Serving the Unserved: A Sustainable Sanitary System to Serve the Remote and Deprived Hamlets

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Abstract

In Egypt, there is about 26,540 Hamlets with population less than 5000 capita – that are not served with an appropriate wastewater collection and treatment system. The commonly applied sanitary system; is a centralized system, where connecting hamlets with the villages is usually neglected due to the high costs affiliated with the erection and maintenance of force-main and the limited number of beneficiaries residing in the hamlets, relative to the high costs associated with erection of the force-main. In addition, installing sanitary systems in such areas is usually infeasible due to the lack of skilled labor & energy shortage. The main focus of this paper is to find a solution for the un-served hamlets, which have rudimentary systems such as open disposal trenches. These systems cause serious problems as it contaminates and increase the ground water table, which threats the health of the inhabitants and the surrounding environment. As a result, the paper proposes a solution for the current problem through designing a sustainable decentralized system, which shall collect the wastewater in-order for it to be efficiently disposed in a proximate drainage or reused in the same area after treatment. Through studying a prototype hamlet in Egypt, the paper proposes solutions for the collection systems and studies their efficiency, the suggested solutions are either a hybrid system between conventional and shallow systems.

Keywords

Septic tank; conventional sewers; shallow sewers; flushing tank, hamlets

INTRODUCTION

Rural Egypt is suffering from low coverage of proper sanitation services. In 2014, it was estimated that about 26,542 hamlets (satellites villages) have no sewage treatment or even proper collection systems. The common existing sanitary system is an open trench disposal system (cesspits) where wastewater is disposed to a small hole in the ground, next to each house and then the waste is left to dissipate in the soil, which contaminates the ground water table and easily reaches the irrigation water in the rural communities, whose main economic activity is based on the agriculture. The aim of the current work is to compare between two systems for sewage collection within the hamlets in Egypt. These two systems include combination of shallow/conventional sewers versus combination of septic tanks and shallow/conventional sewers. The study was carried out on a hamlet in Egypt as a prototype hamlet.

PROTOTYPE HAMLET OVERVIEW

Al-Gozayera hamlet is located in Ismailia governorate in Egypt; it is a small suburb (Ezbet) that is surrounded by two water bodies, Al Rayah drain and irrigation tertiary canal and a camp from the other two sides. The current population is 1138 inhabitants (Abdelwahaab, 2013) residing in approximately 190 houses. The total land area of the hamlet is 100,000 m^2. The population growth in the hamlet will follow a normal annual growth rate of 3.5%. The future population of the hamlet can be calculated using Equation 1.

$$P_f = P_p \times (1 + i)^n \tag{1}$$

Where P_f is future population, P_p Present population, i is the growth rate and n is number of years

Accordingly, the expected population of the hamlet after 10 years is about 1600 capita. This value will be used in designing both alternative solutions of the sewage collection system. The current average water consumption is estimated to be 57 m^3/day. There are governmental and public buildings that are utilizing additional water consumption of approximately 10 m^3/day. Consequently, the current average total flow is about 67 m^3/day. However, it is common in Egypt that the water consumption will increase when the sewage network is upgraded. The average water consumption rate in a rural area ranges from 100 to 150 l/C/d. About 80% to 90% of this amount of water reaches the sewers (Egyptian Code of Practice, 2010). Based on that, the design average sewage flow for the prototype hamlet is considered to be 85 l/C/d.

METHODOLGY

Data Collection. The required data include the current population, topography, water demands and surveying maps. The data collection was done through field visits and meeting local authorities.

Design. The study was conducted in two phases. The first phase is studying shallow system combined with conventional sewers as a solution. The second phase is studying the Septic Tank combined with the Shallow systems and conventional sewers as an alternative solution for the prototype hamlet. The study was done using Sewer-Gems software, which helps in designing and analyzing the network. Finally after studying the two alternatives, a comparison was done to reach the most suitable solution for communities of this size with the same condition in Egypt. Both solutions are assessed according to the cost of each system, excavation volumes, water quality and maintenance.

SOLUTIONS OF THE SEWAGE COLLECTION

Solution 1 (Shallow/Conventional System). The Design used for the sewer line is a conservative design to make sure that there will be no operation problems with the increase of future population. Solution 1 contains a conventional system, which consists of pipes that depend on gravity to move the sewage downward to the pumping station. The manholes are placed along the pipes at equal distances according to the pipes' diameters and at the intersections; change in direction or at drop in the ground level. The pipes should have a minimum scouring velocity to ensure that the pipe is self cleansing, at least once a day, it is minimum 0.6 m/s. Therefore, a flushing box is installed at the beginning of the pipeline to maintain a sustainable design. On the other hand, the prototype hamlet have narrow streets that are less than 3 m in width, therefore, a shallow system is designed for the narrow streets and then it is connected to the conventional system. The shallow system is installed where there is no heavy traffic; this sewerage system uses shallower excavation depths, small pipe diameters and simple inspection units, which make it less costly than the conventional system.

