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Artificial Aquifer Recharge with Treated Wastewater in North Gaza

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Abstract: Groundwater is the only available water supply source within North Gaza. Excessive groundwater abstraction to meet the high increase in domestic and irrigation water demand has lead to groundwater depletion problems and degradation of water quality. The quantity of treated wastewater effluent that would be suitable for reuse is estimated to be 20 MCM by year 2020. The treated effluent reuse could therefore comprise around 36 percent of total water demand by 2020. The use of treated wastewater for irrigation and aquifer recharge will reduce the pressure on groundwater and reduce the gap between demand and resources. This paper has investigated the potential of aquifer recharge in Northern Gaza (Beit Hanon Area) from the treated wastewater at Beit Hanon Treatment Plant. It also identifies the best site for recharge and best recharge mechanism. The design parameters and soil investigation results have indicated that there is a very good potential for aquifer recharge in that area. The expected recharge amount can be up to 67000 mcm/year. Recharge basin area of 84 dunums and recharge facility site area of 125 dunums* (1 dunum= 1000 m^2) at the year 2025. The water balance model has indicated the possibility of water coning however the selected sites minimises the possibility of flow to Israeli side of the boarder. The water quality of recharged water is expected to improve through infiltration process due to aquifer type (alluvial deposits). The study recommended to use the filtration basins with boreholes filled with filter material to connect basin with the aquifer. The aquifer recharge will help in reducing the impact of the saline water intusion due to increased flux into aquifer which naturally flows to the sea.

Key words: Groundwater artificial recharge · Groundwater management · Water demand · Groundwater modelling

INTRODUCTION

The study area covers the Northern part of Gaza (Figure 1). It comprises around 16.5% of the Gaza Strip and forms of three main areas; Jabalya, Beit Lahyia and Beit Hanon. According to 1996 census data, the population in these three areas is 148, 700 inhabitants and expected to increase to 318, 892 in year 2025 [1].

Groundwater is the only available source for water supply in north Gaza. The excessive groundwater abstraction to meet the high increase in the demand has lead to groundwater depletion problems, saline intrusion and degradation of water quality. Chloride concentration ranges from 50 mg/l in the north western parts to 200 mg/l in the middle and to 500 in the southern part of Northern Gaza. While, the distribution of nitrates concentration varies from 50 mg/l in the eastern and northern parts to 200 mg/l in Jabalia area (WHO standards allows for 50 mg/l). Therefore, the utilization of treated wastewater in groundwater recharge is highly significant.

The total projected water demand for domestic and irrigation purposes in Gaza is around 55 MCM by the year 2025. According to Palestinian Water Authority assessment [2], the water deficit in northern Gaza in year 2003 is around 10 MCM/year. The estimated wastewater effluent of North Gaza by year 2025 will be around 17 MCM. This forms 30 percent of total water demand [1, 2].

Hydrological Aspects: The geology of the study area in simplified form is constituted of calcareous sandstone Kurkar formations covered by windblown sand and alluvial deposits in various thicknesses (10 to 25 m).

