A Vision on Developing Countries Sustainable Future A Synergy Effect of Drainage Systems on Wastewater Treatment Plant

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Abstract
Sustainable development is a fluid concept that can be elucidated in different ways, but, at its core agenda is aiming at reconciling the economic, social, environment and politics issues. Facing rapid population growth and over-exploitation of natural resources, water and wastewater management deserves greater emphasis. Particularly, in the developing countries, the concept of sustainable development needs to be incorporated into policies and decision making process.The central idea behind the study in hand is the integration of sustainable development concept into water and wastewater management. In essence, the main aim of this research is to investigate the effect of the combined sewer system on the design capacity of the Wastewater Treatment Plant. This will be achieved by presenting a case study of a Wastewater Treatment Plant located in the Gaza Strip. Data were gathered over a three month period from Beit Lahia Wastewater Treatment Plant. Results indicated an increase in Wastewater Treatment Plant's construction, operational and maintenance cost when considering a combined drainage system, yet, the cost premium is typically not as high as is perceived. Furthermore, addressing Gaza Strip's growing water scarcity and groundwater quality deterioration, planners need to craft strategies that ascertain not only cost effectiveness but also targeting the remaining three sustainability dimensions.
Keywords: Drainage systems, Sustainability, Wastewater treatment plant

1. Introduction

The concept of 'Sustainable Development' has received growing recognition since the eighteenth century, thus, is now standing at the top of many governments and institution's agendas across the world. Depending upon context, demand and interest, various interpretations have emerged for such concept (Balkema, et *al*., 2002). Yet, it has been unified that sustainable development is an avenue that calls for a dynamic balance between the four pillars of economic, social, environment and politics.

Although the discourse surrounding sustainability has come to forefront in the developed countries, developing world are still struggling to embrace such concept. Alongside this fact and in the light of the accelerating population growth and severe environmental degradation, it is vital for the developing countries to envision and plan a sustainable future. Working across various disciplines, a high profile attention should be drawn to water and wastewater management.

Since the development of the combined system in 1855, debates were addressed various techniques to manage both sewage and storm-water runoff. Collectively, decision on which system to adopt has been viewed from different angles and perspectives (Patouillard and Forest, 2011), (De Feo, et. *al*., 2014)). Precisely, water scarcity and deteriorating water quality have major impacts on such decision.

Generally, drainage systems can be classified into combined and separate one. In the combined sewer network, the same pipeline conveys flows of household and industrial wastewater together with surface water runoff to a Wastewater Treatment Plant, where it is treated and then discharged. Meanwhile, the separated system consists of two independent pipes for each type of flow, with storm-water being discharged to the nearest water body and household and industrial waste water being transported to the treatment plant. Since each system has a set of advantages and disadvantages, insight is needed into the sustainability of different systems under various circumstances. With the four dimensions to sustainable development advocated by economic, social, environment and politics, this research will trigger the integration of sustainability into economic management of water and wastewater systems.

To that end, the main aim of this study is to investigate the effect of the combined sewer system on the design capacity of the Wastewater Treatment Plant. This will be achieved by presenting a case study of a Wastewater Treatment Plant located in the Gaza Strip. Under the assumption that part of the city is serviced by a combined system, each unit of the WWTP will be designed. Then, the cost of constructing such plant will be calculated accordingly.

2. Literature Review

Drainage system development has a long history, as since 1800, several strategies have been implemented for managing both storm-water and wastewater. In the past, storm-water management was mainly concerned with collecting and removing excess runoff as quickly and cheaply as possible in an effort to reduce flood risks. As a reflection to the evolving sustainable development goals and growing concerns for the surrounding environment, the attitude towards storm-water management has been broadened to address storm-water as a valuable source. In effect, planning was geared toward protecting storm-water quality by capturing and storing for re-use. Many studies are available in literature investigating various techniques and costs associated with storm-water management ((Dierkes, et *al*. 2002), (Bartens, et *al.,* 2008), (Visitacion et *al*., 2009), (Marsalek and Schreier, 2009), (Trowsdale and Simcock, 2011), (Kaplowitz and Lupi, 2012), (Sitzenfrei, et *al.,* 2013), (Cettner, et *al.,* 2013), (Ashley, et *al.,* 2014), (Hoang and Fenner, 2015)).

