**Annex 15 - Groundwater Quality Monitoring Plan**

# Baseline situation[[1]](#footnote-1)

## Surface Water

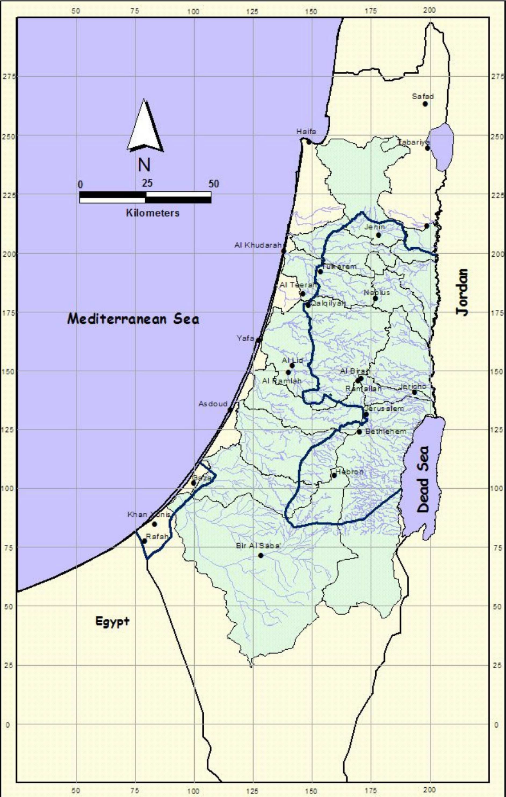
There are no permanent surface water bodies in Gaza Strip. The surface water system in the Gaza Strip consists mainly of valleys (locally named Wadis), which only flood during very short periods during winter. Wadi Gaza is the major Wadi crossing the Gaza Strip in its central part. The geographical basin of the Wadi has a large catchment area where extends far beyond Bear Esaba as shown in the figure 19 below. Since several decades, it rarely flows due to numerous water diversion and storage projects created upstream in Israel. The second Wadi is Wadi Halib which drains the depression of Beit Hanon. The third valley is Wadi Silka near Khan Younes, now a dry wash only flowing after torrential rains and no longer reaching the sea (Ubeid, 2010).

Figure 19: Wadi Gaza catchment area

## Groundwater Aquifer

Gaza coastal aquifer has a considerable value for Palestinian people being the only fresh water source able to satisfy the daily consumption needs. The aquifer occupies the extreme western edge of the shallow coastal aquifer. The coastal aquifer is generally 10-15 km wide, and its thickness ranges from 0 - 200 m at the East and the coastline, respectively.

The coastal aquifer consists primarily of Kurkar Group deposits of Pleistocene age including calcareous and silty sandstones, silts, clays, unconsolidated sands, and conglomerates. Near the coast, coastal clays extend to around 2-5 km inland, and divide the aquifer sequence into three or four sub-aquifers, depending upon location (referred to as sub aquifers A, B1, B2, and C) as shown in the figure 20 below. Towards the East, the clays pinch out and the aquifers are largely unconfined (phreatic).

Within the Gaza Strip, the total thickness of the Kurkar Group is about 100 m at the shore in the South, and about 200 m near Gaza City. At the eastern Gaza border, the saturated thickness is about 60-70 m in the North, and only a few meters in the South near Rafah. Perched water conditions exist throughout Gaza Strip due to the presence of shallow clays. The base of the coastal aquifer is marked by the top of the Saqiya Group, a thick sequence of marls, clay stones and shales that slopes towards the sea. The Saqiya Group pinches out about 10-15 km from the shore and the coastal aquifer rests directly on Eocene age chalks and limestones.

The results of aquifer tests carried out at different places in the Gaza Strip, show that the transmissivity values range between 700 and 5000 square meters per day (m2/d). The corresponding values of hydraulic conductivity K are mostly within a range of 20-80 meters per day (m/d). Most of the tested wells are municipal wells screened across more than one sub-aquifer. Hence, little is known about any difference in hydraulic properties between sub-aquifers (PWA, 2000b). The estimated effective porosity is 25%, where is the Specific yield values are estimated to be about 15-30 percent and specific storativity is about 10 - 4 (PWA/USAID, 2000b) in Selmi, 2013.

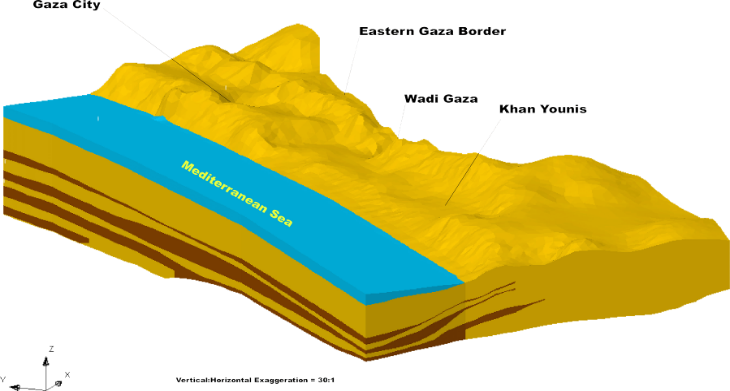


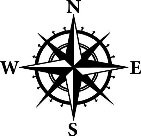
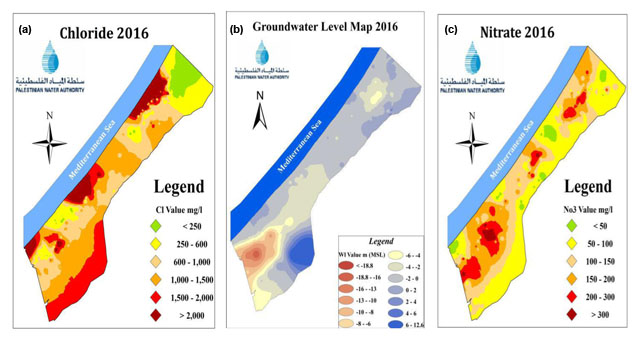
Figure 20: Geological presentation of the Gaza Strip

The total water abstraction from the aquifer in 2009 was estimated between 160 and 165 x 106 m3 while the average of replenishment was estimated between 100 – 110 x 106 m3 (HWE report, 2010), this indicates a deficit in the aquifer balance ranging from 55 to 60 x 106 m3/yr.

