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Framework Analysis of Socio-Economic and Health Aspects of Nitrate Pollution from Urban Agricultural Practices: The Gaza Strip as a case Study

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Abstract

Increased level of nitrate up to 300 mg/l have been detected in groundwater beneath the Gaza Strip, as a result of extensive use of fertilizers. Nitrate concentrations more than 50 mg/l are very harmful to infant, fetuses, and people with health problems. The research carried out in the Beit Lahia village, where strawberry, potato and vegetables in greenhouses irrigated by groundwater wells and citrus irrigated by treated wastewater in Sheikh Ejleen area to investigate the quantities of nitrate washed out in the areas under different crop patters. Additionally the socioeconomic and health aspects of nitrate pollution in the groundwater are investigated. The irrigation of potato, strawberry and greenhouses by groundwater with added fertilizers leading to the human nitrate exposure level of 4667.4, 7618.3 and 7893.3, respectively. Due to the relatively low level of nitrate in treated effluent compared with nitrate in groundwater which was used to irrigate citrus, the human nitrate exposure level accounted for 3244.6. The greenhouses in BeitLahia in sandy soil demonstrated the highest human nitrate exposure level. It is highly recommended to consider the high nitrate content of groundwater wells for irrigation purposes to minimize the input of chemical nitrate fertilizer and to break the cycle of increasing nitrate input to the groundwater from agricultural sector.

Keywords: BeitLahia, Exposure level, Nitrate, Pollution, Potato, Sheikh Ejleen and Strawberry

Introduction

Water quality in the Gaza Strip is highly contaminated, most of the water of the coastal aquifer can be classified as saline and highly nitrate concentration (Qahman et. al, 2005; Hamdan et. al., 2007; PWA, 2013).

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In order to overcome such problems, it needs to have good management approach to balance the abstraction rate from the aquifer and the recharge to achieve the sustainability. (Hussein, 2005). The main cause of nitrate pollution is refer to two sources; the inflow filtration from irrigation systems where the water resources in the Gaza Strip is highly contaminated and the other source is the intensive application of nitrogen. The former use of septic tanks prior to wastewater collection networks installations left high nitrate accumulation in the groundwater. (Mitchell et al., 2003; Babiker et al., 2003; Almasri and Kaluarachchi, 2005; Santhi et al., 2006; Tait et al., 2008).

Nitrate in groundwater in the Gaza Strip has become a serious problem in the last decade as a result of extensive use of fertilizers, discharging of wastewater from treatment plants, and leakage of wastewater form cesspools (CMWU, 2013). In order to identify the most effective nitrogen source to the groundwater, it was found that the land use has great influence on nitrate accumulation in the groundwater (Shomar, 2011; Al-Najar, 2011; PWA, 2013). It has been estimated that indigestion of water containing higher nitrate concentrations causes methaemoglobinaemia i.e. infant cyanosis or blue-baby syndrome in the United States of America (Knobeloch, et. al. 2000; Smith, 2009). A study by Al-Absi, 2008 on Six hundred forty child blood samples were randomly selected from paediatric hospitals in Gaza Strip and analyzed for methemoglobin concentration. The investigation indicates that the prevalence of methaemoglobinaemia in Gaza Strip is considerably high and the average abnormal cases with varied percentage suffering from methaemoglobinaemia is equal to 72-75 % of the total studied cases.

To avoid the nitrate effect on the humans is to stop the source of pollution. Many wastewater reuse pilot projects demonstrations carried out in the Gaza Strip prefacing large scale projects in the scene future. The current pilot experiments principally aim to demonstrate the practical feasibility of treated wastewater for agricultural purposes considering the sustainable development, which should take into account the technical, economic and social constrains (Nassar, et al. 2009). The fertilizing potential of treated wastewater becomes a source of pollution for the environment and deteriorates aquifer due to high nitrogen content.

The problem is exacerbated under using uncontrolled treated wastewater effluent with high nitrate content in the majority of agricultural areas leading to high nitrate concentration in the groundwater aquifer exceeding 600 mg/l in many wells particularly in BeitLahia and Khan Younis (PWA, 2012).

