Evaluating Impacts of Recharging Partially Treated Wastewater on Groundwater Aquifer in Semi-Arid Region by Integration of Monitoring Program and GIS Technique

Case Study: North Gaza Infiltration Basin
انطلاقاً من دور سلطة جودة البيئة في الحفاظ على البيئة الفلسطينية وحمايتها، تعكف سلطة جودة البيئة على دراسة ومراقبة أثر المناطق الساخنة ببيئياً على جودة المياه الجوفية، وتشمل:

- أحواض الترشيح
  - حالة الدراسة: أحواض شمال غزة

- مكبات النفايات
  - حالة الدراسة: مكب غزة

- محطات التحلية
  - حالة الدراسة: محافظات غزة
المحتويات

Introduction

Objective

Methodology

Results and Discussion

Conclusion & Recommendations
Introduction

- The overall annual water use in the Gaza Strip is \( \sim 180 \text{ Mm}^3 \), where the overall annual supply is only \( \sim 120 \text{ Mm}^3 \) leading to an annual deficit of about \( 60 \text{ Mm}^3 \) (Al-Dadah, 2013).

- This deficit has resulted in a continuous declination of the groundwater level accompanied by groundwater quality deterioration.

- The policy by the Palestinian Water Authority (PWA) adheres the use of nonconventional water resources such as wastewater reuse for irrigation and artificial recharge of groundwater (PWA, 2011 & Al-Juaidi et al., 2014).

- The current generated quantities of the wastewater is estimated at 36.5 \( \text{ Mm}^3 \) every year (CMWU, 2013; Abunada and Nassar, 2014; UNSCO, 2012) that are produced by the municipal sewerage systems, a figure which could rise to 57 \( \text{ Mm}^3 \) annually by 2020 (UNSCO, 2012).

Most of these quantities have been disposed either to the sea or flooded to the surrounding areas after being partially treated. Consequently, a severe damage to the environment and the ecosystem is taking place.
Objective

The current study investigates the impacts of recharging partially treated wastewater from the effluent of Beit Lahia wastewater treatment plant (BLWWTP) on groundwater quality.
Project Idea

- Terminal Pumping Station
- Pressure Line (7 Km)
- 9 Infiltration Basins (8.1 hectares)
- Started operation in 4/2009
Risk Management: Effluent Recovery and Reuse Scheme includes:

✓ To mitigate the expected impact of the infiltrated wastewater on the aquifer a Recovery and Reuse Scheme is intended to be implemented.

✓ The concept of the Recovery Scheme is to capture pollution plume via 27 pumping wells by extracting 110% of the infiltrated quantities.

✓ The Recovery Scheme is surrounding the Basins from the North, South and the West (according to the expected flow of the stream).
The North Gaza Emergency Sewage Treatment (NGEST) Project was initiated in 2009 at Beit Lahia city, 9 km to the North of Gaza city with the help of Multi donor trust fund lead by the World Bank.
The current infiltration basin is the largest wastewater infiltration basin in the Gaza Strip and was constructed according to the engineering standards.

Its design capacity is about $35,600 \text{ m}^3/\text{d}$ and it can be upgraded up to $45,000 \text{ m}^3/\text{d}$ according as per the future plans.

Currently, about $20,000 \text{ m}^3$ of treated effluent from the BLWWTP is diverted daily to nine spread infiltration basins with a total base area of 32.4 hectares (ha)

Distributed to nine ponds with an average area of 3.6 ha/pond as shown in Figure 1.
Methodology

Groundwater Quality Monitoring Program

1. Sampling Program
   - Groundwater Sampling from 13 wells
   - Wastewater Sampling
   - Statistical Analysis


3. Data Analysis

Conclusion & Recommendation
Monitoring Program

1. Wells Location

- The groundwater and wastewater samples were collected from the 13 selected water wells (7 water monitoring and 6 agricultural wells).
- The wells located to the west of the infiltration basin are representing the downstream side.
- The water wells are forming two circles around the infiltration basin at a distance of 300 - 600 m from the basin.
The investigations were carried out by collecting groundwater samples from the entire boreholes around the infiltration basins in addition to samples from the recharged wastewater through a long term monitoring program between years 2011-2014.
4. Statistical Data Analysis

- Experimental data was tested for the analysis of variance (ANOVA) before testing the effects of infiltration of partially treated wastewater on groundwater quality parameters.
- The F-test was used to describe this effect.
- A probability level, p of 0.05, was used for all statistical comparisons.
5. Geographic information System (GIS) technique

✓ The Geographic Information System (GIS) was used to visualize the spatial distribution of the impact of wastewater infiltration within an area of about 600m radii around the North Gaza infiltration basin in the periods 2011, 2012, 2013 and 2014.

✓ The current study used the "Inverse Distance Weighting" (IDW), which is the most common method used to interpolate unknown points (Alslaibi et al., 2011).

