meteorology and hydrology. Because of these uncertainties associated with risk assessment; the process gives only an estimation of the risk and not the real impacts accompanied to a certain proposed project or existing facility, so, the results of such an analysis should only be used as a guide in decision making (Langley et al., 2002, MOE, 1999, MOLEP., 2000).

To overcome these uncertainties; the worst scenario or reasonable worst scenario of hazard exposures are supposed. Using higher than the expected exposure cases confirms any expected problems and defines the dangerous pollutants or sensitive exposure pathways for more detailed study. In general, this will give and over estimation to the real risk values. The resulted risk values that exceed the environmental or human health protection standard can be considered as a warning flag, rather than a real risk or impact (MOE, 1999).

## V. Methods and Materials

#### Risk Assessment Models:

The risk assessment work is mainly dependent on deterministic approaches whose objective is to track and follow the transport of the contaminants from its source to the receptor by different pathways. These approached are usually simple, and not necessary to be complicated. The deterministic analysis models usually use the mean or the median values that are at the central part of their distributions. Another method of analysis is the use of model parameter values to foresee the risks for people of exposure more than the $90^{th}$ percentile of the population. To overcome the parameter and approach uncertainty, and to estimate the risk at different pre-selected percentiles of the population, probabilistic analysis is utilized in the risk assessment process. The outputs of such approaches can be presents as point estimates or as probabilistic risk estimates ($50^{th}$, $90^{th}$, $95^{th}$, $97.5^{th}$ and $100^{th}$ percentiles). The values of the estimated risk can be obtained for different categories of receptors; for example; adults, children, residents, etc. (Metcalf and Eddy, 2003).

### STEPS OF RISK ASSESSMENT:

Risk assessment involves four distinct steps; they are:

1. **Hazard Identification:** It includes defining the pollutants that are assumed to pose human health hazards, measuring their concentrations in the environment and identifying the exact form of toxicity and the conditions under which these forms of toxicity may be found in exposed population. The step also includes determining the available evidence and specifying whether a substance or pollutant causes a certain adverse health hazard. As a part of hazard identification, evidence is gathered on the potential for a substance to cause negative health impacts to human or unacceptable environmental impacts. For humans, the principal sources of this information are clinical studies, controlled epidemiological studies, experimental animal studies and from evidence gathered from accidents and natural disasters (Garrick, 2002, Metcalf and Eddy, 2003).
2. **Exposure Assessment:** Exposure is the method by which the hazard comes into contact with the organism; exposure or access is the path that links the gap between the hazard and the population. For humans, exposure can occur through different pathways including air breathing, food ingestion or water drinking, absorption through the skin either via dermal contact or exposing to radiation. The main steps of exposure assessment are: defining the expected receptors from a given population, evaluating pathways and routes of exposure and quantifying the amount of exposures (Garrick, 2002, Watts, 1998, Metcalf and Eddy, 2003).
3. **Dose Response Assessment:** The fundamental goal of this step is to define a relation – usually mathematical – between the toxic substance quantity to which human is exposed and the risk (unhealthy response) of that dose in humans. Typical dose response models that have been proposed and used for human exposure include: the single hit model, the multi-stage model, the linear multistage model, the multi-hit model and the probit model (Metcalf and Eddy, 2003).
4. **Risk Characterization:** It is the last step in risk assessment, in which the question of who is affected and what are the likely effects are defined to the extent they are known. It involves the integration of hazard identification, dose response, and exposure assessments. It gives a general evaluation of the whole risk assessment process quality, as well as the confidence levels the assessors will have to estimate the risk and to formulate conclusions. It provides a risk description to individual persons and to communities in terms of extent and sharpness of potential harm. This step also connects the outputs of the risk assessment process to the risk manager (Garrick, 2002, Metcalf and Eddy, 2003).

For carcinogenic pollutants, human exposures were transformed into a lifetime cancer risk. Many standards specify a lifetime risk of 0.000001 or $10^{-6}$ or less to be insignificant. For pollutants responsible for other effects of toxicity – lung disease, birth defects or nerve damage – exposure to such pollutants is compared to an established standards of health protection, and the exposure ratio is then estimated. Obtaining a ratio < 1 indicates that minimal or no negative health impacts are expected (MOE, 1999).