Accordingly, there is bad need to review and highlight the socioeconomic dimensions of wastewater reuse as well as the health impacts in line with the technical aspects of wastewater reuse schemes to break the cycle of input to the environment and to protect the human health. In the Gaza Strip, manure and organic fertilizers are applied intensively without control. The sink of all applied nitrogen infiltrates to the groundwater the main source of water supply for Gaza residents. (Jarboo and Al-Najar, 2014). The nitrate concentration in the majority of agricultural wells is also relatively high, with typical values of 50-300 ppm (PWA, 2012). A large portion of the excess nitrogen is washed down with the irrigation return flow especially in BeitLahia where the sandy soils characterized by little capacity to absorb the ammonia anion and this makes the groundwater highly vulnerable to contamination (Muhammetoglu, et. al. 2005). The goal of the present empirical research is to highlight and propose a framework for investigating the socio-economic and health aspects of pollution by nitrate resulted from water and wastewater reuse in agriculture in the current pilot projects irrigated by groundwater and treated wastewater in the Gaza Strip. The importance of the current research is the consideration of the preventive measure of nitrogen rather than medical treatment of nitrogen pollution effect on the children and old people.

Experimental approach and Methodology

The approach used in this research introduced the sources and sinks of nitrogen that are affecting the soil and groundwater system in BeitLahia village and Sheikh Ejleen area in the Gaza Strip. Soil conditions, type of crop and climate may influence the N-balance considerably. Therefore different balances have been calculated for the following locations/crop/soil types as the following: BeitLahia village: strawberry, Potatoes and greenhouses cultivated on sandy soil. Sheikh Ejleen area: citrus cultivated in loamy sand. The main components in the agricultural nitrogen balance were taken into account in the research are N-application as fertilizer, N-application as organic manure, N-application as irrigation water from groundwater and N-uptake by plants.

Soil samples before cultivation and after harvesting analyzed for N_{min} at three different depths (0-30, 30-60, 60-90 cm).

All soil samples were air dried, ground to pass a 2-mm sieve, extracted with 0.01M $CaCl_2$ solution (1:5 soil /extractant.1 h of shaking) and analyzed calorimetrically in a continuous flow analyzer (Houba et al., 1987).

N leaching was calculated from the difference in N_{min} content of the soil (0-90) between March and September 2013. Irrigation water from the groundwater (wells) and the treated effluent were analyzed for its nitrogen concentration as well as the irrigation quantities are registered to calculate nitrogen input through irrigation water.

A questionnaire made for sixty farms at BeitLahia to find out the types and amount of fertilizer which used in agriculture for different crops as the following: 25 farms of strawberry, 20 greenhouses and 15 farms of potatoes.

Results and Discussion

N-balance of different Crops Cultivated on Sandy Soil (BeitLahia – Irrigated by Groundwater)

Typical amounts of nitrogen that farmers apply for strawberry from different sources such as mineral fertilizers; Ammoniac and 19-19-19 accounted for 63 and 57 kg N/dunum, respectively. Organic source of nitrogen obtained from manure where 26 kg N/dunum. Irrigation water from the groundwater aquifer constitutes a substantial input value of nitrogen to the agricultural lands. Considering the irrigation quantity of 1000 and 400 m^3/dunum from groundwater and rainwater with Nitrate concentration 51 and 7 mg/l, these will add 11.5 and 2.8 kg N/dunum, respectively as shown in Table 1. The annual total applied nitrogen per dunum (1000 m^2) of strawberry is 160.3 kg from mineral fertilizer, manures and irrigation water.

Table. 1: Example for Calculating the Annual Input and Source of Nitrogen Fertilizers per Dunum for Strawberry Cultivation in Sandy Soil in Beit Lahia Village

	Source of Nitrogen	N-content (%)	Application (kg/dunum)	Application (kg N/dunur
Input N-Fertilizer	Ammoniac	21	300	63
	19-19-19	19	300	57
	Manures	1	2600	26
	Irrigation water	Application (m^3/dunum)	N-content (mg NO_3/l)	Application (kg N/dunur
	Drip irrigation	1000	51	11.5
	Rainwater	400	7	2.8
	Total N			**160.3**