✓ IDW is an interpolation method that estimates the cell values by averaging the values of a sample data points in the neighbourhood of each processing cell. The closer the point to the centre of the cell being estimated, the more influence, or weight it has in the averaging process (ArcGIS Desktop, 2010).
Results & Discussion

1. Infiltrated wastewater characteristics

- It can be noticed that there is no considerable change in the wastewater parameters mainly pH, TDS and chloride concentrations.
- However, an increase in BOD, COD, ammonium and TSS level was noticed with time through the years 2008, 2011, 2012 and 2013.
- This quality deterioration might be due to the increase volume of generated wastewater with low treatment capacity of the BLWWTP.
- The effluent of the NGWWTP: Fit to Aquifer Recharge and Unrestricted Reuse
  - BOD$_5$ 10-20 mg/L  TSS 15-20 mg/L
A noticeable increase in the groundwater especially in 2013 which confirms that the recharging was taking place. However, this increase was fluctuating due to the continuous abstraction through the irrigation wells in the vicinity of the area.

The increase in the groundwater level is expected to continue growing once the infiltrated amount grows up to the maximum capacity of the infiltration basin (35000 m³/day).

This suggests a replenishment of the groundwater aquifer may take place once the recharging amount increases which may confirm the potential of using recharged wastewater in improving the groundwater level (Asanoa.T, & Cotruvob .J.A, 2004)
Results & Discussion ... cont
Infiltration Rate vs. Pumped Quantities

Pumping (m³/month)

Average for all basins
Infiltration Rate (same month comparison)
Infiltration rate vs quality of wastewater
Pumped quantities per month

Total Infiltrated Quantities (m³) per month
Cumulative Pumped quantities (MCM)
1. TDS

This may be due to the close level of the TDS concentration in the BLWWTP effluent compared with native groundwater.

The influent to the BLWWTP is collected from within the Gaza northern area where the TDS level in the water network is in the range of ~1000 mg/l.

Consequently, the sewage has naturally almost the same level of TDS. The chemical analyses for samples from the BLWWTP effluent showed that the TDS level is in the same range (1500 to 1700 mg/l).

However, the TDS concentrations in wells Q64, Q20 fluctuated due to pumping rate and up coning phenomena.
Results & Discussion ...cont
2. Chloride (Cl)

- It is worth mentioning that the chloride level in the agricultural wells (Q64 and Q20) was relatively high compared with other water wells which might be due to the over use and the high pumping rate from these two wells (70 m³/h).

- This was supported by the relatively high concentration of the EC (2900 μ.s/cm) for those two wells compared with others.

- This ensues that the chloride concentration in the groundwater is highly affected by the original level experienced at the BLWWTP effluent and the wastewater infiltration has improved its quality.

the wastewater passing through before it reaches the groundwater aquifer.
This results agrees with the one reported by (Icekson-Tal and Blanc, 1998) where they found that the SAT system reduced the level of the chloride in the effluent in the Dan Region from 289 mg/l where it was dropped down to 266 mg/l due to the SAT effect.
A significant drop in nitrate concentrations was also noticed in all monitoring wells compared with the base line 2008 year (P<0.05).

The closer the water well to the infiltration basin, the higher the drop in the nitrate concentration is (i.e. the drop was obvious in water wells SW, DB4, MW3, MW5 and Q53).

This reduction in nitrate level may be due to the partially treatment taking place at the BLWWTP.

On the other hand, less reduction in nitrate level was noticed in water wells which are further away from the infiltration basins (i.e. wells Q15, Q64 and Q20) at a distance of about 600 m from the infiltration basins.
Similar results were also reported for the Dan Region case (Details about Dan Region) where the total nitrogen in the applied effluent decreased by more than 70% through the SAT processes showing a significant nitrogen removal (Icekson-Tal and Blanc, 1998)
Results & Discussion ... cont

4. Ammonia (NH$_3$)

- Unlike the chloride and the nitrate levels, results of the level of Ammonia (NH$_3$) from the infiltration basin at North Gaza infiltration basin site showed a significant increase especially in year 2013 and 2014 where the maximum level of Ammonia was 1.83 mg/l and 3.66 mg/l for 2013 and 2014, respectively.

- This suggests a significant increase ($p<0.05$) compared with previous years and the 2008 baseline year (0.1 mg/l). Moreover, it was noticed that NH$_3$ level for the wells SW, MW4, MW5 and Q53, closer to the infiltration basins and lie within a 300 m radius from the infiltration basin (Figure 8), is above the allowable limit of food and agriculture organization (FAO) standards for irrigation (5-30 mg/l) after four years of wastewater infiltration (2014) compared with previous years.