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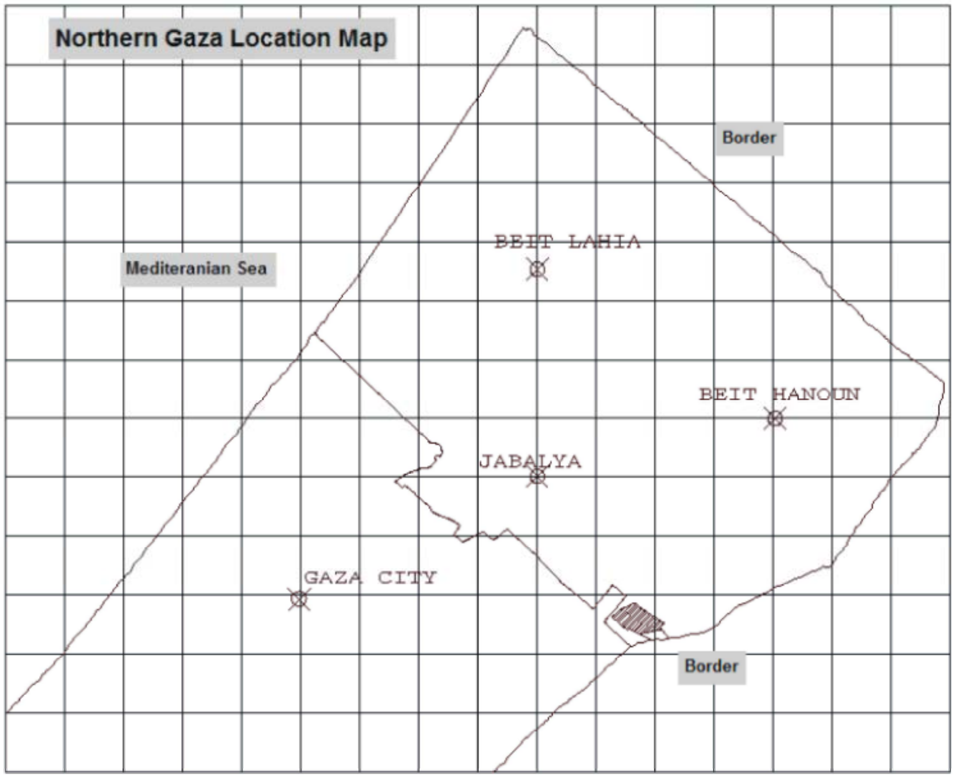

Fig. 1: Location Map for Northern Gaza and Recharge Site

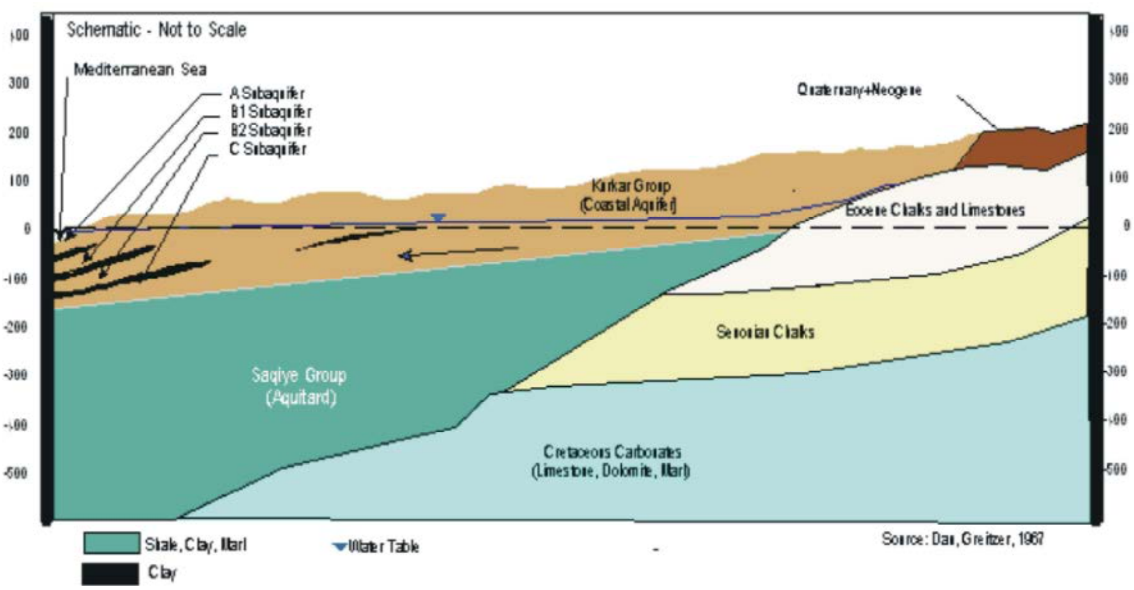

Fig. 2: Geological Cross Section

The quaternary deposits are very compact and constitute the min coastal aquifer n the study area. Quaternary formation comprises mainly form the Pleistocene formation, which include the marine Kurkar formation and the continental Kurkar formation (Figure 2) [2, 3].