Based upon the previous steps, the risk value can be calculated by using the Equation adopted by Watts, 1998.

$$I = \frac{CW \times IR \times EF \times ED}{BW \times AT} \qquad (1)$$

$$Risk = HI = \frac{I}{RfD} \qquad (2)$$

Where;

I = Daily intake (mg/kg.day)
CW = Contaminant Concentration (mg/l)
IR = Ingestion Rate (l/day)
EF = Exposure Frequency (days/year)
ED = Exposure Duration (years)
BW = Body Weight (kg)
AT = Averaging Time (years)
HI = Hazard Index
$R_fD$ = Reference Dose

## VI. RESULTS AND DISCUSSION

Nitrate, a soluble non-carcinogenic chemical, will be used in the risk assessment task. It is a pollutant that has a reference dose ($R_fD$) of 1.6 mg/kg/day and the exposure route is ingestion. Nitrates level in excess of 150 mg/L poses an extreme risk to infants' health in the form of blue baby syndrome. Moreover, high nitrates may have carcinogenic effects for adults (Sharma and Reddy, 2004, Agha, 2006). The concentrations for the years 2007, 2011, 2015 and 2018 of municipal wells in Gaza Governorates will be used in risk assessment calculation and presentation.

By referring to Figures 8 to 11, it is clear that the risk value of adults is acceptable (slightly less than 1) in 27, 45, 38 and 22 municipal wells only for the years 2007, 2011, 2015 and 2018 respectively. This indicates that these wells may be used for municipal purposes. Most of these wells are located the Middle and Gaza Governorates. Few of them are located in Rafah, North and Khan Younis Governorates. This unbalanced distribution is due to intensive agricultural activities the Northern and Rafah Governorates and lack of full sewage network coverage in Khan Younis Governorate. The remaining wells all over the Gaza Strip can't be used for some municipal purposes since the associated health risk to its direct use is unacceptable. Therefore, the probability the appearance of adverse health effects on people who drink this water is high. It is worth to mention that the number of suitable wells for municipal purposes increases in the year 2011 due to digging new wells in Al-Mawassi area (that has good water quality). Unfortunately, the quality of this water is deteriorated immediately. This is because Gaza aquifer is over pumped with four folds of its sustainable yield, resulting in sweater intrusion.

The situation is riskier for the case of children (as indicated in Figures 12 to 15) once they depend on theses municipal wells for drinking purposes. For the case of infants, the situation is the riskiest once they depend on theses municipal wells for drinking purposes, as shown in Figures 16 to 19.

By referring to Figures 12 to 19; one may conclude that the risk value for children and small infants is unacceptable in almost all wells of Gaza Governorates. For the case of children, the number of wells with acceptable risk value is 3, 5, 1, 0 wells for the years 2007, 2011, 2015, and 2018 respectively. On the other hand, for the case of infants, only 2 wells had acceptable risk value for the year 2011. Currently, none of the wells is suitable for drinking purposes for children and infants all over Gaza Strip. Be referring to the risk values for the year 2018, it is noted that the smallest value of the risk for the children is 1.5 while for infants it is 2.1 (>1), which is unacceptable while the largest value is > 30 and 40 for children and small infants respectively; which is extremely risky.

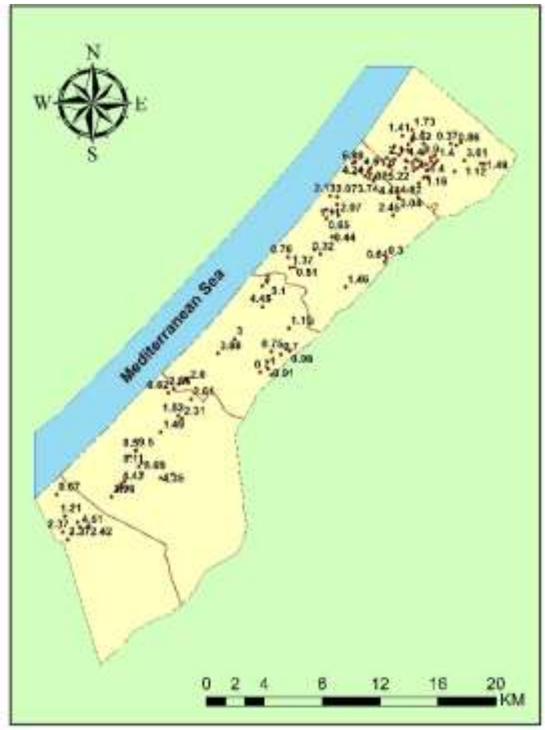



Figure 8 Risk Map for Adults (2007)


Figure 9 Risk Map for Adults (2011)