Solution 2 (Alternative Solution). This solution incorporates the septic tank with the shallow system, as the shallow system is used to collect the wastewater from houses and then disposed it in a septic tank for a primary treatment and then the wastewater is flowing full in small diameter pipes to the pump station and treatment plant. The septic tank is built underground and it is made of concrete or glass fiber. The idea of the septic tank is that wastewater enters and stays for at least 24 hours, where an anaerobic reaction occurs, which is considered as pretreatment for the wastewater as the sludge settle and the floatable material are trapped at the top of the tank. Therefore, there are three layers in the tank the first layer contains the floatable material (scum), the second layer contains everything that is heavy and settles (sludge). In the middle the wastewater becomes nearly clear because it is free of solids. As raw sewage enters the tank, it pushes the existing water out of the septic tank solids-free. The exiting pipes are similar to conventional sewer systems, except that the wastewater is pre-settled and solids are removed before entering the system, therefore, the sewer diameter is much smaller and flowing fully as the wastewater was pretreated. The system can be constructed using less conservative design criteria (lower slopes, fewer pumps, less pipe depth, etc.) resulting in significantly lower costs. Moreover, the pipes has much less risk of clogging than the conventional system, hence, the sewers can be laid at shallow depths, can have fewer inspection ports, and it can have no or a slight slope.

DESIGN CRITERIA AND EQUATIONS

The sewers are designed according to Manning equation as described in Equation 2

$$V = \frac{1}{n} R^{\frac{2}{3}} \sqrt{S} \qquad (2)$$

Where V is the velocity of flow, n is manning's roughness coefficient, R is hydraulic radius and S is channel slope.

The design criteria that were used in designing the three different sewer systems, conventional, shallow and septic tank were included in Table 1. The peak factor of the population is calculated using Equation 3:

$$P.F. = \frac{5}{P^{0.167}} \qquad (3)$$

Where P.F. is the peak factor and P is the population in thousands.

Since the hamlet has low sewage flow, which might cause deposition of suspended solids in the pipes (conventional or shallow system) during the night were the flow at its minimum, a flushing box (Figure 1) is recommended to be installed at the beginning of the sewer lines as it releases a large volume of water in a very short interval of time which creates a scouring velocity that cleans the sewer from any deposited solids. Equation (4) is used to design the flushing box.

$$T = \frac{2A}{C_d . a} \sqrt{\frac{H}{2g}} \qquad (4)$$

Where T is time, A is area of water in flushing box, C_d is discharge coefficient, a is the orifice area, H is the height of water and g is the acceleration due to gravity.

Table 1. Design Criteria for the three systems.

Criteria	Conventional* System	Shallow System	Alternative solution With Septic Tanks**
Pipes Alignment	Middle of the street	Middle of the Street	Middle of the Street
For Streets' Width	More than 3 m	Less than 3 m	Any
Minimum Diameters	200 mm	150 mm	50 mm
Min. Cover	1 m	0.45 m	0.5 m
Slope Min.	3.25 m/km	3.5 m/km	0 m/km
Velocity Min.	0.6 m/s	0.6 m/s	-
Velocity Max.	2.5 m/s	2.5 m/s	2.5 m/s
Pipes Connection	Manhole	Inspection Chamber	Inspection Chamber and Inspection Ports

* Based on the Egyptian Code of Practice (2010)
** This applies to pipes collecting wastewater from septic tanks

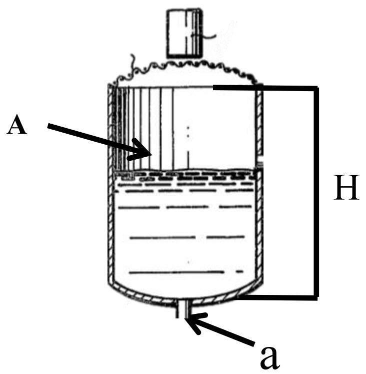

Figure 1. Schematic Diagram of a Typical Flushing Box

The septic tanks were designed with a retention time of more than 24 hours, where this value is the minimum to ensure the separation of solids from liquid according to Khan et al. (2007). The tank will be designed according to average flow rate (Q_{ave}) and will be checked at the peak flow.