### Northern Aquifer

The ambient water quality in this study focused on chloride and nitrate concentrations since these are the most important contamination indicators in the groundwater in the Northern Gaza aquifer, according to historical statistics. The reference level over which the water is to be considered a source and under which the water is to be considered a sink is set as follows based on the World Health Organization drinking water guidelines: 50 mg/l for NO3, and 250 mg/l for Chloride.

The highest chloride sources are expected in the areas affected by seawater intrusion and the deeper groundwater layer. Figure 21 shows the chloride concentration map for year 2016 using the average quality values for year 2016. Examining its data, it is apparent that the seawater intrusion zone covers the western part with 2 to 3 km inland the aquifer. Most of the municipal wells were concentrated in this zone and due the high pumping rate of these wells resulted in accelerating the seawater intrusion. Generally, the chloride concentrations in the abstracted water exceed 250 mg/l in most of the Gaza Coastal Aquifer.



**Legend**

**Cl Value mg/l**

< 250

250 - 600

600 - 1000

1000 - 1500

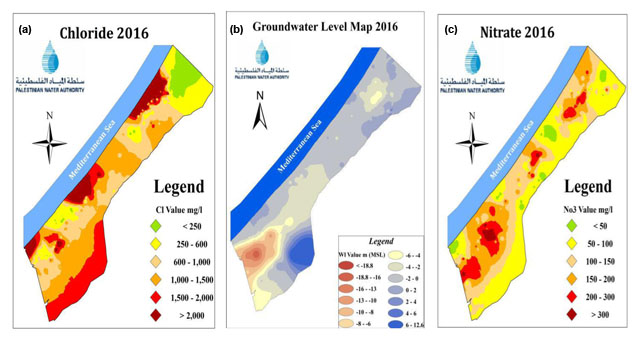
> 2000

1500-2000

Figure 21: Chloride concentration contour maps for year 2016

Figure 22 shows the nitrate concentration contour maps for 2016 using the average quality values for 2016 collected from municipal and agricultural wells. The figure shows that NO3 concentration exceeds the WHO drinking water and irrigation guidelines in most of the Northern Gaza aquifer.

In the area around the proposed infiltration site the average nitrate concentration ranged between 55 to 113 mg/l from a maximum nitrate concentration in the groundwater of 30 mg/l at the infiltration site in 2006. This indicates that the increase of the nitrate concentration is due to the operation of the infiltration basin using partially treated wastewater.



50 - 100

100 - 150

150 - 200

200-300

> 300

<50

**Legend**

**NO3 Value mg/l**

NO3 Value (mg/l)ff

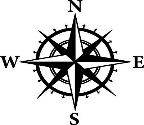


Figure 22: Nitrate concentration contour maps for year 2016

### Infiltration Site

The assessment of the aquifer water quality in the infiltration site has been based on:

* The aquifer water quality baseline survey carried out by PWA (Recovery Wells Geoinvestigations), included in Annex 4 of ESIA.
* The water sampling of the aquifer close to the basin carried out during design of the recovery scheme project through two circles as shown in Figure 23 and, the water analysis during the current project, .

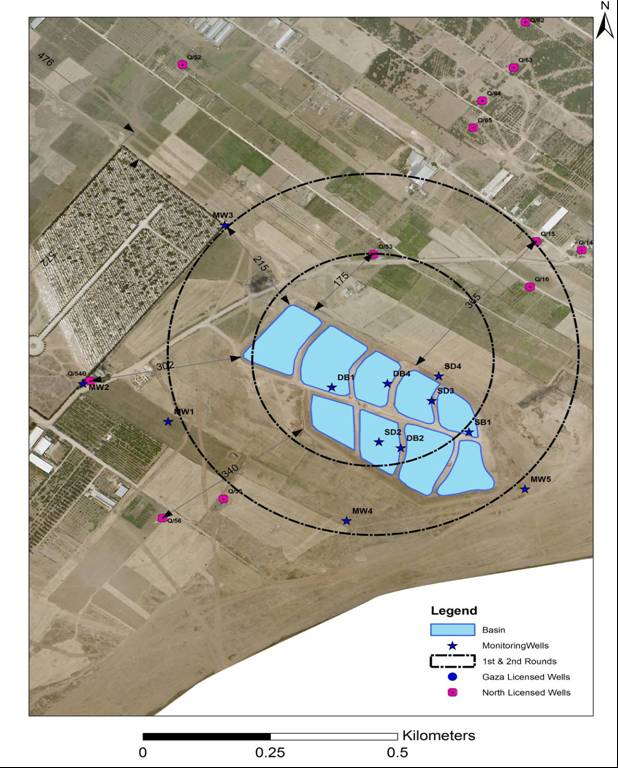


Figure 23: Location of Sampled Wells close to the infiltration basin

Figure 24 shows the results of Cl concentration in the wells close to the infiltration basin for the years 2007-2012. Chloride concentrations were found to range between 350 to 650 mg/l, after which the trend continued to be steady. Well Q53 was an exception where a decrease in the Cl concentration was exhibited, dropping from 610 mg/l in 2009 to 350 mg/l in mid-2012. This could have been as a result of the operation of the infiltration basin. The well is around 175 m from the basin which indicates that the infiltrated wastewater reached this well since the Cl concentration of this well is very close to the value of Cl concentration on the infiltration basin (around 330 mg/l).

Examining Figure 25, it can be seen that the steady trend is maintained, ranges being around 350-400 mg/l. The chloride values of the agricultural well Q53 is also in line with the results of the first stage recovery wells, where chloride concentrations have been found within the same range.