The strawberry uptake of Nitrogen is approximately 6-10 kg N/dunum (FAO, 2003). Because of the high N-application rate, the N-uptake is considered 10 kg N/dunum. The difference between the quantity of nitrogen input from various sources and the plant uptake is termed as N- excess/sink. It should be noted that the sink depends on the irrigation method and practice. If excess irrigation is applied, then losses of nitrogen as NO_3 form from the soil increase toward the groundwater. These chemical characteristics of nitrate make it susceptible to leaching down through the soil and into ground water (Barry, et. al. 2009). Most manure is transformed into mineral nitrogen within one or two years and depends mainly on the environmental conditions of temperature and microbial activities in the soil (Schulz, *et al.*, 2002). According to Canter, 1996 most of nitrogen form is organic in the soil concentrated on the living plants and animals which decomposed to humus. The residual nitrogen in the soil is very low due to the high solubility and infiltration to deeper layers leading to dentrification in the anaerobic sub layers. Moreover, the plant uptake is considerably high comparing to the other macronutrients in the soil (Tesoriero et al., 2000). Accordingly, a large portion of the excess nitrogen is washed down with the irrigation return flow in BeitLahia where the sandy soils have little capacity to absorb the ammonia anion and this makes the groundwater highly vulnerable to contamination by nitrate and other pollutants as well. A groundwater geochemical study is conducted for Gaza Strip showed that SO_4 and NO_3 are from wastewater infiltration and intensive agricultural practices.

Based on the standards of the World Health Organization (WHO), the groundwater in the Gaza Strip is chemically unsuitable for drinking purposes due to the high nitrate concentration (Abu Jabal, *et. al*., 2014).

Increasing plant uptake to minimize the leaching of nitrogen to the groundwater is not considered feasible while decreasing fertilizer application should be seriously considered to monitor the input of nitrogen to the soil and groundwater.

Considering the input and output of nitrogen 160.3 and 10 kg/dunum of strawberry, respectively. This means the excess (sink) of nitrogen is 150.3 kg from each dunum per year.

In the same way, the N-excess of nitrogen/sink in sandy soils cultivated with potato, citrus and greenhouses is calculated in Table 2.

The sink from Strawberry, potato, greenhouses and citrus is accounted for 136.18, 128.5, 194.9 and 97.5 kg/dunum, respectively.

N-balance of Citrus (Sheikh Ejleen – Irrigated by Treated Wastewater)

Citrus is the main consumer product of water in the Gaza Strip (MOA, 2013). The total cultivated area exceeds 37,000 dunum. The N-application is based on available data from Sheikh Ejleen Pilot Project (PWA, 2013). The threat of groundwater contamination increases under irrigation by treated wastewater on sandy soils which characterized by high infiltration rate. Determination of nitrogen pollution source is very necessary for environmental and land use stakeholders to adopt the necessary mitigation measures and regulations to prevent the leaching of nitrate to the groundwater (Lee et al., 1994; Tesoriero and Voss, 1997; Ramanarayanan et al., 1998). Many concerns should be considered such as the wastewater nitrogen content, the water table depth and the soil texture (porous, sandy). In addition to plant food nutrients, soil-related impacts of wastewater consider the plant production by: (1) The losses in the income; (2) reduction on soil fertility; (3) reduction on the land value; and (4) the expenses of mitigation measures (IWMI, 2002).

The farmers pay no attention to the available N load in treated wastewater and add more quantities of organic and inorganic fertilizers. The increase in treated wastewater amounts applied with irrigation resulted in the increase of nitrogen storage in the soil profile.

Percolation and leaching of nitrates occurs when the rainfall during the year exceeded the mean annual rain in the area and the amounts of treated wastewater applied with irrigation satisfied the evapotranspiration demands. The annual total applied nitrogen per dunum of Citrus is 97.5 kg from mineral fertilizer, manures and nitrate from treated wastewater as shown in Table 2.

Table (2): The average input, output and excess/sink of nitrogen fertilizer from 25 farms of strawberry, 20 greenhouses, 15 farms of potatoes in sandy soil in Beit Lahia village irrigated by groundwater and one farm of citrus irrigated by treated effluent in Sheikh Ejleen area.