RESULTS AND DISCUSSION

Solution 1 (Shallow/Conventional System). After calculating the wastewater flows and evaluating the surveying maps, the pipes layout was set with an appropriate manholes' distances and with pipes laid exactly in the middle of the streets. The final pipes layout is shown in Figure 2 and the design obtained for the shallow system is shown in Table 2, where the pumping sump depth resulted to be 5 m in depth.

Table 2. Solution 1 Results (Shallow - Conventional Sewer System)

Diameters	150 mm for the shallow & 200 mm for the conventional
Covers	0.6 to 1.5 in Shallow & 1 m to 5 m for Gravity
Velocities	0.29 m/s to 0.91 m/s in all the system
Slopes	5 to 20 m/km

In order to increase the low velocities in the system to be minimum 0.6 m/s, which is the minimum scouring velocity that cleans the pipes, a flushing tank is installed. Two types of flushing tanks are used in the system. The first flushing tank will be for sewers that are less than 33 m in length with volume of 0.5 m^3 and the second tank will have a volume of 1 m^3 and it would be for shallow sewers with lengths up to 65 meters. After adding both flushing tanks to the system at the beginning of the sewer lines, the minimum velocity in the system became 0.82 m/s after having as low velocities as 0.29 m/s. Table 3 summarizes the flushing tank results.

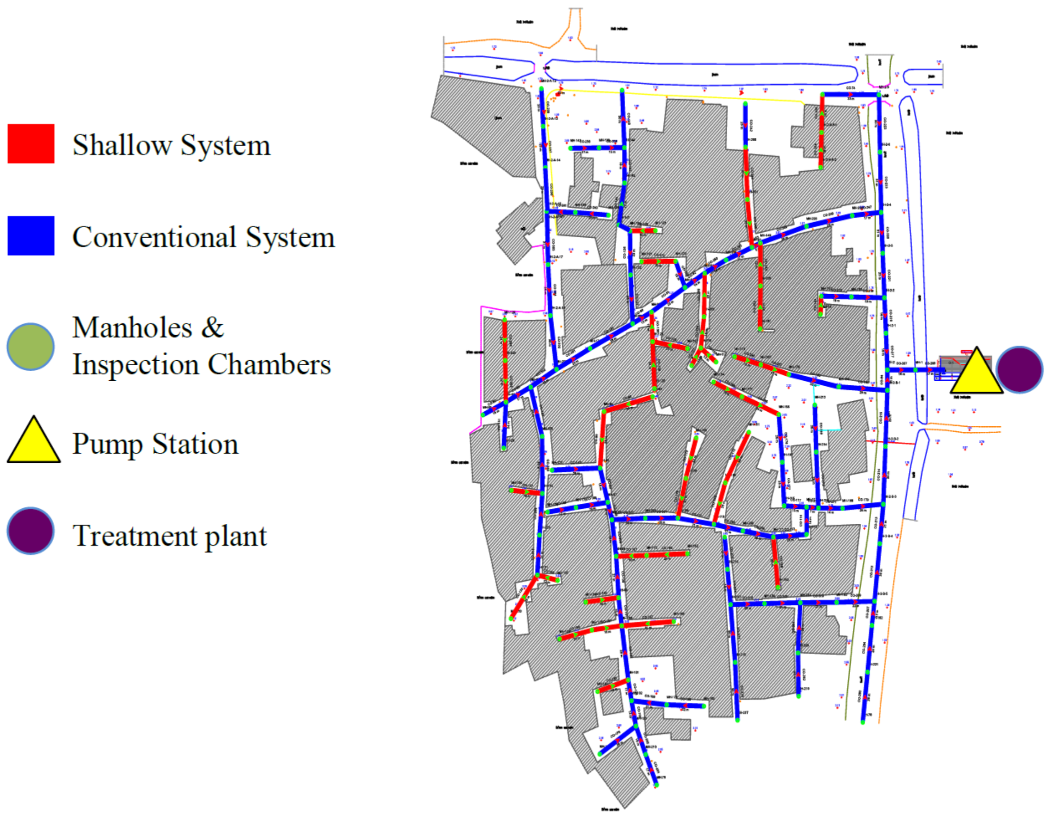

Figure 2. Layout of Solution 1 (Shallow/Conventional System)