Meanwhile, modern sewage systems were first built in the mid-nineteenth century. The population growth, the industrial revolution and the sweeping of deadly cholera and typhoid epidemics throughout the world have paved the road to the development of wastewater drainage systems (Angelakis and Snyder, 2015). With time, as cities around the world grow, the construction of pipe systems aiming at diverting wastewater and storm-water wastes away from building was put forward.

Historically, until the middle of the 20^{th} century, most sewer systems were constructed as combined systems in the U.K. Then, there has been a shift away from combined system to separate one (Burian, et *al*. 2000). In line, with the belief that combined systems were cheaper to build than a separate system, most of the United States were serviced by combined system (Tibbetts, 2005). Furthermore, Toronto was served predominantly by a combined system until the 1970, when it was decided that the existing system is totally inadequate. Simultaneously, connections between water and management of wastewater began to receive focused attention as both groundwater levels and quality were start to decline across major parts of the world. For this reason, recent trends have been directed towards the development of separate sewerage systems.

For decades, the advantages and disadvantages of separate system with respect to combined one have been much debated in literature. Combined system can be constructed at lower cost and the strength of sewage is reduced by dilution with storm-water. On the contrary, combined system can impose public health danger during heavy storm and the storm-water is unnecessary polluted.

Ultimately, wastewater and water management must be addressed in an integrated manner. Therefore, this study will take a step forward by bringing together the drainage system and WWTP into the decision framework.

3. Wastewater Treatment Plant

In general, wastewater undergoes five major processes at the Wastewater Treatment Plant (WWTP) including: Preliminary treatment, Primary treatment, Secondary treatment, Disinfection and finally sludge treatment (Naidoo and Olaniran, 2014).

Firstly, the preliminary treatment is designed to remove grit, gravel and screening of large solids from wastewater. As the influent passes through screens, consisting of upright bars spaced one to three inches apart, large and floating pieces of trash such as rags, sticks, cans and plastic cups is removed. Removal of this material is essential to protect the subsequent treatment units. This is followed by the primary treatment with the aim to remove suspended solids by sedimentation. In the Primary treatment, the BOD_5 and the total suspended solids of the incoming wastewater can be reduced by 20-30% and 50-60% respectively.

Typically, after the primary treatment, the wastewater moves on to secondary treatment where the biological treatment takes place. The main objective of the biological treatment is to reduce the concentration of organic and inorganic contents resulting in a high quality effluent. In particular, Activated Sludge (AS) is the most popular biological waste water treatment systems consisting of three basic interrelated components; Aeration Tank, Secondary Clarifier and a sludge recycling system. Firstly, in the Aeration tank wastewater is aerated with oxygen allowing microorganisms to breakdown organic matter and other nutrients for their survival and growth and converts it into carbon dioxide, new cell mass and biomass. Likewise the Nitrification process, the ammonia (NH_4) is also oxidized to nitrate (NO_3) for which pumped oxygen is required. Then, under anoxic conditions, nitrate (NO_3) is further converted into nitrogen (N_2) and oxygen (O_2) through Denitrification. Concurrently, phosphate elimination is achieved through bio-P process by adding iron or aluminium salts as flocculants. Following the aeration stage, the activated sludge is separated from liquid by gravity sedimentation and the clarified liquid is discharged from the system.

Along with other treatment processes, disinfection is considered to be the final stage before discharging of the effluent. It is a necessary step, carried out with the aim to destruct any remaining bacteria to prevent disease spread. A number of chemicals and processes can be used to disinfect wastewater such as chlorine. In which, wastewater spends a minimum of 15-20 minutes in chlorine-contact tanks mixing with sodium hypochlorite.

Finally, with sludge being generated in the primary and secondary settling tanks, managing such sludge is essential. A series of consecutive technologies is applied aiming at reducing the sludge volume as well as stabilizing the organic materials. In essence, the sludge volume reduction can be achieved by thickening, dewatering and drying; meanwhile, digestion, incineration, chlorine oxidation or lime oxidation can be applied to stabilize the organic matter. Typically, thickening is the first treatment step for reducing the sludge volume by the removal of excess water. As the sludge is allowed to settle and compact in a gravity thickener tank. Then, the thickened sludge is withdrawn from the bottom of the tank and pumped to a digester, where it can be treated anaerobically. At this stage, the organic solids are decomposed into biogas through Hydrolysis, Acidogenesis and Methanogenesis. Biogas primarily consists of a mixture of about 60-70% methane (CH_4), carbon dioxide (CO_2) and traces of other gases (Nallamothu et *al.,* 2013). After digestion, the sludge is passed to a dewatering unit, as the water content is reduced by 90%. In which, water is being separated from solids through fast spinning of a centrifuges.