Crop	Input (kg N / dunum)		Output (kgN / dunum)	N-excess (sink)
	fertilizers	water	Plant uptake	
Strawberry	132.24	13.94	10	136.18
Potato	131.4	7.1	10	128.5
Greenhouses	199.8	9.1	14	194.9
Citrus	116.5	10	20	97.5

Framework for Analyzing Socioeconomic and Health Aspects of Excess Nitrogen

Determination of the quantity of leached nitrate to the groundwater is not an easy issue, it refers to many parameters interacted together like the type of land use, the soil nitrogen content, soil chemistry and biological activity and soil nitrogen interaction. The nitrogen forms are changed in the soil such as mineralization of organic nitrogen, transformation of ammonium to nitrate in the aerated soil layers and the dentrification process which leads to the losses of nitrate from the soil environment. According to Meisinger et al., 2006 about 10–30% of the nitrogen additions in agricultural land reaches to the groundwater. In The Gaza Strip more than 60% of added nitrogen from different sources (irrigation water, mineral fertilizers and organic manure) constitute a potential risk to the groundwater. In general, the concern is given to the difference of input and output of nitrogen to the agricultural system casing a sink of nitrogen in the soil which is potentially will be leached to the groundwater.

Farmers in the Gaza Strip are not aware of the nitrate content of the treated effluent wastewater and keep adding the mineral fertilizers neglecting the other sources of nitrogen input. Such behavior affect both the community and the public health, therefore public awareness and education by demonstration programs should be assigned. The following calculation model is used to assess the nitrate risk to human health, the model consider the value of public health impact according to IWMI, 2001 due to the cultivation of strawberry, potato, vegetables in green houses and citrus in different areas of Gaza Strip irrigated by different water sources and various nitrogen content. The irrigation has two different effects which can be economically evaluated: The positive item (benefit) represented by the quantity of water that could be reach to the ground water and contributes to the rise of water table while the negative item (cost) is the quality of the infiltrated water which contaminate the groundwater with nitrate.

The quantity of irrigation water reach to the groundwater could be evaluated on moneywise based on the prize of the water in the region (Joosten et al., 1998; IWMI, 2002). Groundwater in the Gaza Strip is more than the source of water, it is the sign of life where domestic, industry and agriculture depend on it, at the sometime no other source of water looks in the near horizon. It is estimated that more than 30% of irrigation water reach to the groundwater CAMP, 2001). Due to the geographical location of the Gaza Strip as a coastal area the decrease of water table leads to sea intrusion casing sever deterioration of groundwater quality affects all walks of life including ecological system, food safety and security and leading to serious economic problems.

The other point of view is formulated based on the level of nitrate of the infiltrated water to the already contaminated groundwater in the Gaza Strip. Therefore the nitrate effect and impact to human health have to be determined. The parameters which should be determined as emphasized by IWMI, 2001 are: "identification of risk, estimation of human exposure, risk level based on risk per unit of intake and total potential intake". Nitrogen application rates, nitrogen leaching fraction and base level nitrate concentrations in groundwater can be used to estimate the amount of nitrates (in kg/ dunum per year) added to ground water. The incidence of nitrate-related health impacts could be measured as a ratio of human exposure level to the total water consumption. The nitrate-related human health impacts could then be evaluated using the below method of valuing public health impacts as shown in tables 3, 4 and 5.

Nitrate Risk to Human Health

Nitrate risk to human health can be estimated as follows:

Excess Nitrates: $N_e = N_t - N_c$ (IWMI, 2001)

Nitrate Risk Factor: $RF_n = (N_t - N_c) / (N_c)$

Human Nitrate Exposure Level: $HN_{el} = RF_n * PCWI$

Where

N_e is the excess nitrate in kg/dunum to groundwater

N_t is the total nitrate in kg/dunum to groundwater

N_c is the nitrate requirement of crop in kg

RF_n is the Nitrate Risk Factor

HN_{el} is the human nitrate exposure level

PCWI is the per capita water intake per irrigation season

Soil weight in the rhizosphere = Cultivated area * Root depth * Bulk density * % of wet area

Quantity of nitrogen in soil = Soil weight in the rhizosphere * Nitrogen concentration in soil

Table (3): Framework to Calculate Nitrate Risk to Human Health as a Result of Cultivation of Strawberry in Beit Lahia