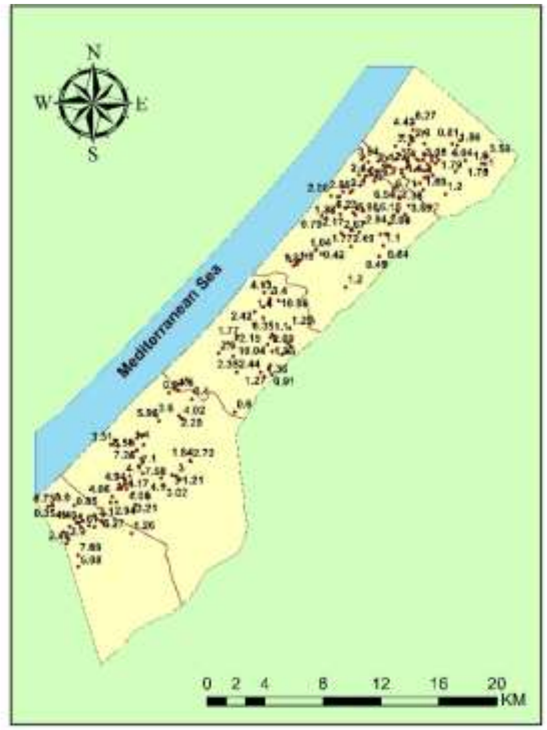



Figure 10 Risk Map for Adults (2015)

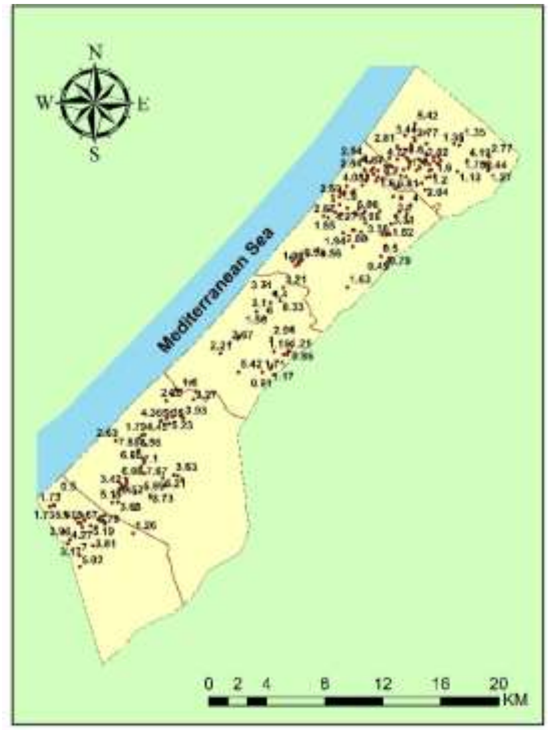



Figure 11 Risk Map for Adults (2018)


Figure 12 Risk Map for Children (2007)


Figure 13 Risk Map for Children (2011)


Figure 14 Risk Map for Children (2015)

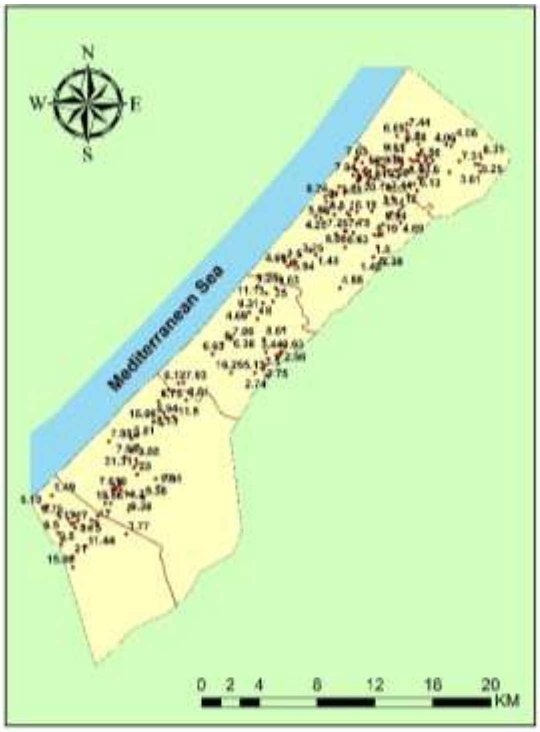



Figure 15 Risk Map for Children (2018)


Figure 16 Risk Map for Infants (2007)


Figure 17 Risk Map for Infants (2011)


Figure 18 Risk Map for Infants (2015)