The marine Kurkar forms a good aquifer and most of abstracted groundwater in Gaza from this aquifer. Marine Kurkar formation is composed of shell fragments and quartz sand which are cemented together by calcareous material and coarse calcareous sandstone that is hard to differentiate from overlaying Continental Kurkar. The thickness of this formation varies between 10 and 100 m and it becomes thicker near the coast. Underlying this layer there is a thick formation (several hundred of meters) of impervious shales (marine clay), known the Saqiya formation. It is clear from the geological section that clay layer is not very deep, its thickness varies from 7 to 10 m. In addition to top clayey layer there are clay lenses with different sizes. The most effective ones are near the coast, towards the eastern border these lenses are few and thin.

The aerial extent of this aquifer covers the whole of North Gaza. The aquifer near the cost is subdivided into a number of sub aquifers separated by impervious and semi-impervious clay and silt layers. The lower clayey layers tend to be more thick and continuos toward the coast and its thickness increases in the dipping direction to about 15-20 m thick and demolishes gradually to the east at a distance of 4-5 km. The lower sub-aquifers are confined whilst artesian conditions disappeared in the eastern parts where the aquifer becomes unconfined [3].

The thickness of saturated zone ranges from 60 m in the east along the borders to 150 m in the north western parts. Depth to water table is controlled mainly by ground elevations it ranges from 2 to 5 meters depth near the coast to 60 meters in the eastern parts. Groundwater level is more or less close to sea level. The water table ranges between 4 m asl in the north-eastern parts to -3 m bsl in the areas of high intensive pumping [3].

The exploitable part of the aquifer is the shallow one, the vertical distribution of water quality various from one place to another. But in general terms, water quality deteriorates with depth. The bottom parts are highly saline. Moreover, the confined part of the aquifer (clayey bounded sub-aquifers) near the coast has not be exploited providing that the water quality is poor near the sea.

The previously shown water table contours for the years 1935, 1969, 1998 and 2015 indicates that, the groundwater flow directions are from north to south and from east to west. The flow direction has been influenced by the ground water abstraction conditions especially the areas with high intensive pumping as shown in the water levels distribution map for the year 1998 (Note some of these records are taken from pumping wells).

Aquifer Recharge Site Assesment: The site where the treatment plant is located was identified as the site for aquifer recharge. This is mainly due to proximity of the site to treated wastewater which minimises the transfer cost. Figure 3 shows the location of treatment plant and recharge site. In order to asses the suitability of this site for recharge, the following criteria are took placed .

- Topsoil (soil type and thickness) and topography
- Depth to water table (unsaturated zone thickness)
- Infiltration rate (vertical and horizontal aquifer permeability)
- Groundwater flow direction and hydraulic gradient
- Concentration of nitrate and chloride
- Available area
- Distance from border

In order to understand the soil properties of the identified site, a soil investigation scheme was implemented which includes:

- Drilling 4 boreholes, one deep around 80 m until it reaches the water table, one mid-deep around 30 m and two shallow around 8 m.
- Describe the lithological units
- Prepare sieve analysis for collected samples
- Conduct soil permeability test tests at top 10 meters of the deep and middle depth in addition to 8 meters boreholes
- Conduct down hole permeability tests at both the deep and mid-depth boreholes
- Collect information from the existing wells close to the site to establish the groundwater level close to the site and the groundwater quality (chemical analysis).
- Conduct evaporation test