Parameters	Abbre	Units	Values
Nitrogen irrigation water information			
Irrigation water quantity		m^3/dunum	1000
Total nitrogen of irrigation water (groundwater)	N_t	mg/l	22.5
Soil nitrogen information			
Area		m^2	1000
Root Height		m	0.2
Bulk density		Ton/m^3	1.2
Percentage of wet area			0.35
Nitrogen in soil		mg/kg	10
Soil weight available in root zone		Kg/dunum	84
Crop type			strawberry
Nitrogen requirement of crop	N_c	Kg/dunum	10
Irrigation system type information			
Irrigation system type			Drip
Irrigation system efficiency			80%
Per capita water intake per irrigation season	PCWI		540*
Amount nitrogen in soil		Kg/dunum	0.84
Nitrogen in chemical fertilizer and manure		Kg/dunum	132.24
Total nitrogen of irrigation water	N_t	Kg/dunum	22.5
Nitrogen available to crop		Kg/dunum	151.08
Excess nitrogen (N)		Kg/dunum	141.08
Excess nitrates that reach groundwater (NO_3)	N_e	Kg/dunum	624.8
Nitrate risk factor	RF_n		**14.1**
Human nitrate exposure level	HN_{el}		**7618.3**

*540 = 3 L/c/d * 180 day

Table (4): Framework to calculate Nitrate Risk to Human Health as a result of cultivation of Potato in BeitLahia

Parameters	Abbre	Units	Values
Nitrogen irrigation water information			
Irrigation water quantity		m^3/dunum	400
Total nitrogen of irrigation water (groundwater)	N_t	mg/l	22.5
Soil nitrogen information			
Area		m^2	1000
Root Height		m	0.25
Bulk density		Ton/m^3	1.2
Percentage of wet area			0.35
Nitrogen in soil		mg/kg	10
Soil weight available in root zone		Kg/dunum	105
Crop type			Potato
Nitrogen requirement of crop	N_c	Kg/dunum	10
Irrigation system type information			
Irrigation system type			Drip
Irrigation system efficiency			80%
Per capita water intake per irrigation season	PCWI		360
Amount nitrogen in soil		Kg/dunum	1.05
Nitrogen in chemical fertilizer and manure		Kg/dunum	131.4
Total nitrogen of irrigation water	N_t	Kg/dunum	9
Nitrogen available to crop		Kg/dunum	139.65
Excess nitrogen (N)		Kg/dunum	129.65
Excess nitrates that reach groundwater (NO_3)	N_e	Kg/dunum	574.2
Nitrate risk factor	RF_n		**13**
Human nitrate exposure level	HN_{el}		**4667.4**

Table (5): Framework to calculate Nitrate Risk to Human Health as a result of cultivation of greenhouses in Beit Lahia

Parameters	Abbre	Units	Values
Nitrogen irrigation water information			
Irrigation water quantity		m^3/dunum	400
Total nitrogen of irrigation water (groundwater)	N_t	mg/l	22.5
Soil nitrogen information			
Area		m^2	1000
Root Height		m	0.25
Bulk density		Ton/m^3	0.2
Percentage of wet area			0.35
Nitrogen in soil		mg/kg	10
Soil weight available in root zone		Kg/dunum	84
Crop type			Potato
Nitrogen requirement of crop	N_c	Kg/dunum	10
Irrigation system type information			
Irrigation system type			Drip
Irrigation system efficiency			80%
Per capita water intake per irrigation season	PCWI		360
Amount nitrogen in soil		Kg/dunum	0.84
Nitrogen in chemical fertilizer and manure		Kg/dunum	199.8
Total nitrogen of irrigation water	N_t	Kg/dunum	18
Nitrogen available to crop		Kg/dunum	218.64
Excess nitrogen (N)		Kg/dunum	204.64
Excess nitrates that reach groundwater (NO_3)	N_e	Kg/dunum	906.3
Nitrate risk factor	RF_n		**14.6**
Human nitrate exposure level	HN_{el}		**7893.3**

Table (6): Framework to calculate Nitrate Risk to Human Health as a result of cultivation of Citrus in Sheikh Ejleen]

