ARTIFICIAL INFILTRATION OF GROUNDWATER

A tool towards the Sustainability of Water Resources in the Gaza Strip

Sami M. Hamdan
M.Sc. Environmental Engineering and Sustainable Infrastructure
Palestinian Water Authority

Ibrahim S. Jaber
M.Sc. Economic Sciences
Palestinian Water Authority

Abstract

The coastal aquifer in the Gaza Strip has been exploited to a large extent in the last two decades. The abstraction reached about twice the annual supply for this reservoir. After the establishment of the Palestinian Water Authority, many efforts were proposed and practiced to control this limited resource to save its sustainability. Technical and Socioeconomic solutions together could bring the resource to be utilized in a sustainable way.

One of the technical solutions is the use of surplus stormwater and treated wastewater to increase the supply in the way of decreasing the water deficit. Artificial infiltration undergoes physical, chemical and biological processes. The experience showed a successful treatment in elimination of bacteria, viruses and nitrate due to those processes. The topography, hydrogeology and soil in the Strip encourage this part of solution, where the aquifer features show large capacity to store large quantities, especially in the winter season.

On the other hand, socioeconomic aspect is studied to implement this solution. The price per each cubic meter of this solution is compared with prices of other solutions e.g. desalination and imported water. It is more economic than the latter solutions, in addition to its social, health and environmental impacts.

1. Introduction

Water resources in The Gaza Strip are very limited. Rapid increasing of population in addition to the increase per capita consumption increase the demand of water, where the later much exceeds the natural supply of the resource. The resource over exploitation makes it unsustainable which threatens the future generations. To make the balance between the outflows and inflows of the resource, many tools are viable for implementation in Palestine in general and in the Gaza Strip in particular. Artificial recharge of groundwater is one of the important tools towards achieving the sustainability of groundwater reservoir. This option was and still used in some areas in indirect way through the uncontrolled wastewater system, overflow of untreated wastewater or direct infiltration from cesspits. Managed artificial infiltration of groundwater will help in the sustainability of the aquifer in different ways. It decreases or stops the declination of groundwater, stores water in the wet years or seasons, stops seawater intrusion and gets rid of the flooding stormwater and treated wastewater.

The paper will focus on the Gaza Strip, which severely suffers from the water deficit, at the same time; the cities of the Strip are flooded from rainfall every year. Several millions of cubic meters of rainfall are wasted every year, either by evaporation or through surface runoff to the sea. Due to the continuous expansion of urban areas and pavement of roads, the surface runoff increases rapidly. These will urge the Palestinians towards thinking of using infiltration basins despite of the relatively high costs of land.

2. Water Resources

The water resources in the Gaza Strip depend mainly on groundwater, which is partially renewed from rainfall. The formation of groundwater system is composed of quaternary deposits in the form of calcareous sandstone known locally as Kurkar. Its thickness varies from 160 meters in the West to about 10 meters in the east(1). The aquifer is separated into three sub-aquifers making them as confined aquifers in the western part of the Strip along the coast. The groundwater system is confined from bottom by Tertiary formation known as Saqeya layer, which consists of clay, marl and shale. The aquifer has a porosity of about 25%.

Groundwater

The completely dependence of water needs on groundwater led to its deterioration. There is about 3,000 water wells penetrating the groundwater reservoir. About 100 wells of which are utilized by municipal and industrial purposes. The water demand in the year 2000 reached 63 million m^3 for municipal and industrial uses and 89 million m^3 for agriculture (4). This gives a total demand of 152 million m^3 in the year. The total supply of the aquifer is 98 million m^3 (3). The total deficit is 54 million m^3 annually, which results in continuous declination of groundwater levels and deterioration of its quality (Fig.1&2). Chloride concentration i.e. salinity is increasing continuously, where salinity increased suddenly because of seawater intrusion in other places close to the sea shore in the middle part of Gaza Strip.