4. Case Study

Gaza is a narrow strip of land along the Mediterranean coast consisting of five governorates including Gaza, Middle, Northern, Khanyounis and Rafah. With population of approximately 1.7 million and a total area of 365 km^2, it is considered to be one of the most populated regions worldwide. Currently, Gaza Strip (GS) is confronted with environmental and human health crisis related to steady increase in wastewater volume production. The rapid rate of population growth in the Gaza Strip and dependence upon ground water as a single water source present a serious challenge.

There are three wastewater treatment facilities in Gaza strip, Beit Lahia (BLWWTP), Gaza City (GWWTP) and Rafah (RWWTP). Beit Lahia Wastewater Treatment Plant is located at the eastern north of Beit Lahia city at the north of the Gaza Strip. The plant serves the town and camp of Jabbalia, part of Beit Lahia and the nearby town of Beit Hanoun. It was constructed in stages, commencing in 1976 and was further expanded in 1991 to increase its capacity to 5,000m^3 per day. It was designed as two anaerobic lagoons, two actively aerated lagoons, two facultative lagoons and one setting tank. The area's total population served by the plant is around 270,000; were 75% of population is connected to sewage system in this area.

In parallel, the Gaza Strip is facing a water crisis, reflected in a shortage of water supply for both domestic and agricultural uses. This is caused by both the over-exploitation of groundwater by three times safe yield rate to meet the demand and the degradation of ground water quality. With the vast majority of the Coastal Aquifer now having nitrates more than 300 mg/litre and chloride ranging from 600 to 1,000 mg/litre (PWA, 2014), they exceed the World Health Organization (WHO) standards with nitrates to be less than 50 mg/litre and chloride to be less than 250 mg/ litre.

4.1. Methodology

In this study, data gathered over a three month period, from January – March 2012, from Beit Lahia Wastewater Treatment Plant. Vital data related to storm-water and wastewater was measured; meanwhile, other design parameters were set as design criteria as shown below.

Design Criteria

Wastewater (WW) Flow = 9100 m^3/day
Storm-water (SW) Flow = 27100 m^3/day
Combined Flow (CF) = 36200 m^3/day
F/M = 0.05 kg BOD_5/kg TS.d
Part PO_4 in bio-sludge = 0.02
Primary SS Removal = 60%
Surface Overflow Rate= 40 $m^3/d/m^2$
COD = 2.3 BOD_5
TS = 4 mg/L

Measurements

WW Influent BOD_5 = 400 mg/L
SW Influent BOD_5 = 100 mg/L
CF Influent BOD_5 = 175 mg/L
Effluent BOD_5 = 40 mg/L
WW Influent PO_4 = 10 mg/L
Effluent PO_4 = 1 mg/L
Combined Influent PO_4 = 8 mg/L
$q_{s\,v}$ = 500 L/(m^2/h)
ISV = 100 mL/g

Meanwhile, the price details used for calculations are as follows:

Construction Price = 22.5 $/$m^2$
Sludge Disposal Price = 0.1 $/kg
Energy Price = 0.15 $/kwh
$FeCl_3$ Price = 0.07 $/L

4.2 Calculations

Each unit of the WWTP was designed with wastewater flow only and then with combined flow. Then, the cost of constructing and operating such plant considering both alternatives were calculated accordingly.