Parameters	Abbre	Units	Values
Nitrogen irrigation water information			
Irrigation water quantity		m^3/dunum	1000
Total nitrogen of irrigation water (**TWW***)	N_t	mg/l	22.5
Soil nitrogen information			
Area		m^2	1000
Root Height		m	1.35
Bulk density		Ton/m^3	1.2
Percentage of wet area			0.35
Nitrogen in soil		mg/kg	10
Soil weight available in root zone		Kg/dunum	567
Crop type			Citrus
Nitrogen requirement of crop	N_c	Kg/dunum	20
Irrigation system type information			
Irrigation system type			Drip
Irrigation system efficiency			80%
Per capita water intake per irrigation season	PCWI		540
Amount nitrogen in soil		Kg/dunum	5.67
Nitrogen in chemical fertilizer and manure		Kg/dunum	116.5
Total nitrogen of irrigation water	N_t	Kg/dunum	22.5
Nitrogen available to crop		Kg/dunum	140.17
Excess nitrogen (N)		Kg/dunum	120.17
Excess nitrates that reach groundwater (NO_3)	N_e	Kg/dunum	532.2
Nitrate risk factor	RF_n		**6.01**
Human nitrate exposure level	HN_{el}		**3244.6**

***** TWW: treated wastewater

It is obviously shown from above results obtained from the frame work analysis, the nitrate risk to human health varies from crop to another, depending on the following factors:

1. Quantities of fertilizers added from soil and irrigation water.
2. Nitrogen uptake by plants
3. Source of irrigation water (groundwater or treated wastewater)

The nitrate risk factor in citrus is lower than the strawberry crop in spite of irrigating 1000 m^3/dunum for each while the human nitrate exposure level in strawberry records high value of 7893.3 due to the increasing of fertilizers added to strawberry.

The nitrogen uptake by strawberry is very low, therefore the quantity of N-NO_3 is very high, revealing the absence of awareness of farmers towards best management of N-fertilizers application which lead to tremendous economic losses of monetary and reflecting weak knowledge of fertilizers economics and it will lead to duplicated health problems. On the other hands citrus irrigated with treated wastewater characterized by enrich nutrient load specially NO_3 which is reasonable human nitrate exposure level due to the benefits of nutrition load from irrigation without adding chemical fertilizers. The potato cultivated in BeitLahia in sandy soil demonstrated medium value of human nitrate exposure level in comparison to strawberry and citrus due to the lower quantity of irrigation water used in seasonal manner. Soil type also plays a significant role in valuing human nitrate exposure level due to the fertilizer and water holding capacity of soil. Nitrate is easily leached and has a high mobility to the ground water because of its physio-chemical characteristics (Chowdary et al., 2005). Nitrogen is a macronutrient required for the plants to increase the plant yield and growth, but when the nitrogen added to the soil is quantities more the plants uptake, the excess nitrate leached to the groundwater specially in sandy soil and excessively irrigated fields (Shamrukh et al., 2001; Kraft and Stites, 2003; Babiker et al., 2003; Dunn et al., 2005).

Conclusions & Recommendations

The used approach in the current research is a pioneer initiation to draw the attention of decision makers and the stockholders to the level of nitrogen danger in the groundwater and the exposure level to the humans. Furthermore, the research approach could quantify the nitrogen input to the groundwater. Once the cause of nitrogen pollution is diagnosed, the preventive measures could be easily applied. The results of the questionnaires indicated that the substantial cause of the water pollution by Nitrate is the over application of fertilization and uncontrolled wastewater reuse schemes which eventually lead to groundwater pollution. Using ground water and treated effluent wastewater for irrigation purposes is source of nitrogen in the Gaza Strip, therefore the nitrogen content should be considered as a fertigation (irrigation and fertilizer) system. The nitrate risk factor varies from crop to another according the knowledge of farmers. Citrus is lower than the strawberry crop in spite of irrigating 1000 m^3/dunum for each.

While the human nitrate exposure level in strawberry records high value is due to the excessive amount of fertilizers added to strawberry. The public awareness and knowledge of socio-economic dimensions of nitrate pollutions and its related consequences are important and imperative for farmers who used over application of N-fertilizers to avoid further problems and economic losses. Further studies are needed to optimize the nitrogen input to the urban agricultural system in the Gaza Strip to prevent the exposure of humans to nitrate and to prevent groundwater pollution at the sometime increase the productivity of crops to suite the high market demand.

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