Fig1. Groundwater level a.m.s.l. in well L/66

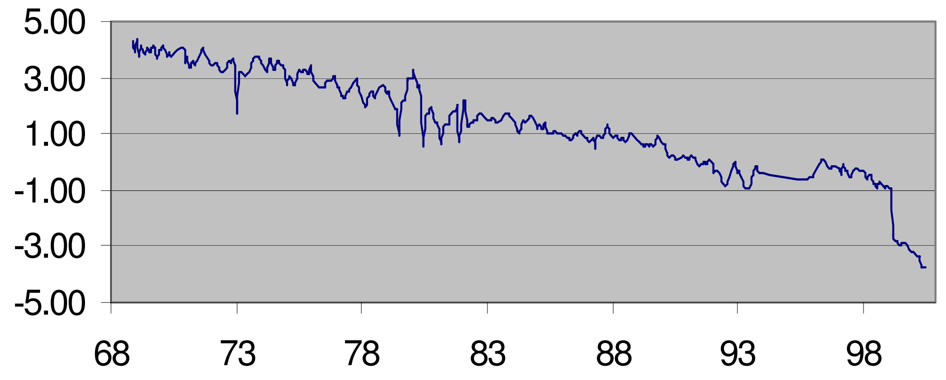
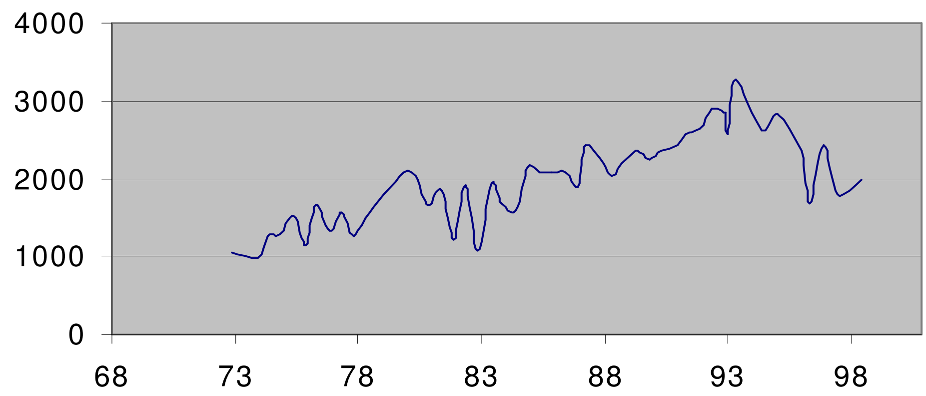


Fig 2. Chloride content (mg/l) in well L/66



Pollution is not less important where nitrate level, indicator of pollution reached about 550 mg/l in some wells because of uncontrolled wastewater overflow from the wastewater treatment plants for the cities and from direct infiltration of raw sewage from cesspits in the unsewered areas. In case of controlled wastewater, the latter will be well treated and diverting it to special infiltration areas will alleviate the risk of pollution and also decrease the water deficit.

3. Artificial Infiltration

Artificial infiltration of water means in this paper the use of infiltration basins through which water is stored and infiltrate to the groundwater through the permeable bottom of these basins. However, artificial recharge of groundwater could be as artificial infiltration in basins or through injection wells. The later is not preferable, because it needs high quality treated water, either wastewater or stormwater. Also, accumulated problems of bacterial growth and clogging of the screens of the injection wells make this option very difficult and expensive to maintain it every period. Artificial infiltration is more viable to use in the Gaza Strip.

History

Artificial recharge of groundwater has been practiced worldwide. It implies a significant percent of the total water supplies of some countries. For example, in Canada about 34000 m^3 per day infiltrate in spread basins. In Germany 20% of the public water supply come through infiltration of river water and its recovery. The same is in Netherlands (15%) and Sweden (25%).

In the Gaza Strip, the first experience was applied in the early nineties, where about 80 dunums basin was constructed in the Gaza city to collect stormwater from the city and divert it to this basin, where water was supposed to be injected through special wells close to the basin. Unfortunately, due to bad management of wastewater collection, the wastewater penetrated the stormwater network and flew to this reservoir and changes it to a mixed wastewater and stormwater system. However, this reservoir known as Sheikh Radwan basin has been reconstructed by the Palestinian Authority and the wastewater has been converted to the right wastewater pipes. As a resource, the collected stormwater is wasted by pumping it to the sea, and minor part infiltrate downward due to the impermeability of soil at the bottom of the pool.