The borehole results from the three sites indicated that below top soil there are stiff silty clay layer which was encountered in all boreholes for a depth of between 7 – 23 m below ground level (bgl). Below the clay layer, the Kurkar Formation was encountered consisting of fine to medium grained sand, with minor amounts of gravel and silt. Overall the clay thickness is greatest on the western boundary of the site (20 – 23.5 m) and generally consistent at 7 – 10 m in the remainder of the site. Groundwater was encountered in Borehole 1 at 51 m bgl, corresponding to a groundwater elevation of 1.3 m below sea level. The range of permeability values within the Kurkar Formation is 0.2 – 13.7 m/day. The average value is 9.5 m/day. Taking into account the type of permeability

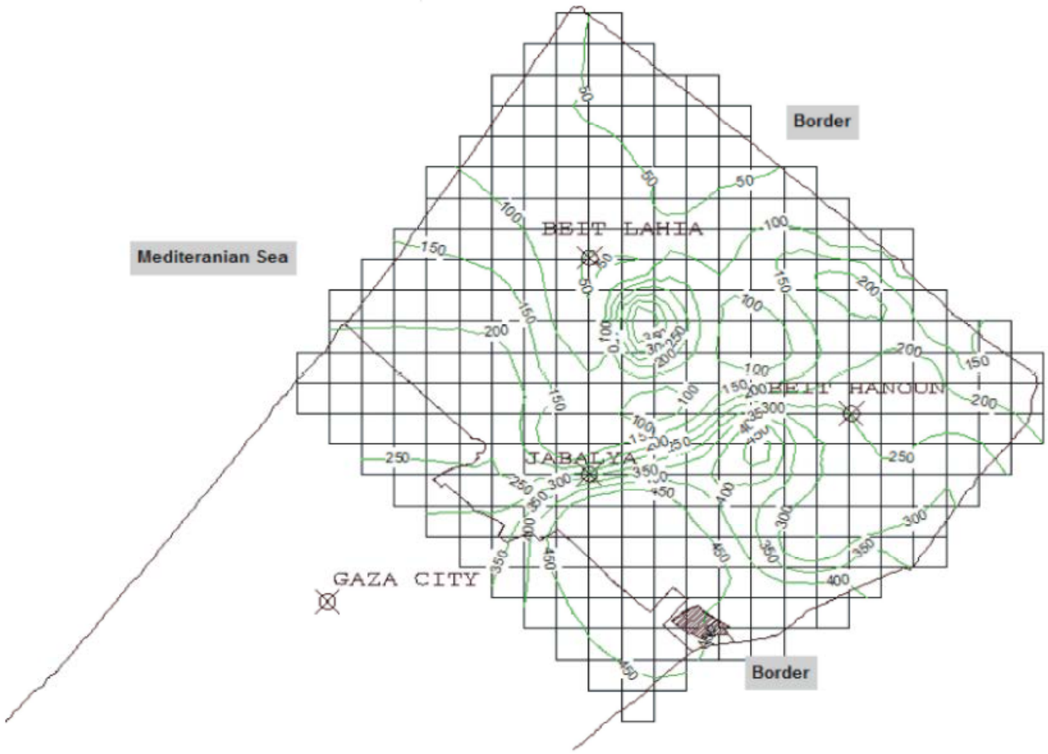

Fig. 3: Chloride concentration

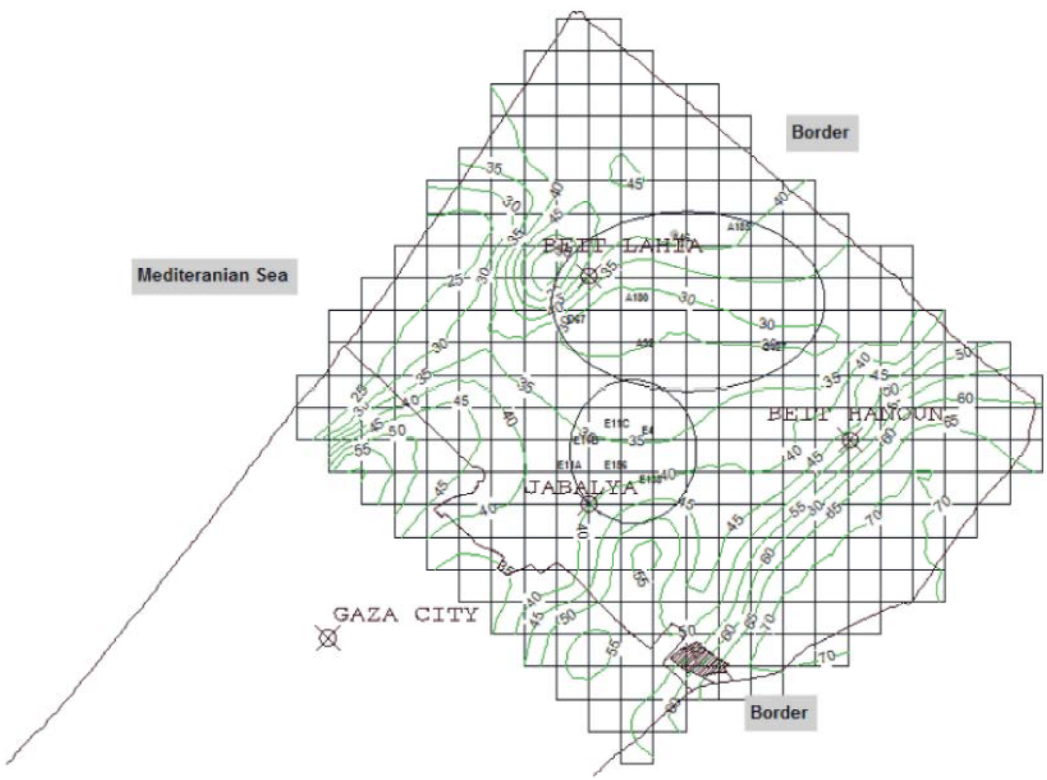

Fig. 4: Nitrate concentration

test, the range of results and the sieve analysis results, a value of 2 m/day has been selected for the vertical permeability and a value of 8 m/day has been selected for the horizontal permeability. The nitrate concentration of the groundwater is around 50 mg/l while the chloride concentration is around 450 mg/l [4]. Figures 3 and 4 shows the distribution of Chloride and Nitrate in the vicinity of the recharge site.

As a result this site is suitable for recharge providing there will be boreholes that penetrate the clay layer.

Design of Recharge Scheme: Due to the presence of the clay layer the best recharge scheme consists of excavated and embanked ponds, approximately 2 - 3 m deep, with approximately one metre of water within the pond. At the base of the pond, a filter layer would be provided. Beneath the filter layer, large diameter holes would be bored through the clay layer and filled with