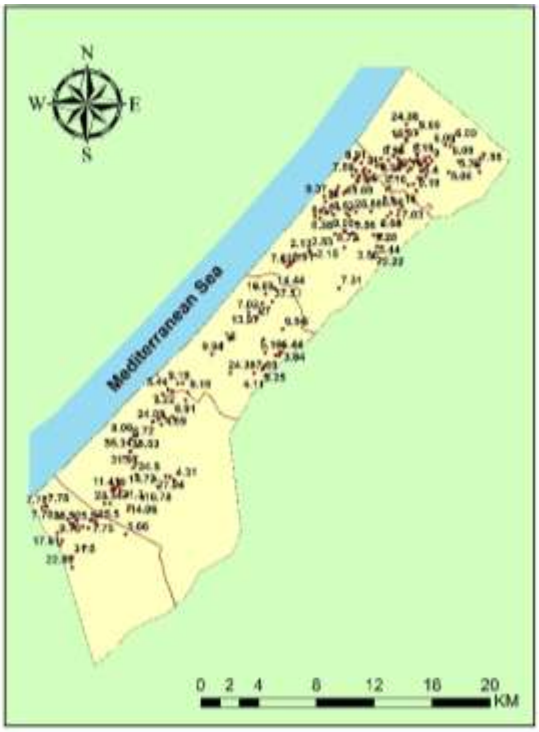



Figure 19 Risk Map for Infants (2018)

The causes of higher risk values for small infants and children than adults are that; the dose is normalized to the body weight which is small for children and infants in addition to that the immunity system of children and infants is still feeble. Groundwater should not be used for drinking purposes to children and small infants all over the Gaza Governorates.
In Gaza Governorates, it is recognized that the health risk value due to drinking of groundwater is acceptable for adults at a very limited number of wells, while it is un-acceptable at all for small infants. The risk value is expected to increase in the future since the concentrations of nitrate are likely to increase unless immediate actions and intervention plans are taken.
Qrenawi in 2006 performed risk assessment of drinking groundwater in Northern Jordan. The study was supported by experimental measurements and the health risk values were acceptable for adults ($0.269 < 1$) while it was unacceptable for small infants ($1.037 > 1$). The outcomes of these studies indicate that the problem of groundwater contamination is a regional problem and therefore efforts are to be united and cooperation should be implemented to the highest levels to find reliable solutions.

## VII. Risk Management

Risk assessment alone gives a quantification of the risk (numeric value); however, the risk assessment is usually performed through risk management. Risk management is considered as a decision making process and is based on a quantitative value obtained from risk assessment coupled with judgment and experience (Watts, 1998). The primary function of risk management is to propose mitigation options that should minimize the risk and this can be accomplished by different actions, including: avoidance of the action, lowering the amount of the action, correcting the impacts by rehabilitation or restoration, compensating for the impact by providing substitute resources or environments (Petts and Eduljee, 1994).
Risk management is commonly described as the process of evaluating alternative regulatory or other actions directed at reducing the health risk, and selecting among these alternatives. The selected alternative should be applicable, for example; reducing the risk values in Gaza Governorates' wells to the acceptable levels needs the reduction of nitrate to 50 mg/l, 16 mg/l and 11 mg/l for adults, children and small infants respectively which is not applicable at this time for the case of children and small infants due to the current local complicated situation.
Health risk can be managed when dependency of groundwater for drinking purposes is reduced or eliminated. Residents of Gaza Governorates have the right to know that their sources of water are contaminated to unsafe levels.

## VIII. Conclusions and Recommendations

- The problem of groundwater in Gaza Governorates is a combined one since it is a quantity and a quality problem.
- The health risk values for adults are acceptable in only 8 municipal wells in Gaza Governorates which means that 237 wells should not be used for some municipal uses and direct drinking without proper treatment.
- The risk values for small infants is unacceptable in all municipal wells in Gaza Governorates indicating that none of them is suitable for drinking.
- The main sources of nitrate in Gaza Governorates are: infiltration of untreated wastewater to the subsurface layers, leaching of chemical fertilizers and landfills' leachate.
- The problem of groundwater contamination is a regional problem that needs gathering efforts to find suitable and sustainable solutions.
- Risk assessment is widely used in the last decades as a powerful decision support tool.
- Immediate actions should be taken to minimize the risk associated with drinking groundwater to the acceptable levels in order to protect the public health of people who rely on this groundwater.
- Looking for alternative water resources is to be put on the top of the agenda of responsible authorities to play their roles so that the public health is protected.
- Community participation should be encouraged through education and awareness campaigns. Schools, universities and Non-Governmental Organizations (NGOs) have the right form to conduct such activities.
- Residents of Gaza Governorates who depend on groundwater in drinking have the right to know that their source of water is unsafe.
- Further studies that consider the impact of nitrate in groundwater on the public health in Gaza Strip should be performed. These studies are to be supported by field surveys and reviewing medical reports to find a relationship between nitrate concentration and accompanied diseases.

## IX. Acknowledgements

This work has been performed during the study at PhD Program in Water Technology, Civil Engineering Department at The Islamic University of Gaza. Special thanks are directed to the Middle East Desalination Research Centre (MEDRC) for their fellowship and financial support, and for the Palestinian Water Authority (PWA) for providing data.

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