In 1997 and 1998, two projects have been started, the first one in Gaza city treatment plant, where part of the effluent is diverted to infiltration basins which have infiltration capacity less than the effluent flow. The rest of effluent is pumped to the sea. The second project is the stormwater collection in North Gaza, where stormwater is collected in retention basin in Jabalia City and then pumped to infiltration basins located close to the existing wastewater treatment plant at Beit Lahia. Anther project will be started soon in Khanyonis area, where stormwater will be collected from all areas in the City and diverted or pumped to a large infiltration basin in the west of the City. Other two small infiltration basins inside Khanyonis camp will be used in this project too. Infiltration of treated wastewater is planned to be implemented in spread basins besides the proposed wastewater treatment plants of both Khanyonis and Rafah.

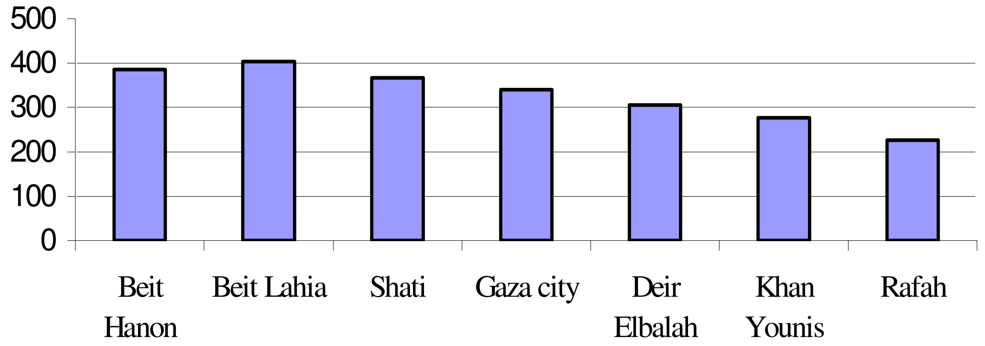
Sources of infiltrated water

The sources of water to be infiltrated are mainly from both stormwater, urban runoff and treated wastewater.

Stormwater

The Gaza Strip receives an average annual amount of rainfall fluctuates from 220 mm in the south to 400 mm in the north. The annual distribution in different areas of the Strip is shown in Fig. 3. The potential collected stormwater in the rainy season 1991/1992 reached about four million m^3 according to the calculations based on Khanyonis master plan, where the stormwater in the same year was estimated as seven million m^3 in Gaza City. The urban development is proceeding steadily and more amounts of urban stormwater are expected, and consequently the amounts of natural recharge of rainfall will be decreased. The loss of the urban runoff will increase the balance of water resources and then the collection of this runoff and diverting it to infiltration basins became an urgent priority in the Palestinian projects according to the policies of the Palestinian Water Authority. In Deir Elbalah area located in the middle of the Strip, water runoff accumulates in depressions before reaching the sea making large areas flooded for the whole rainy season until water evaporates. This causes problems to the inhabitants in addition to the loss of potential resources of water in this area that suffers from water scarcity. As preceded above, stormwater projects started as the case in Khanyonis City in the south and almost finished in Beit Lahia in the north. In Gaza City that has the largest amount of urban runoff; most of that water is lost through runoff to the sea.

Fig 3. Average annual rainfall (mm)



Wastewater

Wastewater is not less than stormwater, where the effluent in the current situation is infiltrated close to the existing treatment plants without sufficient treatment to cope with the Palestinian standards. These standards indicate that 15 mg/l as suspended solids, 10 mg/l as biological oxygen demand and 30 mg/l as nitrate[(4)]. The wastewater overflow is found in Beit Lahia wastewater treatment plant. Another case is found in Gaza wastewater treatment plant but the effluent is infiltrated by human control. In Rafah treatment plant the effluent is pumped to the Mediterranean Sea. The wastewater flows in the existing treatment plants are shown in table 1 bases on [(4)]. The percentages of connecting houses are shown too.