porous media. The design of each basin would include consideration of storm rainfall and evaporation. To match the progressive increase in effluent quantity, pond construction would be phased. For operational and maintenance reasons, multiple ponds will be required. The system is expected to be simple to operate with low operational costs.

Alternatively, the artificial borehole recharge scheme is not favourable due to;

- The installation and maintenance of injection boreholes is already complex with natural, perfectly limped water, their use in granular terrain for injecting wastewater although it has been treated, would involve the most sophisticated technology. In addition injecting wastewater can not be employed except in extensively fractured or even karstic terrain. Based on geological features in Gaza Strip in general and in North Gaza in particular, only surface spreading infiltration basins are believed to be a reliable and cheap option. The main constraint in using this technique is the site and land required for infiltration basins
- Without the protective effect of a sand filter (as in a basin scheme), there is greater risk that the aquifer would become blocked by suspended particles or algae growth. Providing a second filter system is considered to be uneconomic. The risk of blocking would need to be overcome by frequent pumping of the boreholes and if necessary, periodic cleaning and refurbishment;
- In view of the operational requirements, a borehole scheme would require a large number of cased and screened boreholes, together with inter-connecting pipeline, pumps for injection and recovery and flow control systems;
- A borehole system is likely to require skilled personnel to operate the scheme and due to the maintenance requirements, incur higher operational costs than a basin scheme.