Primary Settling Tank Design

Primary Settling tank are normally designed on the basis of surface overflow rate at the average flow rate. When the area of the tank is established, the detention time in the tank is then governed by the water depth as follows:

With Wastewater Flow:		*With Combined Flow:*	
A =	Q / SOR	A =	Q / SOR
A =	227.50 m^2	A =	905.00 m^2
h =	3.50 m	h =	3.50 m
Detention Time =	V0/Q	Detention Time =	V0/Q
Detention Time =	2.1 h	Detention Time =	2.1 h

Aeration Tank Design:

The Food-to-Microorganism ratio (F/M) is a significant parameter in the Aeration Tank design, as it is responsible for the decomposition of organic matter. For this particular study, the F/M ratio was assumed to be 0.05 kg BOD_5/kg TS.d, as the recommended range for the F:M ratio in an aeration tank is 0.05 to 0.10. Based on this assumption, the volume of the aeration tank for the wastewater flow was determined and the F/M ratio was then calculated for the combined flow.

Aeration Tank Design			*Aeration Tank Design with combined flow*	
F/M =	(Q.C) /(V.TS)	Based on	F/M =	(Q.C) /(V.TS)
V =	12740 m^3	F/M = 0.05	F/M =	0.09 OK

Secondary Settling Tank Design

Following the aeration stage, the secondary settling tank is provided to facilitate the sedimentation of the cells produced during the activated sludge treatment. The area of the secondary settling tank for both waste water flow and with combined flow is shown below:

With Wastewater Flow		*With Combined Flow*	
A =	Q / q_a	A =	Q / q_a
q_a =	q_{sv}/(Isv*TS)	A =	q_{sv}/(Isv*TS)
q_a =	1250.00 L/m^2h	q_a =	1250.00 L/m^2h
A =	303.33 m^2	A =	1206.67 m^2
h = 3.5 m		h = 3.5 m	

Cost Calculations:

In order to determine the most economical alternative, separate or combined sewage system with respect to the WWTP, a cost estimate including construction, operation and maintenance costs has to be conducted for the WWTP.

- **Construction Extra Cost:**

Considering the combined flow, the extra construction cost that would be incurred when designing various units of the WWTP is:

Primary Settling tank extra cost =	15243.75	$
Secondary Settling tank extra cost =	20325.00	$
Aeration tank extra cost =	0.00	$
Equalization tank cost =	27000.00	$
Total of construction extra cost =	62568.75	$
Total of construction extra cost =	0.40	$/$m^3$

- **Operational Cost:**

With the fact that WWTP operation costs can amount up to 50 % of the total annual costs, it is of great importance to evaluate the operational cost for the two options. Commonly, the composition of the operational cost includes: staff, energy, chemical materials, disposal and maintenance.

Firstly, for both options under consideration, it will be assumed that the same number of staff will be needed and will not be further analyzed.

Secondly, considering that wastewater treatment is an energy intensive process, energy costs associated with operating WWTP represents a substantial portion of the plant's total budget (Long and Cudney, 2012).

Energy Cost			*Combined Energy Cost*		
Planed wastewater Load =	2548	kg BOD_5	Planed wastewater Load=	4445	kg BOD_5
Planed wastewater COD =	5860.4	kg COD	Planed wastewater COD=	10223.5	kg COD
Planed wastewater O_2 =	4102.28	kgO_2	Planed wastewater O_2 =	7156.45	kgO_2
Planed wastewater COD =	2461.37	kwh	Planed wastewater COD=	4293.87	kwh
Energy Cost =	369.21	$	Combined Energy Cost =	644.08	$
			Extra Energy Cost =	0.002	$/$m^3$

Regarding the costs for chemicals; the main focus will be on the cost of $FeCl_3$ for phosphate elimination as follows:

Phosphate Balance:

Planned Phosphate Balance

Planed Influent PO_4 = 91 kg
Planed Effluent PO_4 = 9.1 kg
Planed In load PO_4 = 50.96 kg
Added to balance PO_4 = 30.94 kg

Phosphate Balance for combined flow

Combined water Influent PO_4 = 289.6 kg
Combined water Effluent PO_4 = 36.2 kg
Combined In load PO_4 = 88.9 kg
Added to balance PO_4 = 164.5 kg

Therefore,
Extra amount of PO_4 = 133.6 kg
Amount of Fe = 360.6 kg
Extra amount of $FeCl_3$ = 70680 L
Extra Cost of $FeCl_3$ = 4948 $
Extra Cost of $FeCl_3$ = 0.03248 $/m^3$

The sludge disposal cost is calculated as:
Planned Wastewater load = 3640 $kgBOD_5$
Combined Wastewater load = 6350 $kgBOD_5$
Extra Sludge Disposal = 3523 kgTS
Extra Cost Sludge Disposal = 352.3 $
Extra Cost Sludge Disposal = 0.0017 $/m^3$

Finally, maintenance costs typically include repairs for mechanical, electrical, electronic and civil parts as well as minor or major replacements like small or large parts for pumps, blowers or motors.