Table 1. Wastewater flows in Gaza governorates

	Percent of connecting houses	Flow (m^3/day)
North Gaza	65%	7690
Gaza	78%	6110
Rafah	25%	2500
Middle area	0	0
Khanyonis	0	0

The weighted average percent of the whole Gaza Strip is only 46% [(4)], and this amounts about 6 million m^3 of wastewater per year. If the unsewered area of the Gaza Strip is connected, the total amount will reach about 13 million m^3 per year.

Stormwater and wastewater form together about 30 million m^3 per year, which have a significant percent of the current total demand of about 160 million m^3 per year. The Palestinian policy relies on these two potential resources if they are infiltrated to the groundwater system. This, of coarse will play a major role towards achieving the sustainability of groundwater resources in the Gaza Strip.

Processes

Artificial infiltration has been practiced since the beginning of the 20^{th} century. Processes were noticed and explained from practice. So, there are no exact calculations of the speed of any process accompanying the infiltration of water. However, processes are estimated at certain rates and mitigation of their adverse impact was proposed.

Clogging of the top layer of soil is the most important in the infiltration basins, where the suspended fine particles found in the water are retained at the top surface of basin bottom reducing the rate of infiltration. Clogging could occur as a result of chemical reactions resulting in some compounds precipitation during flushing of water into the basin. The clay part of the bottom soil could be dispersed and float to the top leading to sealing of the basin bottom. If the water is shallow, i.e. less than 3.0 meters, the algae have the opportunity to grow and clog the voids of the soil. Consequently, the basins are maintained every period to get rid of clogging and improve the infiltration conditions of the basins.