In view of the above points, the basin recharge scheme was would be more economic and easier to operate than a borehole scheme.

Design Basis for Recharge Scheme: In order to examine the technical feasibility of the basin recharge scheme, it is necessary to consider not only the infiltration of effluent through the recharge facilities, but to also consider the groundwater flow through the unsaturated and saturated zone of the underlying aquifer. The design basis for the recharge facilities are briefly described below:

The design process commences with the selection of the key design data and design criteria. The design criteria include consideration of the safety factor and safety margins used in the design. The selection of appropriate safety factors needs to take into account the extent and likely accuracy of the information available;

- The infiltration area is initially calculated based upon the highest expected monthly inflow rate and the expected vertical aquifer permeability. A safety factor is then applied to the results;
- The preliminary engineering and operation of the scheme are then considered. The operation of the scheme, in particular the length of the flooding and drying cycles, as well as the pond storage and potential inflow rate, all influence the overall operational efficiency of the scheme and the number of basins required to achieve a uniform flow rate;
- Maintenance requirements in terms of the need to be able to take one basin out of service, also has to be considered, to ensure that sufficient surplus capacity exists within the scheme;
- The infiltration area required is then adjusted to take into account the operational efficiency of the scheme based upon operational and maintenance requirements;

- The design of the filter and drainage layers includes consideration of the permeability of each layer and the compatibility of the grading within each layer;
- Finally the aquifer water table elevation below the site is estimated on the basis of the annual average effluent flow to ensure that the vertical drains will function correctly at all times;

The conceptual design of the recharge facilities has taken into consideration the hydrogeological characteristics of the site, the capacity of the sewage treatment works, the potential for direct reuse of effluent for irrigation, the operation of the scheme and the likely shape and size of the basins and adjacent earthworks. Each point is briefly discussed in the following sub-sections.

Hydrological Characteristics: The key hydrogeological characteristics are the vertical and horizontal permeability of the unsaturated and saturated Kurkar Formation. These are intrinsic properties that cannot easily be modified. All other aspects such as the thickness of the clay layer can be accommodated within the design process however an excessively thick clay layer will increase scheme costs and may constrain scheme capacity. From the soil investigation results, the vertical permeability of the unsaturated Kurkar Formation is 2 m/day and the horizontal permeability of the saturated Kurkar Formation is 8 m/day. By using a safety factor of 2, the effective vertical permeability used within the scheme design is therefore 1 m/day. The aquifer transmissivity was used to estimate the water table increase beneath the site due to recharge. Within the design, a safety margin of at least 3 metres between the maximum groundwater elevation and the base of the vertical drains was allowed.

Design Load: The estimated peak monthly effluent by year 2025 is 67000 m^3/day in year 2025 [5]. If by this date the treated effluent is fully reused for irrigation, the maximum inflow rate would be approximately 34, 000 m^3/day. This represents the expected range of uncertainty in the 2025 flow rate and hence the infiltration capacity required for the scheme.

The treated effluent will be subjected to disinfection and rapid gravity filtration as part of the treatment process. The resulting effluent will have very low suspended solids (average of 15mg/l). The duration of flooding and drying cycles used in effluent recharge basin design is influenced by several factors as indicated below:

- At least two days is required for complete drying and removal of dried solids from the surface of the sand filter;
- The duration of the flooding cycle can normally be lengthened if tertiary treated effluent is used, as the rate at which the sand filter becomes blocked is significantly reduced;
- In all cases the need to prevent excessive algae growth within the recharge basin tends to limit the flooding cycle duration to approximately 2 days.

A short flooding period of 1 day together with a drying cycle of 2 days, tends to limit the operational efficiency of the scheme thereby increasing the overall area of the recharge basin. Increasing the flooding period to 2 days helps to improve operational efficiency. The total length of the flooding and drying cycle also influences the number of recharge basins needed to achieve a uniform inflow rate.