- This might be due to the high concentration of Ammonia in the BLWWTP effluent in year 2013 and 2014 (88 mg/l) compared with that concentration in 2011 (4.5 mg/l).
ويوضح الشكل أن أحواض الترشيح 2 ساهمة في تدني مستوى جودة المياه الجوفية نتيجة لرفعها تركيز الأمونيا في المياه الجوفية بالقرب من أحواض الترشيح في عام 2013 عما كانت عليه في عام 2011 و2012 وازدياد رقعة المنطقة الملوثة.
5. Boron (Br)

- Boron concentration was monitored in the BLWWTP effluent between 2008 and 2013 suggesting a fluctuated level of boron where it ranged from 0.31 to 0.35 mg/l.
- This level may resulted in high Boron in the surrounding wells, with obvious increase in the closest wells to the infiltration basins. Results showed that boron concentration in the groundwater ranged between 0.02 and 0.05 mg/l in 2008 (before infiltration started) and increased rapidly to 0.4-1.56 mg/l and 0.3-1.22 mg/l in 2011 and 2013, respectively.
- These results reflect the influence of the native groundwater on boron. It suggests that the infiltration of the wastewater through the sandy aquifer has minimum to no effect on the reduction of Boron level.
The study conducted at the Dan Region (WHAT IS THIS STUDY, Give details) area, boron was removed during percolation in the early stages. However, after several months, boron was gradually increased in the recovery wells until it reached the same concentration as the effluent (Icekson-Tal and Blanc, 1998) which suggested the deterioration efficiency of the SAT system. Boron removal was minimal (1.8%) as its level was 0.54 mg/l in the applied effluent same as the level in the groundwater (Hamdan et al., 2011).
Although the quantity of the infiltrated wastewater to the aquifer is currently small compared to the basin maximum designed capacity, it has had a slight positive impact on improving the continuous declined water table level as it replenished the aquifer and increased its level by about 1.0-2.0m.

Moreover, infiltrating partially treated wastewater can pose some enhancements or risks to groundwater physicochemical and biological properties:

- The recharged wastewater can improve the quality of the groundwater aquifer once its primarily quality is better as in the case of chloride and nitrate.
- Recharged effluent increased the level of ammonium concentrations in the aquifer representing a challenge for artificial recharge of groundwater under the local conditions.
- Continuous recharge with high concentration of TSS may result in slowing down the infiltration rate due to clogging and thus early failure of SAT system.
- Boron concentration is alarming as it exceeds the FAO recommended value of 0.7 mg/l. There might be a need for an early stage treatment for boron before the wastewater being recharged to the aquifer by applying a conventional treatment technologies (metal hydroxide precipitation) to reduce the boron level.
However, the decrease in chloride and nitrate concentrations in the recipient aquifer represented good motivation to carry on such projects and to take into account the lessons learned through this project. **Care should be taken in applying pre-treatment to eliminate and reduce the unlikely parameters before being discharged or infiltrated into the groundwater aquifer.**
التوصيات

- تحسين جودة المعالجة للمياه العادمة قبل الترشيح وخاصة تركيز الأمونيا لما لها من تأثير كبير في تحسين أو تدني جودة المياه الجوفية في المنطقة. بالإضافة إلى ضرورة خفض تركيز TSS لما لها من دور كبير في سرعة تسديد الأحواض وبالتالي انخفاض معدل الرشح.

- الإستمرار في برنامج المراقبة الحالي مع الأخذ بعين الاعتبار زيادة عدد الآبار في المنطقة الغربية للمراقبة الدورية لجودة المياه الجوفية ومدى كفاءة نظام الترشيح وصلاحية آبار الاسترجاع للاستخدام من خلال تحديد الآبار الآمنة والغير آمنة للإستخدام الأدمي والزراعي وفقاً لمدى إنتشار الملوثات.

- حفر مزيد من آبار المراقبة بدورات قطرها أوسع من الدائرة المقام عليها الآبار الحالية (على مسافة أبعد) ليتسنى مراقبة أدق لمنسوب المياه الجوفية حيث أن الآبار الزراعية غير ممثلة لنظرأ للضخ المستمر منها.

- ضرورة فحص تركيز المنظفات (Detergents) في المياه العادمة المعالجة والمياه الجوفية بشكل دوري.
شكر وتقدير

تتقدم سلطة جودة البيئة بخالص شكرها وتقديرها لسلطة المياه الفلسطينية – وحدة المشاريع لتعاونها في توفير كل البيانات والتقارير اللازمة لإتمام هذه الدراسة ونجاحها. بالإضافة لتسهيل أخذ العينات في الموقع والتعاون المشترك في ذلك.


4. Institute of Water and Environment North Gaza Emergency Sewage Treatment Project (NGEST), Aquifer Water Quality Baseline Survey; Al Azhar University, Gaza, Palestine, August, 2008.


6. Institute of Water and Environment North Gaza Emergency Sewage Treatment Project (NGEST), Groundwater Quality Monitoring; Al Azhar University, Gaza, Palestine, March 2011.

7. Institute of Water and Environment North Gaza Emergency Sewage Treatment Project (NGEST), Groundwater Quality Monitoring, Fourth Round analysis; Al Azhar University, Gaza, Palestine, February, 2012

الملحق
شكراً لكم
آذاننا صاغية لملاحظاتكم
ومناقشةكم البناءة