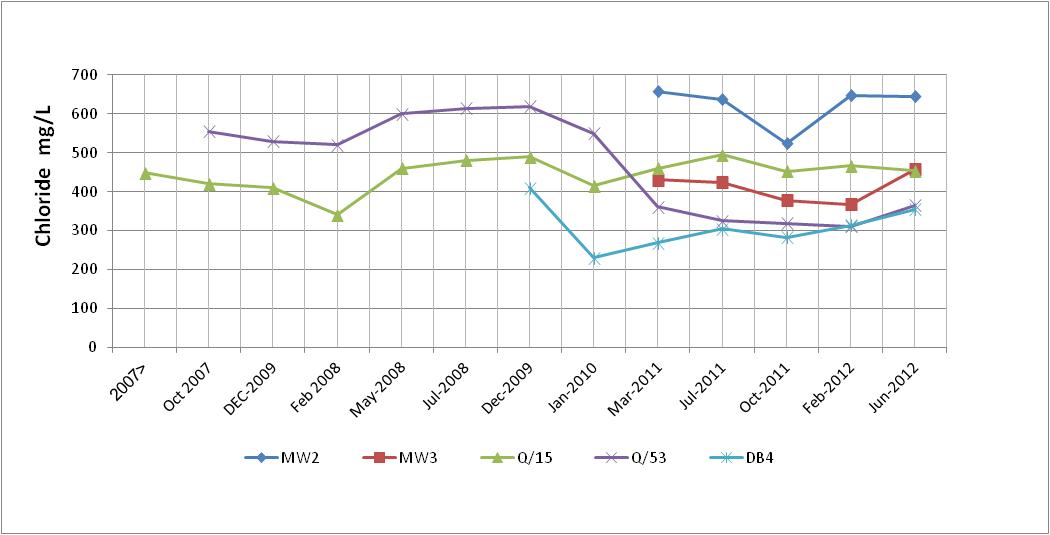


Figure 24: Cl Concentration in the Wells Close to the Infiltration Basins (2007-2012)

Figure 25: Cl Concentration in the Wells Close to the Infiltration Basins (2010-2014)

Looking at the nitrate results, it can be seen that concentrations range from 20mg/l to 150 mg/l in 2017, both in the monitoring wells and in the recovery wells, indicating some increase in nitrate concentrations since 2012. These numbers far exceed the WHO standards that indicate a maximum value of 30 mg/l . Figures 26 and 27 also shows that there is a drop of the nitrate concentration in the aquifer surrounding the basin; this may due to the reduction of agricultural practice in the area.

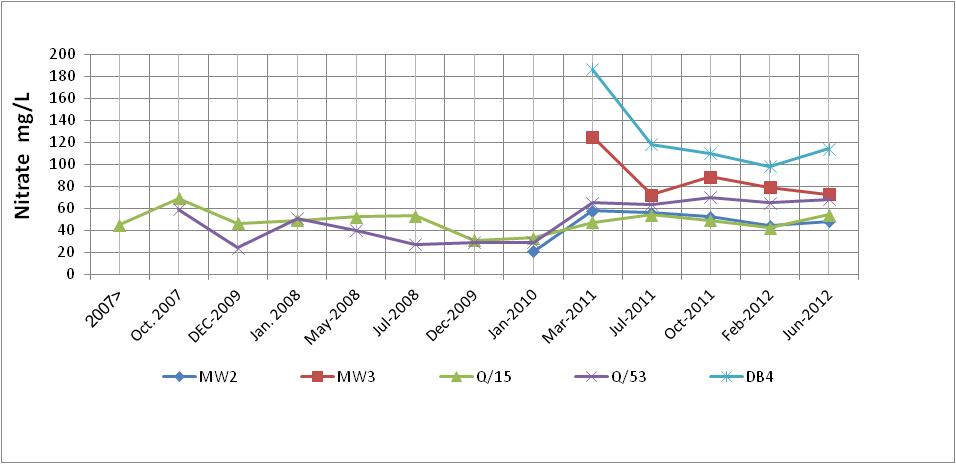


Figure 26: Nitrate concentration in the wells close to the infiltration (2007-2012)

Figure 27: Nitrate concentration in the wells close to the infiltration (2010-2014)

Pathogenic bacteria is has also been investigated in the groundwater in wells in close proximity to the infiltration basin, since partially treated sewage has been infiltrating the aquifer for 9 years. Table 14 presents the microbiological analyses of groundwater samples from the wells close to the infiltration basin and Table 13-24 shows the analysis of BOD and COD in the same wells. The following can be concluded:

* the groundwater is free of Salmonella, Nematodes and Amoeba &Gardia.
* Total Bacteria count ranges between 30 to 395 cfu/ml and the total coliform ranges between 6 to 650 cfu /100ml. While no direct standards has been found indicating restrictions and permissible total bacterial count limits, use of reclaimed water for irrigation with high bacterial count should be exercised with care, especially in the case of crops that are to be eaten uncooked.
* Fecal coliform was found to be compliant with the Palestinian permissible limit of 200 for High quality water (Type A) in most wells with the exception of Q64. The reason of such FC existence may be attributed to the direct pollution through the well pipe from animal wastes such as birds.
* It can be seen that the BOD in the years 2014-2016 in most wells exceed 10mg/l.

Table 14: Microbiological analysis for groundwater samples from wells close to the infiltration basin

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Well no.** | **2007-2012** | | | **2010-2014** | | |
| **Total Bacteria Count Stdcfu/1ml.** | **Total coliform**  **cfu /100mL** | **Faecal coliform**  **cfu /100mL** | **Total Bacteria Count Stdcfu/1ml. (2010)** | **Total coliform**  **cfu /100mL** | **Faecal coliform**  **cfu /100mL** |
| Mw1 | 40-105 | 6 | 2 | 105 | 16-650 | 3 |
| MW2 | 60-205 | 10 | 4 | 250 | 73-172 | 4-30 |
| Mw3 | 40-350 | 14-25 | 9 | 350 | 11-150 | 5-46 |
| Mw4 | 35-182 | 0 | negative | 182 | 39-106 | 2-10 |
| Mw5 | 65 | Over 300 | 7 |  | 50-6200 | 34-100 |
| Site well | 15-55 | 30 | 8 | 15 | 14-300 | 8 |
| Q15 | 60-375 | 30-76 | 20 | 375 | 24-75 | 8-27 |
| Q20 | 353-395 | 3-65 | 2 | 395 | 8-90 | 6-50 |
| Q53 | 30-55 | negative | negative | 55 | 6-86 | 0-4 |
| Q54B | 33-85 | 40 | 25 | 33 | 65-74 | 26-33 |
| **Q64** | **90-310** | **50-1100** | **22** | **310** | **108-656** | **88-252** |
| DB4 | 55-165 | 35-85 | 15-33 | 165 | 85-2000 | 6-33 |