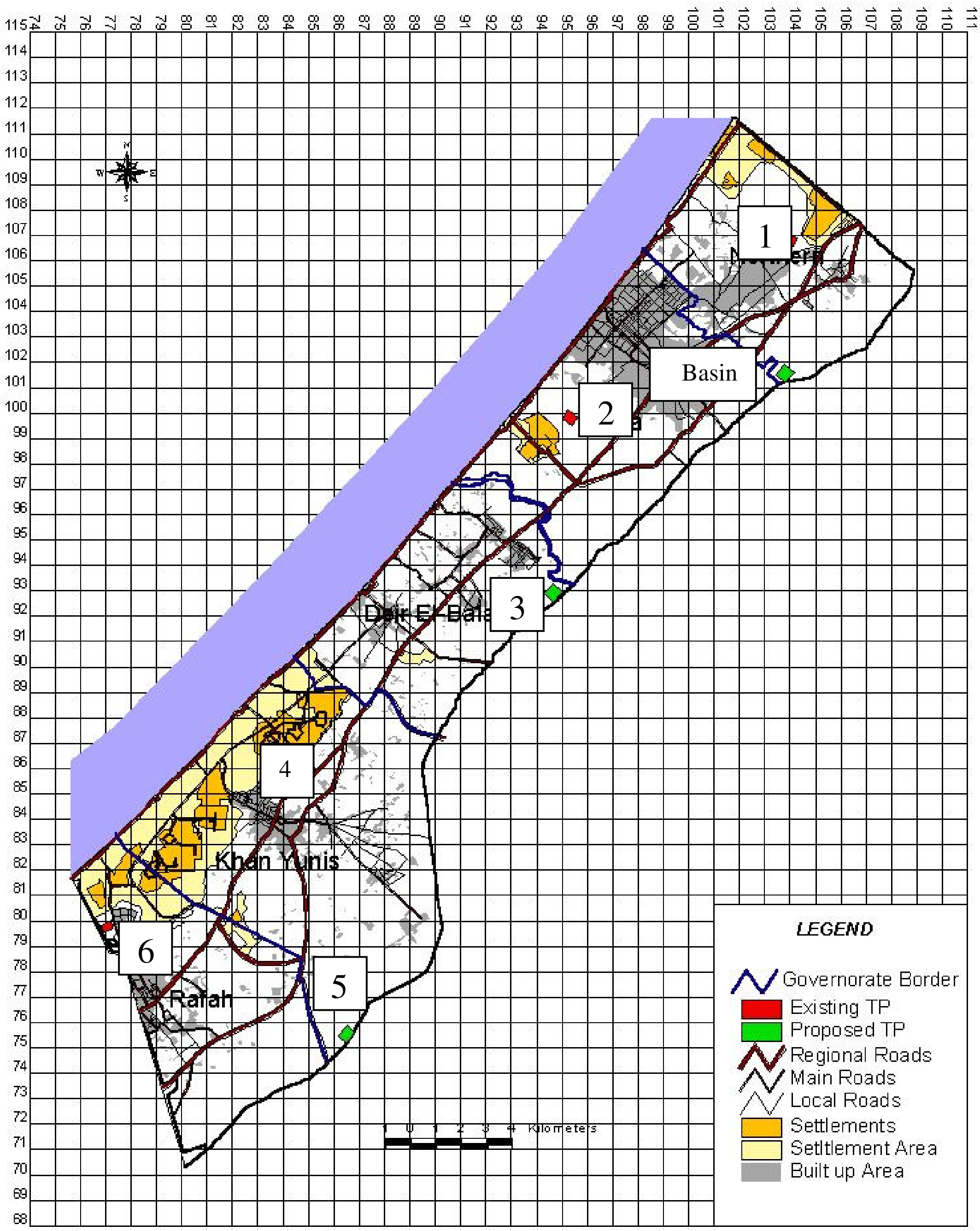


Fig. 4 Map of Gaza Strip showing governorates and infiltration sites

4. Control and Management of Basins

Monitoring requirements

There is a national monitoring system in the Gaza Strip, where groundwater level is measured in about 130 wells every month. And water is sampled and analyzed for about 300 wells every six months. The monitoring of infiltration basin needs a special program to measure the groundwater fluctuations in addition to sampling and analyzing the groundwater close to the basin. This will give precaution if the infiltrated water was not well purified during the infiltration process and soil aquifer interaction.

The water level in the basin itself should be measured every day in addition to the flowing quantities to the basins to predict the efficiency of the system. Due to large number of wells in the Strip, the monitoring wells are taken from the existing agricultural wells, since they will be close to the proposed infiltration basins.

Recovery wells

Recovery wells are used to pump again the infiltrated water after it undergoes soil aquifer treatment process. In Khanyonis City, the infiltration area is located very close to the border of a settlement controlled by Israelis. The groundwater flows, unfortunately to that settlement. However, there is no other alternative place. In this case the recovery wells could be put inside the settlement if there is a political solution let the Palestinian control that area.

In the north, in Beit Lahia the recovery wells are the same as the existing agricultural ones that are located to the west of the existing infiltration basins. Around infiltration basins of Gaza City, there are no wells close to the treatment plant, and more recovery wells are needed.

Basin maintenance

The stormwater in Gaza in general contains high concentration of suspended solids due to the unpavement of many roads in the city. This of coarse affects the quality of infiltrated wastewater after it goes through the sand trap just before the infiltration basin. The technology available in the Strip will not use scraper machine that removes the upper 5-cm of the infiltration basin bottom. Ploughing of the soil will be more economic and practical. This process will improve the infiltration capacity of the basins. Until now, there is no experience of basin maintenance, but the experience of neighboring countries having the same infiltration capacity encourages the Palestinians to use this option. Also, the infiltration processes resulted in high purification of water through the soil aquifer treatment process.

5. Location of Artificial Infiltration Sites

The existing and proposed sites for infiltration are shown in numbers in Fig. 4 which are:

a) Beit Lahia which has been completed this year by donation from Sweden and shown in the site no. 1.
b) Close to Gaza existing wastewater treatment plant, no. 2, and was partially completed but its capacity does not absorb the whole effluent quantities, and part of it goes to the sea.
c) East Gaza in no. 3, which is proposed and will be close to the central wastewater treatment plant. The later is under evaluation for design and construction and funded by the Loan Institute for Reconstruction (KfW).
d) West of Khanyonis no. 4, for infiltration of stormwater. This project is now under construction that has been delayed due to Al Aqsa Intifada. The basin was designed for infiltration of stormwater and is funded by donation from Japan through UNDP. Economic aspects of this project follow in the next chapter.
e) East of Khanyonis, site no. 5, where two wastewater treatments plants are intended to be constructed soon to secure both Khanyonis and Rafah Cities. The infiltration area will be besides the plants.
f) West Rafah close to the existing wastewater treatment plant, where the effluent is discharging to the sand dunes around in site no 6.
g) Other potential sites are available in Deir Al Balah and between Khanyonis and Rafah.