Longer flooding cycles provide greater operational efficiency, but increase the number of ponds required. As the standard of treated effluent is high, a flooding cycle of 2 days has been selected. Depending upon the length of the drying cycle either 4 or 5 ponds will be needed.

Design Criteria: The following criteria have been used in the design of the pond:

- Depth of vertical drainage measures; to penetrate at least 3 m into the Kurkar Formation aquifer below the base of the clay in all boreholes;
- Thickness of coarse sand layer in the base of the pond connecting each vertical drain; 0.3 m;
- Thickness of fine sand layer above the coarse sand layer; 1 m;
- Head of water within the basin above the top of the fine sand layer; 1 m;
- Freeboard above the basin water level to the crest of the embankment; 0.5 m;
- Slope of the embankment and excavation; 1 in 2;
- Crest width of the embankment; 3 m;
- Border width of 2 m around each basin. For multiple basins, this would provide an access route 4 m wide between basins.

A filter layer (layer 1) is needed at the base of the pond to filter out virtually all suspended solids from the effluent in order to prevent potential blockage of the aquifer. This is important as the aquifer below the site is expected to remain unsaturated; hence it would be very difficult in the future to remediate the aquifer should a blockage occur.

Due to the presence of a clay layer at the site, vertical drainage measures will be required to enable the effluent to recharge the aquifer. The cross sectional area of the vertical drains and hydraulic properties of the porous media placed in the drains, needs to be sufficient to discharge the full quantity of effluent.

The vertical drains will probably be bored using an auger with a diameter of between 0.6 – 1.2 m. The bored hole will then filled with carefully selected graded porous media (layer 2). In order, to minimise the cost of the vertical drains; the grading of layer 2 needs to be selected by a high hydraulic conductivity.

A further constraint is the need to prevent the fine particles of layer 1 from being carried into the void space of the coarser particles in layer 2 and thereby blocking will occur. This can be achieved by applying standard filter rules to the design of layer 2, which may then constrain the permeability of layer 2. If this factor causes a significant constraint, a third filter layer or the use of geo-textiles may be required.

The final requirement is the need to ensure that the groundwater mound formed within the saturated aquifer below the recharge facilities does not increase to the point where downward flow in the vertical drains is reduced. The criteria used to evaluate the design are summarised in the table below [6].

Recharge Area: For a range of treated effluent flow rates and taking into account the design criteria proposed in the above table, as well as the potential reuse of effluent for irrigation, the total areas shown in the table below are required. The relative area is the proportion of the maximum area.

Without reuse of the treated effluent for irrigation, the maximum site area needed by the year 2025 is estimated to be 125 dunums. With full potential reuse of the treated effluent for irrigation, the maximum site area needed by the year 2025 is estimated to be 73 dunums. In both cases a total of 6 infiltration basins have been assumed.

Infiltration Impact on Groundwater Elevation: Within the site, ground elevations vary from approximately 49 m to 68 m above sea level. The site investigation results indicate that the thickness of the surface clay layer is quite variable from 7 m to 23.5 m. Placing the infiltration basins within an area of the site where the clay layer is thick will increase the cost of the vertical drainage measures.

In order for the vertical drains to function correctly, a minimum margin of 3 m has been allowed between the base of the drains and the elevation of the groundwater mound beneath the site. In addition, a margin of 3 m has also been allowed between the base of the clay layer and the base of the vertical drains, to ensure that the effluent infiltrates into the unsaturated aquifer. The elevation of the groundwater mound beneath the site depends upon the infiltration rate, the saturated aquifer transmissivity and storativity, the elevation of the natural groundwater table and whether additional groundwater abstraction will take place adjacent to the recharge mound in the future.

The site investigation results have been reviewed to assess if the elevation of the base of the clay layer is likely to constrain the quantity of effluent that can be recharged, in the absence of additional groundwater abstraction. The results are summarised in the table below.