Table 15: BOD5 Concentrations (O2/L) in wells close to the infiltration basin

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Mw1 | MW2 | Mw3 | Mw4 | Mw5 | Site well | Q15 | Q20 | Q53 | Q54B | Q64 | DB4 |
|  | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 | < 5 |
| Mar-11 | 1.8 | 0.8 | 1.5 | 0 | 0 | 1.9 | 1.9 | 2 | 1.9 | < 2.00 | 2 | 11 |
| Jul-11 | 5 | 2 | 4 | 1.9 | 1.8 | 4.9 | 4.9 | 5 | 1.9 | < 2 | 5 | 11 |
| Oct-11 | 5 | 5 | 6 | 5.1 | 5.1 | 5.1 | 5.1 | 5 | 5.1 | < 5 | 5 | 12 |
| Feb-12 | 5 | 5 | 6.5 | 4.9 | 4.9 | 4.9 | 4.9 | 5 | 4.9 | ----- | 5 | 11.5 |
| Jun-12 | 5 | 5 | 6.2 | 4.8 | 4.8 | 4.9 | 4.9 | 5 | 4.9 | < 5 | 5 | 12 |
| Jul-13 | 4.5 | 5 | 8.1 | 5 | 15 | 5 | 15 | 0 | 20 | 0 | 2 | 0 |
| Oct-13 | 4 | 5 | 0 | 10 | 10 | 2 | 7 | 2 | 8 | 9 | 8 | 1 |
| Jan-14 | 5 | 5 | 10 | 5 | 10 | 10 | 5 | 10 | 15 | 30 | 35 |  |
| Apr-14 | 7 | 10 | 15 | 15 | 20 | 65 | 45 | 60 | 45 | 45 | 55 |  |
| Jun-14 | 9.0 | 12.5 | 14.5 | 12.5 | 16 |  |  |  |  |  |  |  |
| Oct-15 | 11.0 | 15 | 14 | 10 | 12 | 15 | 7 | 6 | 10 | 5 | 7 | 10 |
| Dec-15 | 7.7 | 11.7 | 13.3 | 15.7 | 9.7 | 3.0 | 8.0 | 4.0 | 12.0 | 4.0 | 8.0 | 11.0 |
| Apr-16 | 20.0 | 22.0 | 10.0 | 25.0 | 22.0 |  | 20.0 | 5.0 | 20.0 | 22.0 | 15.0 | 20.0 |
| Jul-16 | 25.0 | 25.0 | 17.0 | 27.0 | 25.0 | 30.0 | 25.0 | 15.0 | 25.0 | 22.0 | 25.0 | 20.0 |

Table 16: COD Concentrations (O2/L) in wells close to the infiltration basin

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Mw1 | MW2 | Mw3 | Mw4 | Mw5 | Site well | Q15 | Q20 | Q53 | Q54B | Q64 | DB4 |
| Mar-11 | 5 | 2 | 3 | 0 | 0 | 3 | 3 | 2.5 | 3.5 | 3 | 2 | 25 |
| Jul-11 | 7.2 | 2.8 | 8.4 | 3.2 | 0.8 | 13.6 | 9.6 | 9.6 | 4.8 | 5.6 | 8 | 25 |
| Oct-11 | 4.8 | 7.2 | 8.4 | 2.4 | 2.5 | 7.2 | 8.5 | 7.8 | 5.6 | 6.2 | 2.4 | 24 |
| Feb-12 | 4.2 | 4.4 | 7.2 | 2.8 | 2.4 | 5.6 | 6.2 | 5.4 | 4.4 | ----- | 3.6 | 24 |
| Jun-12 | 4.5 | 4.8 | 8 | 3 | 3.5 | 6.6 | 6.7 | 5.8 | 4.9 | 6.5 | 3.8 | 26 |
| Jul-13 | 2 | 10 | 2 | 16 | 50 | 20 | 40 | 20 | 50 | 5 | 7 | 2 |
| Oct-13 | 17 | 20 | 3 | 30 | 25 | 6 | 14 | 17 | 95 | 20 | 20 | 5 |
| Jan-14 | 38 | 25 | 12 | 35 | 32 | 23 | 20 | 27 | 31 | 89 | 41 |  |
| Apr-14 | 20 | 20 | 30 | 40 | 46 | 170 | 95 | 120 | 40 | 100 | 120 |  |
| Oct-15 | 30 | 36 | 33 | 38 | 37 | 50 | 22 |  | 33 |  |  | 35 |

Metals ions were analyzed in the same wells close to the infiltration by PWA in mid of year 2016. As shown in Table 16, the metals concentrations in all analyzed wells were less than the Palestinian standard values for irrigation. However, there are some wells that have exhibited concentrations of Boron and Mercury higher than the standard values. The wells which have Boron concentration higher than the standard values are MW2, MW3, Q15, Q54B and Q64. The range of Boron concentration is between 0.4 to 1.39 mg/l. The mercury is also found in MW1, MW2, MW4, Q54B and Q64. The concentration of mercury in these wells ranges between 0.001 to 0.10 mg/l, which is higher than the standard value of 0.001 mg/l**[[2]](#footnote-2)**.