Table 3. Flushing Tanks Design Results

	0.5 m^3 Tank	**1 m^3 Tank**
Height (m)	0.5	0.5
L x W (m^2)	1 x 1	1.4 x 1.4
T (sec)	29	58
Orifice Diameter (cm)	14	14
# Of Tanks in the hamlet	9	9
Min Velocity Achieved (m/s)	0.82	0.82

Solution 2 (Alternative Solution). An improved design for small hamlets will be through installing septic tank system along with shallow system that transports water

from the houses to the tanks (Figure 3). The septic tanks were designed on the average wastewater daily flow with retention time of 2 days and 8 hours at its average daily flow, and its holding capacity was checked for Peak flow of 4.62 $Q_{avg.}$ and for the flow of maximum daily, which equals to 1.8 $Q_{avg.}$ and both retention times are more than 24 hours which is the minimum. The design of the septic tank is illustrated in Table 4.

Table 4. Septic Tank Design

Tanks Volumes	16 m^3 to 30 m^3
Retention Time at $Q_{avg.}$	2 days and 8 hours
Retention Time at Q_{Peak} For 2 hours	2 days
Retention Time at $Q_{Maximum\ Daily}$	1 day and 7 hours
When to be cleaned	Every two years

The tanks are designed that the low water level is the capacity of the tank at $Q_{min.}$ and the high water level is the capacity at the peak flow. The pipe that is at the outlet of the tank has a diameter of 50 mm, as effluent will contain very low suspended solids.

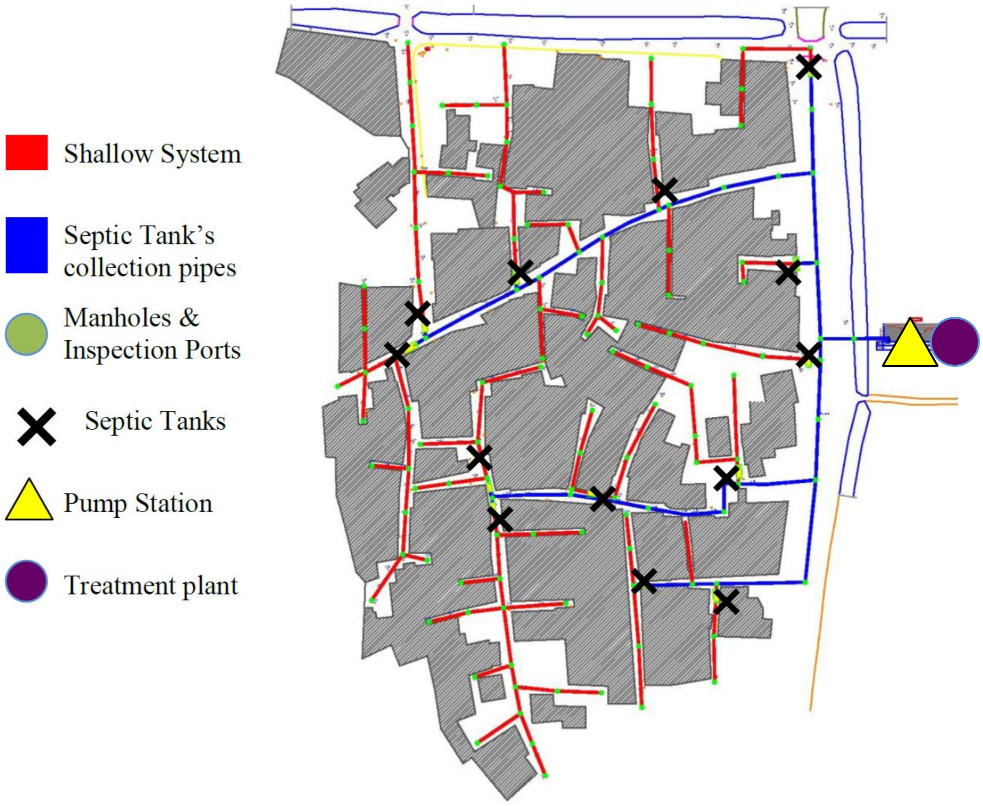

Figure 3. Layout of Solution 2 (Alternative System)

Table 4. Solution 2 Results (Shallow - Septic System)

Diameters	150 mm for the shallow & 50, 100 & 150 mm for Septic
Covers	0.5 to 1.5 m in the shallow and 1 to 3.5 m in the Septic
Velocities	0.3 m/s to 1.95 m/s in all the system
Slopes	3.25 to 20 m/km

The system has a more stable flow rate, since the tanks store the water weather it was the peak time or night time, however the difference would be in the retention time inside the tank which doesn't affect the pump cycle significantly; The average flow for the total system is 5.5 m^3/h and the depth of the sump of the pump is 3 meters depth.