6. Socioeconomic of Artificial Infiltration

Both stormwater and wastewater need mitigation either as getting red of them or treatment. Site no. 4, the stormwater drainage project will be discussed here, where the economic analysis need a certain project. In this site the urban runoff in Khanyonis City is analyzed. Stormwater is collected and diverted to the infiltration area to achieve different benefits, economic, environmental, health and social.

Economic aspect

The economic analyses of the real cost per one-meter cube of infiltrated water ($0.165) is shown in table 2, and the real cost of one meter cube recovered ($0.11) is shown in table 3. The total cost of recharged and recovered water as total is 0.165+0.11= $0.175/m^3, which is less than the cost of imported water from the Israeli company, Mekorot ($0.33/m^3)(5) and also less than the cost of desalinated seawater ($1.85/m^3)(6). Also, the stormwater should be mitigated in all cases, if not used for infiltration; it will be pumped to the sea. If the cost of pumping system will be considered, this will reduce the cost of infiltrated water and makes it more feasible. Figs 5&6 show the distribution of operation cost and the relation between system efficiency and water cost respectively.

Table 2. The Real Cost of Storm Water infiltration

Interest Rate	5%					
Item	**Component**	**Const. Dat.**	**Total C.**	**Life**	**Factor**	**Annual Cost**
Investment Cost						
	Civil Works (Roads)	2001	644,265	40	17.16	37,547
	Pump Station (1)	2001	300,000	15	10.38	28,903
	Pipes (P.V.C)	2001	3,937,000	30	15.37	256,107
	Infiltration basin	2001	3,000,000	30	15.37	195,154
Total Investment			7,881,265			
Sub-Total						**517,711**
Operation Cost						
Manpower	10					60,000
Electricity						2,000
Maintenance	1%					**78,813**
Sub-Total						**140,813**
Total Cost						**658,524**
Infiltration Quantity	m^3					4,000,000
Total Cost	$\$/m^3$					***0.165***
	NIS/m^2					**0.675**
Operation Cost	$\$/m^3$					**0.035**
	NIS/m^4					**0.144**

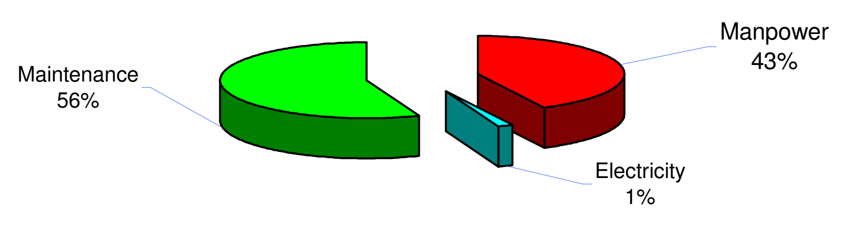
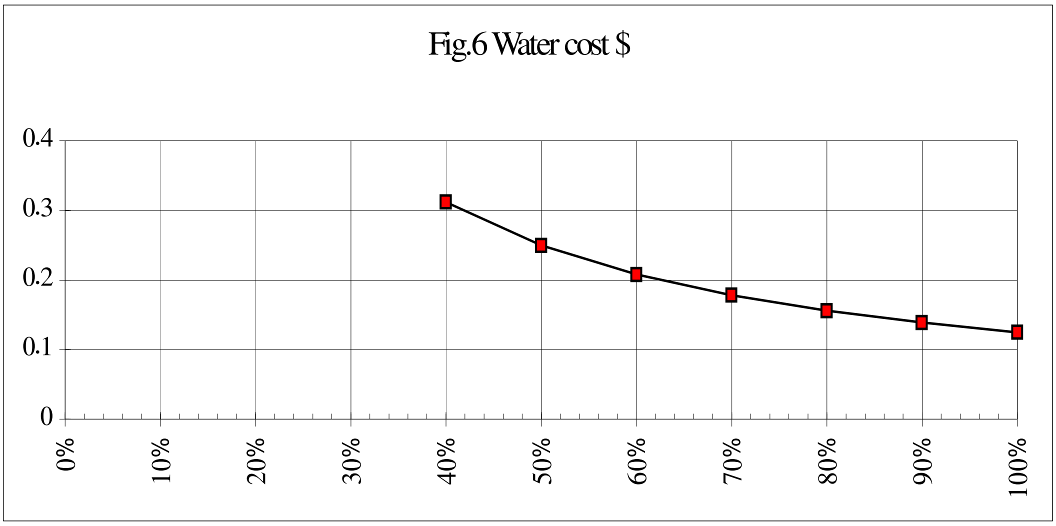