Table 17: Ion concentrations in wells close to the infiltration basins

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Parameter** | **Palestinian Technical Specs 34-2012** | **MW1** | **MW2** | **MW3** | **MW4** | **Q15** | **Q54B** | **Q64** |
| Silver, mg/l | 1 | 0.005 | 0.005 | 0.005 | 0.01 | 0.01 | 0.01 | 0.01 |
|
| Aluminum, mg/l | 5 | 0.1 | 0.032 | 0.052 | 0.03 | 0.03 | 0.42 | 0.03 |
| Boron, mg/l | 0.7 | 1.557 | 1.396 | 1.21 | 0.4048 | 1.166 | 1.527 | 1.19 |
| Cadmium, mg/l | 0.01 | 0.0006 | 0.001 | 0.0006 | 0.001 | 0.001 | 0.001 | 0.001 |
| Cobalt, mg/l | 0.05 | 0.0032 | 0.002 | 0.0031 | 0.0069 | 0.001 | 0.0033 | 0.001 |
| Chromium, mg/l | 0.1 | 0.0173 | 0.01 | 0.0118 | 0.01 | 0.01 | 0.0303 | 0.01 |
| Copper, mg/l | 0.2 | 0.009 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Iron, mg/l | 5 | 2.7 | 0.66 | 0.67 | 0.67 | 0.26 | 0.17 | 0.27 |
| Manganese, mg/l | 0.2 | 0.21 | 0.005 | 0.005 | 0.0218 | 0.005 | 0.0883 | 0.005 |
| Nickel, mg/l | 0.2 | 0.004 | 0.001 | 0.0008 | 0.001 | 0.001 | 0.001 | 0.001 |
| Lead, mg/l | 0.2 | 0.095 | 0.088 | 0.093 | 0.099 | 0.092 | 0.09 | 0.089 |
| Zinc, mg/l | 2 | 0.05 | 0.014 | 0.012 | 0.027 | 0.008 | 0.0576 | 0.0257 |
| Mercury, mg/l | 0.001 | 0.001-0.0071 | 0.01 | 0.003 | 0.004 | 0.003 | 0.006 | 0.009 |
| Phosphorus, mg/l | 30 | 20 | 14-32 | 16-29 | 16-20 | 14-25 | 2-55 | 3-40 |

Table 18: Water analysis of major parameters in the stage 1 recovery wells

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Parameter | RW24 (29/10/2017) | | RW26 (12/10/2017) | | RW27 (22/10/2017) | | RW28 (21/10/2017) | RW29 (29/10/2017) | |
| 11:30AM 100m3/h | 16:00 200m3/h | 11:30AM 100m3/h | 16:00 200m3/h | 11:30AM 100m3/h | 16:00 200m3/h | ND | 11:30AM 100m3/h | 16:00 200m3/h |
| Acidity (PH) | 7.62 | 7.445 | 8.386 | 8.123 | 7.461 | 7.451 | 8.104 | 8.021 | 7.461 |
| E.C. (µS/cm) | 2340 | 1405 | 2120 | 2130 | 2020 | 2000 | 2020 | 2140 | 2130 |
| T.D.S (mg/l) | 1405 | 1390 | 1272 | 1278 | 1212 | 1200 | 1212 | 1285 | 1278 |
| T.A. (mg/l) | 660 | 650 | 688 | 682 | 644 | 638 | 660 | 605 | 560 |
| T.S.S. (mg/l) | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| B.O.D. | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| NO3 (mg/l) | 37 | 35 | 25 | 20 | 62 | 63 | 150 | 92 | 90 |
| NH3-N (mg/l) | Nil | Nil | 1 | 1 | Nil | Nil | Nil | Nil | Nil |
| NO2 | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| Cl (mg/l) | 444 | 440 | 444 | 386 | 444 | 425 | 367 | 386 | 452 |
| PO4-P (mg/l) | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil | Nil |
| SO4 (mg/l) | 60 | 60 | 42 | 43 | 50 | 50 | 48 | 64 | 60 |
| Na (mg/l) | 450 | 445 | 404 | 406 | 380 | 385 | 385 | 422 | 420 |
| K (mg/l) | 3 | 3 | 10 | 11 | 10 | 10 | 8 | 3 | 3 |

Table 19: Comparison of key parameters of reclaimed water in Recovery Well 24

| Parameter | RW24 (29/10/2017) | | Palestinian | Jordanian | WHO |
| --- | --- | --- | --- | --- | --- |
| 11:30AM 100m3/h | 16:00 200m3/h |  |  |  |
| Acidity (PH) | 7.62 | 7.445 | Compliant | Compliant | Compliant |
| E.C. (µS/cm) | 2340 | 1405 |  |  |  |
| T.D.S (mg/l) | 1405 | 1390 | compliant with B,C &D |  |  |
| T.A. (mg/l) | 660 | 650 |  |  |  |
| T.S.S. (mg/l) | Nil | Nil | Compliant | Compliant | Compliant |
| B.O.D. | <10 | <10 | Falls in the A category | Compliant and suitable for unrestricted irrigation | Compliant |
| NO3 (mg/l) | 37 | 35 | Falls in the D category | Suitable for all types of crops except Cooked vegetables, recreations parks, playgrounds and sideways inside cities | Not Compliant |
| NH3-N (mg/l) | Nil | Nil | Compliant | Compliant | Compliant |
| NO2 | Nil | Nil | Compliant | Compliant | Compliant |
| Cl (mg/l) | 444 | 440 | Slightly higher than permissible 400 mg/l | Slightly higher than permissible 400 mg/l | Slightly higher than permissible 400 mg/l |
| PO4-P (mg/l) | Nil | Nil | Compliant | Compliant | Compliant |
| SO4 (mg/l) | 60 | 60 | Compliant | Compliant | Compliant |
| Na (mg/l) | 450 | 445 | Not compliant | Not compliant | Compliant |
| K (mg/l) | 3 | 3 | No standards indicated | No standards indicated | Slighly higher than the permissible 2 mg/l |
| SAR | 10.89 | | Exceeds SAR value of 5.83 me/l | Slightly exceeds SAR value of 9me/l | <15 Falls within permissible range |

Table 20: Comparison of key parameters of reclaimed water in Recovery Well 26

| Parameter | RW26 (12/10/2017) |  | Palestinian | Jordanian | WHO |
| --- | --- | --- | --- | --- | --- |
|  | 11:30AM 100m3/h | 16:00 200m3/h |  |  |  |
| Acidity (PH) | 8.386 | 8.123 | Compliant | Compliant | Compliant |
| E.C. (µS/cm) | 2120 | 2130 |  |  |  |
| T.D.S (mg/l) | 1272 | 1278 | Does not meet any of the water quality standards. | Non-Compliant | Compliant |
| T.A. (mg/l) | 688 | 682 |  |  |  |
| T.S.S. (mg/l) | Nil | Nil |  |  |  |
| B.O.D. | <10 | <10 | Falls in the A category | Compliant and suitable for unrestricted irrigation | Compliant |
| NO3 (mg/l) | 25 | 20 | Falls between the A-C category | Compliant and suitable for unrestricted irrigation | Compliant |
| NH3-N (mg/l) | 1 | 1 |  |  |  |
| NO2 | Nil | Nil |  |  |  |
| Cl (mg/l) | 444 | 386 | Non-compliant/marginal compliance | Non-compliant/marginal compliance | Not indicated |
| PO4-P (mg/l) | Nil | Nil |  |  |  |
| SO4 (mg/l) | 42 | 43 | Well below limits, Compliant for unrestricted use | Well below limits, Compliant for unrestricted use | Well below limits, Compliant for unrestricted use |
| Na (mg/l) | 404 | 406 | Non-compliant | Non-compliant | Below requirement of 920 mg/l |
| K (mg/l) | 10 | 11 | Not indicated | Not indicated | Higher than required 2 mg/l |