COMPARISONS OF THE TWO SOLUTIONS FOR SEWAGE COLLECTION

Each solution has its own pros and cons; for Solution 1, its advantages are having minimal intervention by users, low health risks and moderate operation cost. It also avoids causing smell that attracts flies and it can be extended as the community changes and grows. On the other hand, some of the disadvantages of Solution 1 are that it is costly to maintain, it has frequent problems with blockages, and an adequate system for treatment and disposal is required. For Solution 2, it has lower pipe diameters; it doesn't have costly manholes just inspection ports and no minimum slope required. Moreover, the system doesn't have costly manholes, but only inspection chambers made of local material and finally, the tanks can be de-sludge every two years, which decreases the maintenance cost. Table 5 shows the component of each system, its quantity and its unit cost, which helps in giving an estimate of the total cost of each system.

Table 5. Cost Analysis for chosen components in the Solution 1 – shallow/conventional system and Solution 2 - alternative system

Solution 1 - Shallow and Conventional System

Name	Quantity	Unit Cost	Cost
150 mm Pipes	581 m	EGP 400.00	EGP 232,400.00
200 mm pipe	2279 m	EGP 500.00	EGP 1,139,500.00
Inspection Chamber	28	EGP 800.00	EGP 22,400.00
Manholes	75	EGP 3,000.00	EGP 225,000.00
Drop Manholes	9	EGP 5,600.00	EGP 50,400.00
Excavation	2008 m^3	EGP 19.00	EGP 38,152.00
	Total Cost		EGP 1,707,852.00

Solution 2 - Alternative System

Name	Quantity	Unit Cost	Cost
50 mm Pipes	946 m	EGP 200.00	EGP 189,200.00
100 mm pipe	405 m	EGP 300.00	EGP 121,500.00
150 mm pipe	1470 m	EGP 400.00	EGP 588,000.00
Septic Tanks	13	EGP 16,023.00	EGP 208,299.00
Inspection Chamber	122	EGP 800.00	EGP 97,600.00
Inspection Ports	17	EGP 300.00	EGP 5,100.00
Excavation	1718 m^3	EGP 19.00	EGP 32,642.00
	Total Cost		EGP 1,242,341.00

The above table shows that the pipes' diameters in Solution 2 is less, where about 48% of the used pipes are 50 mm and 100 mm pipes, while in Solution 1, about 80%

of the pipes are 200 mm in diameter, which affect the cost considerably. Solution 1 contains costly manholes and drop manholes that covers 75% of all the pipe transitions and at a price that starts from EGP 3,000, while Solution 2 consists of inspection chambers and ports that has 80% less unit price than the manholes. In addition, the excavation quantities were reduced in Solution 2 since the alternative system has less pipe diameters and fewer slopes constrains. Solution 2 proved to be effective as it is about 30% less cost than Solution 1. For pumping the sewage to the treatment unit, Solution 2 is more effective as it has more stable flow because it balances the flow between peak hours and nighttime; moreover, the sump depth in the alternative solution was less, which allows using a pump with less pumping head which reduces the cost, therefore, less energy is used to operate the pump in this solution. Also, the septic tank act as a primary treatment for the wastewater, therefore, the water quality that comes out of Solution 2 requires less costly treatment system for disposal or reuse in irrigation. Moreover, the sludge that comes out of the septic tanks can be used as a fertilizer to the land, which makes this system sustainable for the small communities similar to the prototype hamlet.

CONCLUSION

Solution 2 (the alternative system), which is a combination of shallow system, septic tanks and gravity sewers, was deemed better.

Most of the hamlet's roads are less than 3 meters wide, except for the main roads that are about 4 to 7 meters. Therefore, in the narrow roads a shallow system (gravity sewer) is recommended to provide a design with smaller pipes diameters and shallower depths, which decrease the cost of excavation and installation; moreover, inspection chambers that are small chambers made of concrete were used instead of manholes, reduces the cost as well. After collecting the wastewater from houses on narrow roads through shallow sewers, it will be connected with septic tanks in the main road. Then the effluent of the septic tanks will be collected in gravity pipes with small diameter and slope. This can be due to the absence of suspended solids in the wastewater, which were removed in the septic tank. This had significantly lower the overall costs of this system. In the meantime Solution 2 provides a partially treated sewage that can reduce the cost of the wastewater treatment plant. Therefore, this design accommodates the low flow of the small hamlets, and at the same time is more cost effective.

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