The above results are based upon the following assumptions [3, 6]:

- Groundwater elevation at the site; 0 m above sea level
- Saturated aquifer thickness of 70 m, horizontal permeability of 8 m/day, transmissivity of 560 m^2/day and storativity of 0.2.
- Recharge basin area of 84 dunums and recharge facility site area of 125 dunums at the year 2025.

Based upon the above assumptions, it is concluded that if the elevation of the base of the clay layer is less than approximately 40 m above sea level, then the maximum recharge rate could be less than the target value of 67000 m^3/day. It is therefore recommended that the recharge basins should be located within the vicinity of Boreholes 2, 3, 4 and 5. Locating part of the basins in the vicinity of Borehole 1 will give less operational flexibility in the future.

Environmental Issues: The main environmental issues resulting from the recharge scheme are listed below:

Table 1: Criteria for Evaluation of Design [6]

Criteria	Safety Factor / Margin
Area of the basin in relation to the unsaturated zone infiltration rate	Safety Factor > 2
Basin fine sand filter (layer 1) infiltration capacity	Safety Factor > 4
Vertical drainage and basin coarse sand filter (layer 2) infiltration capacity	Safety Factor > 4
Grading of basin fine sand filter / coarse sand filter / vertical drainage media	Filter grading to pass general filter rules
Depth of vertical drains below the base of the clay layer.	Minimum Margin 3 m
Depth of unsaturated zone below the base of the vertical drains (m)	Safety Margin > 3 m

Table 2: Area required for Infiltration in Various Scenarios

Year	Reuse For Irrigation	Flow (m^3/d) Maximum Monthly	Total Site Area (1000 m^2)	Relative Area
2005	Y	9, 484	30	0.24
2010	Y	14, 291	39	0.31
2015	Y	24, 382	57	0.46
2020	Y	30, 928	68	0.54
2025	Y	33, 907	73	0.58
2005	N	18, 742	47	0.38
2010	N	28, 242	63	0.51
2015	N	48, 182	96	0.77
2020	N	61, 117	116	0.93
2025	N	67, 003	125	1.00

Table 3: Estimated Maximum Recharge Rate at each Borehole

Investigation Borehole	Estimated Ground Elevation (m)	Elevation – Base of Clay Layer (m)	Elevation – Base of Vertical Drain (m)	Maximum Elevation – Top of Groundwater Mound (m)	Estimated Maximum Recharge Rate (m^3/d)
1	49.67	26.2	23.2	20.2	35, 000
2	51.93	43.4	40.4	37.4	65, 000
3	55.04	48.0	45.0	42.0	73, 000
4	59.30	49.3	46.3	43.3	75, 000
5	62.30	52.3	49.3	46.3	80, 000
6	56.30	36.3	33.3	30.3	52, 000
Minimum	40.2	37.2	34.2	59, 300	

- An increase in the groundwater elevation within the saturated Kurkar Formation aquifer beneath the site;
- A change in the groundwater quality as a result of reused effluent mixing with the native groundwater quality.

Each item is briefly discussed in the following sub sections in terms of the existing situation, a review of the likely impacts and discussion of potential mitigation measures.

CONCLUSIONS

- Aquifer recharge is important to Gaza aquifer due to high demand which greatly exceeds water supply; More than 70% of the aquifer is brackish water; Saline Intrusion is expanding with time.
- The projected wastewater effluent by year 20025 indicated that significant amount of water will be available for both irrigation and recharge. In the winter the need for recharge becomes high to utilize treated wastewater instead of flowing to Wadi Gaza or to sea.
- Aquifer recharge will improve water quality and reduce the water deficit between inflow and outflow of the alluvial deposits aquifer.
- A combined system of ponds with filtration boreholes is the most appropriate and economical system for recharge of treated wastewater into alluvial deposits aquifer.
- There is potential to recharge up to 67, 000 m^3/day, the required area will be for recharge basin is around 84 dunums and recharge facility site area of 125 dunums by the year 2025.
- The recharge ponds are designed in such a way to avoid water mound in the aquifer systems which might allow for backflow to Israeli side.

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