Table 21: Comparison of key parameters of reclaimed water in Recovery Well 27

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Parameter | RW27 (22/10/2017) | | Palestinian | Jordanian | WHO |
| 11:30AM 100m3/h | 16:00 200m3/h |  |  |  |
| Acidity (PH) | 7.461 | 7.451 | Compliant | Compliant | Compliant |
| E.C. (µS/cm) | 2020 | 2000 |  |  |  |
| T.D.S (mg/l) | 1212 | 1200 | Falls in categories B-D | Non-Compliant | Compliant |
| T.A. (mg/l) | 644 | 638 |  |  |  |
| T.S.S. (mg/l) | Nil | Nil |  |  |  |
| B.O.D. | <10 | <10 |  |  |  |
| NO3 (mg/l) | 62 | 63 | Falls in category D | Not suitable for unrestricted irrigation- Marginally meets criteria for Field Crops, Industrial Crops and Critical Trees | Far exceeds permissible limits |
| NH3-N (mg/l) | Nil | Nil |  |  |  |
| NO2 | Nil | Nil |  |  |  |
| Cl (mg/l) | 444 | 425 | Slightly exceeds permissible limits | Slightly exceeds permissible limits | Slightly exceeds permissible limits |
| PO4-P (mg/l) | Nil | Nil |  |  |  |
| SO4 (mg/l) | 50 | 50 | Compliant | Compliant | Compliant |
| Na (mg/l) | 380 | 385 | Higher than permissible limits | Higher than permissible limits | Compliant |
| K (mg/l) | 10 | 10 | Higher than permissible limits | Higher than permissible limits | Higher than permissible limits |

Table 22: Comparison of key parameters of reclaimed water in Recovery Well 28

| Parameter | RW28 (21/10/2017) | Palestinian | Jordanian | WHO |
| --- | --- | --- | --- | --- |
|  | ND |  |  |  |
| Acidity (PH) | 8.104 | Compliant | Compliant | Compliant |
| E.C. (µS/cm) | 2020 |  |  |  |
| T.D.S (mg/l) | 1212 | Slightly exceeds the A category but meets categories B-D | Exceeds all limits | Compliant |
| T.A. (mg/l) | 660 |  |  |  |
| T.S.S. (mg/l) | Nil |  |  |  |
| B.O.D. | <10 |  |  |  |
| NO3 (mg/l) | 150 | Far exceeds permissible limits | Far exceeds permissible limits | Far exceeds permissible limits |
| NH3-N (mg/l) | Nil |  |  |  |
| NO2 | Nil |  |  |  |
| Cl (mg/l) | 367 | Borderline compliant with the permissible 400 mg/l | Borderline compliant with the permissible 400 mg/l | Borderline compliant with the permissible 400 mg/l |
| PO4-P (mg/l) | Nil |  |  |  |
| SO4 (mg/l) | 48 | Compliant | Compliant | Compliant |
| Na (mg/l) | 385 | Higher than permissible limits | Higher than permissible limits | Compliant |
| K (mg/l) | 8 | Higher than permissible limits | Higher than permissible limits | Higher than permissible limits |

Table 23: Comparison of key parameters of reclaimed water in Recovery Well 29

| Parameter | RW29 (29/10/2017) |  | Palestinian | Jordanian | WHO |
| --- | --- | --- | --- | --- | --- |
|  | 11:30AM 100m3/h | 16:00 200m3/h |  |  |  |
| Acidity (PH) | 8.021 | 7.461 |  |  |  |
| E.C. (µS/cm) | 2140 | 2130 |  |  |  |
| T.D.S (mg/l) | 1285 | 1278 | Slightly exceeds the A category but meets categories B-D | Exceeds all limits | Compliant |
| T.A. (mg/l) | 605 | 560 |  |  |  |
| T.S.S. (mg/l) | Nil | Nil |  |  |  |
| B.O.D. | <10 | <10 |  |  |  |
| NO3 (mg/l) | 92 | 90 | Far exceeds permissible limits | Far exceeds permissible limits | Far exceeds permissible limits |
| NH3-N (mg/l) | Nil | Nil |  |  |  |
| NO2 | Nil | Nil |  |  |  |
| Cl (mg/l) | 386 | 452 | Slightly exceeds permissible limits | Slightly exceeds permissible limits | Slightly exceeds permissible limits |
| PO4-P (mg/l) | Nil | Nil |  |  |  |
| SO4 (mg/l) | 64 | 60 | Compliant | Compliant | Compliant |
| Na (mg/l) | 422 | 420 | Higher than permissible limits | Higher than permissible limits | Compliant |
| K (mg/l) | 3 | 3 | Slightly higher than permissible limits | Slightly higher than permissible limits | Slightly higher than permissible limits |

Table 24: SAR Calculations

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Parameter** | **RW24** | | | **RW26** | | | | **RW27** | | | **RW28** | **RW29** | | |
|  | S1 | S2 | Avg. | S1 | S2 | Avg | S1 | | S2 | Avg | ND | S1 | S2 | Avg |
| Na (meq/L) | 19.57 | 19.36 | 19.47 | 17.57 | 17.66 | 17.62 | 16.52 | | 16.75 | 16.64 | 16.74 | 18.36 | 18.27 | 18.32 |
| Ca (meq/L) | 3.72 | 3.58 | 3.65 | 4.20 | 4.11 | 4.16 | 3.45 | | 3.38 | 3.42 | 3.67 | 3.08 | 2.99 | 3.04 |
| Mg (meq/L) | 2.79 | 2.69 | 2.74 | 3.14 | 3.08 | 3.11 | 2.58 | | 2.53 | 2.56 | 2.75 | 2.31 | 2.24 | 2.28 |
| SAR (meq/L) | 10.89 | | | 9.24 | | | | 9.63 | | | 9.34 | 11.24 | | |