Fig 5. Operation Cost Distribution

Table 3. The Real Cost of recovered water

System efficiency		90%						
Interest Rate	5%							
Item	**Dim**	**Material**	**Quantity**	**Unit Cost**	**Total Co.**	**Life**	**Factor**	**Annual Cost**
Wells			1	112000	112,000	25	14.09	7,947
Pipes	10	U.P.V.C	5000	33.62	168,100	15	10.38	16,195
Sub-Total					280,100			**24,142**
Running Cost								
Wells and Network		O&M	2.5%					7,003
		Energy						27,048
Contingency								1,703
Sub-total								**35,753**
Total Cost								**59,894**
Water Production		**m^3**						**624,800**
Total Cost		$/m^3$						*0.10*
		NIS/m^3						0.39
Real cost		$/m^3$						0.11
		NIS/m^3						**0.44**
Cost of Operation		$/m^3$						0.06
		NIS/m^3						0.23
Real cost		$/m^3$						0.06
		NIS/m^3						**0.26**
		System efficiency	**Cost $/m^3$**	**Cost NIS/m^3**				
		100%	**0.10**	0.29				
		90%	0.11	0.32				
		80%	0.12	0.36				
		70%	0.14	0.41				
		60%	0.16	0.48				
		50%	0.19	0.58				
		40%	0.24	0.72				



Environmental impact

The environmental impact of this project is not assessed in figures, but it could be sensed through the conservation of water resources, mitigation of stormwater flooding and erosion and minimizing the maintenance of roads. Also, it has positive health impact to avoid mixing of stormwater with the wastewater. It reduces the waterborne diseases. Water flooding mitigation will constrain the spread of insects e.g. mosquitoes.

Social impact

The implementation will give convenience to the inhabitants whose houses are surrounded by ponds in the rainy days and they can not move from houses easily. The water resources will be improved, and the people will get more water that increases the welfare and improvement of social and economic situations of the family and reduction of poverty and ignorance in the poor communities.

7. Conclusion

Artificial infiltration of groundwater became a necessity towards sustainable water resources management. It can participate with about 20% of the total demand of water in the Gaza Strip, and this covers about 50% of the total deficit of the resource. The processes accompanying infiltration purify water through water soil aquifer interaction. Artificial infiltration has been practiced in Gaza, and other projects are under construction based on the general policies of the Palestinian Water Authority.

The economic analyses of Khanyonis stormwater project showed that infiltrated and recovered stormwater is cheaper than other solutions e.g. desalination or imported water from Israeli company (MEKOROT). The project has, also its positive social, environmental and health impacts.

References

1. Abed, A. 1985. Geology of Palestine, Palestinian Encyclopedia.
2. El Sheikh et al. 2000. Management of Desalination Plants and Distribution. Options of Desalinated Water. IWTC 2000, Fifth International Water Technology Conference, Alexandria, Egypt.
3. Hamdan, S. 1999. Potential artificial recharge of groundwater in the coastal region of Palestine. Stockholm, Sweden, 1999.
4. PWA 2000. Water Sector Strategic Planning Study. Final Report. Ramalla, Palestine, 2000.
5. PWA- MEKOROT files of water supply in the Gaza Strip.
6. PWA, SOGREA 1999. Technical Assistance for the Construction of A Desalination Plant in Gaza. Gaza, Palestine.