Table 25: Summary of concentrations and compliance to standards (WHO, Palestinian and Jordanian)

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Critical range in wells (borderline to high) | Most stringent Limit | Compliance criteria |
| BOD5 | 15-65 | 10 | concentrations exceeding limits found |
| COD | 50-170 | Up to 50 | Mostly within range |
| PH |  | 6-9 | All lie within range |
| NO3 | 53-79 | 55 | concentrations exceeding limits found |
| Cl | 262-891 | 250 | Concentrations found exceeding limits |
| Heavy metals (in general) |  | Boron: 0.7  Mercury : 0.001 | In just a few instances high concentrations of :   * Boron were exhibited in high concentrations, exceeding the allowable 0.7mg/l * Mercury was found to be in concentrations higher than the allowable limits in some measurements wells   Generally, all metals found well below limits |
| Phosphorus | 30 | 2-55 &3-40 | Found to exceed allowable limits in 2 of the wells. |
| Total Bacteria count | 6000 in MW5 | 2000 | Found to exceed allowable limits in MW5 of the wells. |
| Fecal coliform count | 10 for unrestricted irrigation | 8-52 |  |

# **Project scenario and suitability** of recovered water for irrigation purposes

The project will result positive impacts on water resources in general, and ground water in particular. The effluent recovered from the groundwater will offer an additional water source of irrigation, as water resources in the Gaza Strip are scarce. It is of ultimate importance however, that the water quality is suitable for the type of crops and exposure to the farmers and the public.

In the analysis carried out in 2012, it was concluded that the expected water quality from the recovery wells would be suitable for unrestricted use in irrigation. The conclusion at the time was developed through groundwater modelling, using the water analysis of samples taken from existing monitoring wells for calibration. Conclusions reached were mainly based on BOD, which was 5mg/l in the existing monitoring wells at the time.

Conducting a comparison using currently available data and analysis results of **constructed** recovery wells (presented in the baseline chapter), the modeling conclusion back in 2012 can be verified and confirmed. While BOD levels have increased from the 5mg/l back then, the values are still lower than the permissible 30mg/l, the Palestinian limit for unrestricted groundwater use (10mg/l).

Results of the model also shows that, at the beginning of year 2018, the pollution plume extends to a distance of about 500 m (nitrate concentration contour line is 80 mg/l) in the North-West direction of the basin (See Figure 49); as wastewater with bad quality has been infiltrated in the basins since 2009 (15,000 – 20,000 m3/day).

The model results showed that even after the operation of the treatment plant for seven years (up to year 2025), polluted zones will still exist and some agricultural wells will be affected in the absence of the project (pollutant levels reaching 80mg/l at some areas).

After the operation of stage 1 wells, the situation will be highly improved and the nitrate levels will be brought down to almost half the concentration. After the operation of stage 2 wells, the project of concern, the area of influence will be constrained and the polluted zone in the North-west direction will become smaller, until it disappears completely in 2042.

# Groundwater Quality Monitoring Plan (GQMP)

A comprehensive groundwater monitoring plan will be set up by the project, in order to maximize the expected positive impacts on the groundwater and monitor these impacts with adequate frequency. The plan is prepared to safeguard against unexpected delays during construction of the wastewater treatment plant and the recovery scheme. The GQMP will use the network of 15 Monitoring Wells to perform the testing and analysis of groundwater. Water extracted from the Recovery Wells will also be tested. Water quality will be tested against Palestinian and Jordanian Standards for irrigation. For mercury and boron, signaled as potentially present in high concentrations in the baseline, higher standards (WHO/EU Drinking Water Standards, <https://www.lenntech.com/who-eu-water-standards.htm>) will be followed, in order to follow a zero risk policy. The following table summarizes the standards applicable to irrigation water:

Permissible limits for different parameters of water reclaimed for irrigation

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Palestinian Standards 34-2012 ( treated wastewater standards for irrigation purposes)** | | | | **Jordanian Standards for permissible limits for groundwater injection** | | | | **WHO standards** |
| **Chemical and biological (mg/l)** | **D** | **C** | **B** | **A** | **flowers** | **Field Crops, Industrial Crops and Critical Trees** | **Fruit trees and aspects of external roads and green spaces** | **Cooked vegetables, recreations parks, playgrounds and sideways inside cities** |  |
| BOD5 | 60 | 40 | 20 | 20 | 15 |  | 300 | 30 |  |
| TSS | 90 | 50 | 30 | 30 |  |  |  |  |  |
| FC | 1000 | 1000 | 1000 | 200 |  |  |  |  |  |
| COD | 150 | 100 | 50 | 50 | 50 | 500 | 500 | 100 |  |
| DO | <1 | <2 | <3 | <4 | <2 |  |  | <2 |  |
| TDS | 1500 | 1500 | 1500 | 1200 | 15 | 300 | 200 | 50 | 2000 |
| PH | 6-9 | 6-9 | 6-9 | 6-9 | 6-9 | 6-9 | 6-9 | 6-9 | 6.0 – 8.5 |
| NO3-N | 40 | 30 | 20 | 20 | 45 | 70 | 45 | 30 | 10 |
| NH4-N | 15 | 10 | 5 | 5 |  |  |  |  | 5 |
| Total N | 60 | 45 | 30 | 30 | 70 | 100 | 70 | 45 |  |
| Cl | 400 | 400 | 400 | 400 | 400 | 400 | 400 | 400 |  |
| SO4 | 300 | 300 | 300 | 300 | 500 | 500 | 500 | 500 |  |
| Na | 200 | 200 | 200 | 200 | 230 | 230 | 230 | 230 | 920 |
| Mg | 60 | 60 | 60 | 60 | 100 | 100 | 100 | 100 | 60 |
| Ca | 300 | 300 | 300 | 300 | 230 | 230 | 230 | 230 | 400 |
| SAR | 5.83 | 5.83 | 5.83 | 5.83 | 9 | 9 | 9 | 9 |  |
| PO4-P | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 2 |
| Al | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |  |
| As | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |  |
| Cu | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |  |
| Fe | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |  |
| Mn | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |  |
| Ni | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |  |
| Pb | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |  |
| Se | 0.02 | 0.02 | 0.02 | 0.02 | 0.05 | 0.05 | 0.05 | 0.05 |  |
| Cd | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |  |
| Zn | 2 | 2 | 2 | 2 | 5 | 5 | 5 | 5 |  |
| Cr | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |  |
| B | 0.7 | 0.7 | 0.7 | 0.7 | 1 | 1 | 1 | 1 | 0 – 2 |
| E-Coli | 1000 | 1000 | 1000 | 100 | <1.1 |  | 1000 | 100 |  |
| K |  |  |  |  |  |  |  |  | 0 – 2 |

Recommended microbiological WHO quality guidelines for wastewater use in agriculture

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Category** | **Reuse condition** | **Exposed group** | **Intestinal nematodes(arithmetic mean no. of eggs per liter** | **Faecal coliforms (geometric mean no. per 100 mlc)** |
| A | Irrigation of crops likely to be eaten uncooked, sports fields, public parksdd | Workers, consumers, public | <1 | < 1000 |
| B | Irrigation of cereal crops, industrial crops, fodder crops, pasture and treese | Workers | < 1 | No standard recommended |
| C | Localized irrigation of crops in category B if exposure of workers and the public does not occur | None | Not applicable | Not applicable |

## Monitoring Wells Locations

Locating the appropriate monitoring point locations is essential in designing a monitoring network capable of providing data of adequate quality to achieve the program objectives. At times, monitoring well locations may be prescribed by the regulations under which the groundwater monitoring program is being developed. For example, some regulations require monitoring locations to be placed at a designated “point of compliance,” which is often at the property boundary or a groundwater discharge location. For other groundwater monitoring programs, the groundwater professional should select monitoring locations that provide the most reliable data needed to detect or assess a groundwater contaminant plume. To verify that the monitoring network can accomplish this goal, target monitoring zones must be selected based on the site hydrogeological conditions and anticipated contaminant pathways.

The overall strategy of the groundwater monitoring program in this project is to evaluate the status of the groundwater quality after infiltration of partially treated and treated wastewater. The monitoring wells are distributed in two rows: the first around 400 to 500 m from the infiltration basin, and the second will be 1100 to 1200 m from the basin.

The first monitoring well row is located before the first row of recovery wells in the direction infiltration basin, and the second row of the monitoring wells should be located after the second row of the recovery wells, to check the quality of groundwater outside the recovery wells areas. The monitoring network will also use the existing 5 monitoring wells constructed recently by PWA to monitor the infiltration basin in addition to the stage 2 recovery wells. In addition, the recovery wells will be part of the monitoring network.

Table 66: Stage 2 monitoring well coordinates

|  |  |  |
| --- | --- | --- |
|  | **x-coordinates** | **y-coordinates** |
| **MW1** | 102862.41 | 101410.5 |
| **MW5** | 103879.64 | 101410.5 |
| **MW7** | 104483.92 | 101782.59 |
| **MW8** | 104350.46 | 101327.96 |
| **MW9** | 103291.12 | 101065.89 |

## Parameters to be Monitored

The main objective of monitoring is to check the groundwater quality after infiltration and check the operation of the Soil Aquifer Treatment process. Critical parameters expected to provide insight on the status of groundwater after infiltration of partially treated wastewater Monitoring Plan for Using Recovery Water (treated wastewater) will be measured. This will be facilitated by the setting-up of a laboratory for NGEST, financed under the project, that will allow more autonomy and reactivity to perform and analyze testing.

### Objectives

Water quality monitoring plays an important role in water management to protect the environment and human health.

The main objectives of the monitoring program are:

* to assess the quality of water entering the pilot area.
* to quantify the variation in irrigation and drainage water at the pilot area
* to assess the impact of the use of drainage water on crop production (quality & quantity).
* to assess the impact of the use of drainage water on the soil quality
* to provide the decision makers with the information required to propose and implement mitigation measures
* to develop public information and awareness programs on water quality

### Parameters to be measured

* Irrigation Water: all parameters should be measured twice a year, during the minimum and maximum river flows in February & August respectively (from the sampling sites in the pilot area) are Inorganic elements (Aluminum, Arsenic, Cadmium, Cobalt, Copper, Iron, Manganese, Nickel, Lead, Selenium, Zinc and Molybdenum), pH, F, NO3, SO4, Cl, TDS, BOD, COD, Fecal Coliform, Oil and Grease, Benzene, Organic Compound (Trichloroacetaldehyde, Propionaldehyde, Phenol, AtrazineDimethoate, Chlorpyrifos).
* Heavy metals: as the baseline analysis has shown possible high levels of heavy metals such as mercury and boron, the plan will need to carefully verify and monitor concentrations for these elements. This will take the form of monthly assessments for mercury and boron during the first six months of the implementation of the plan; if concentrations are consistently under the permissible limit, frequency will be shifted to quarterly measurements for a year; after which it may be shifted to semiannual measurements.
* Soil: The following parameters should be measured in the soil once a year: Arsenic, Cadmium, Chromium, Lead, Nickel, Copper, Zinc, Atrazine. If the levels of mercury and boron are close to the permissible limits, they will also be periodically tested in the soil in order to control accumulation.
* Crops: The following parameters should be measured in crops at the harvesting period: Arsenic, Cadmium, Chromium, Lead, Nickel, Copper, Zinc, and Atrazine. If soil samples present values exceeding internationally recognized standards for boron and mercury, these elements will also be tested in plants to control absorption, bioaccumulation and possible health hazards for consumers.

1. Source : ESIA of the project, 2018 [↑](#footnote-ref-1)
2. **Note: These results seem to be an anomaly in the pattern of Hg concentrations, which have been shown to be low in other measurements performed in 2016 and later. Ministry of Health of the Palestinian Authority confirms that its own measurements have shown levels of mercury under the acceptable limit.**  [↑](#footnote-ref-2)