Table (1): Summary of Cost Components

Description	Planned WWTP	Combined WWTP	Current WWTP	Extra req.	Extra Cost
Primary Settling Tank	228.00 m^2	905.00 m^2	Open Area	677.00m^2	**$ 15244**
Secondary Settling Tank	300.00 m^2	1200.00 m^2	Open Area	900.00m^2	**$ 20325**
Aeration Tank	12740.00 m^3	12740.00 m^3	12740.00 m^3	-	**$ 0**
Equalization Tank	-	1200.00m^2	Open Area	1200.00m^2	**$ 27000**
Energy	2461 kwh	4294 kwh	-	1833 kwh	**$ 274.5**
Phosphate	30.94 kg	164.5 kg	-	133.6 kg	**$ 4948**
Sludge Disposal	4732 kg	8255 kg	4732 kg	3523 kg	**$ 352.3**
Maintenance	0.006 $/m^3$	0.006 $/m^3$	0.006 $/m^3$	27100m^3	**$ 162.6**
Total Construction Extra Cost					**$ 62570**
Total Maintenance & Treatment Procedures Extra Cost					**$ 5737.4**
Total Construction Extra Cost / m³					**$ 0.40 $/m³**
Total Maintenance & Treatment Procedures Extra Cost / m³					**0.04 $/m³**

4.3 Discussion

Results demonstrate that while there can be an additional WWTP 'construction' and 'operational & maintenance' costs associated with combined system as compared to a separate one, the cost premium is typically not as high as is perceived, see (Table 1). Concurrently, based on literature, the construction cost of the combined system is 40% less expensive than the separate system ((Iwugo, et *al*., 2002) and (De Toffol et *al*., 2007)). Up to this point, although conclusion can be drawn to install a combined system rather than separate one, yet, this decision should be deliberately explored.

With an even hand on the case under consideration, a deeper understanding is needed upon making such decision. In the Gaza Strip, groundwater is the primary source of water for various human activities. In the past few years, the area witnessed excessive pumping to meet the increasing water demand; resulting in a reduction in the groundwater level. In turn, the balance between the fresh and saltwater boundary in the aquifer has been affected inducing sea salt intrusion. Recent studies revealed deterioration in the water quality in most Gaza Strip wells; as chloride and nitrate concentrations are exceeding the maximum limits (Moghier and Aiash, 2013). In addition, salt intrusion has caused soil salinity which adversely affects crop growth and yields (Diby and Harshad, 2014). To alleviate the effects of both salt intrusion and soil contamination, several management strategies and a variety of remediation technologies have been discussed in literature. For instance, physical subsurface barriers, extraction barriers, freshwater injection barriers and modified pumping patterns are among the strategies addressed to control salt intrusion (Sriapai et *al.*, 2012). However, these methods are considered to be expensive and not easily implemented. Meanwhile, for the soil salinity, no single documented technique is appropriate for all contaminant types; which makes the remediation process a tough one.

It is evident that each region across the world has different drivers and priorities. However, a great potential is directed towards building a sustainable future. In the light of the ongoing problem of saltwater intrusion in the Gaza Strip, which limits the use of fresh groundwater in many areas, it is important to adopt sustainable management actions that meet the demand given scarce water resources. Action in this regard is needed and recommendation is given for separate drainage system as it involves capturing water and directing it to other uses.

While in some cases, decision makers may only compare the advantages and disadvantages of combined and separate drainage systems during the planning stage, this study places a greater emphasis on how this decision can be integrated within an overall system of water management

5. Conclusion

Sustainable planning is considered an effective approach that will provide a valuable insight to the case under consideration. Thus, building up a decision based not only on cost savings, but also securing the environment.

This study placed sustainable development of water and wastewater sectors within the broader framework of sustainable development. In essence, it explored the effect of combined sewer system on the design capacity of each unit of a wastewater treatment plant located in the Gaza Strip. Translating this impact in terms of cost should guide decision makers to approve combined drainage system; as relatively minuscule cost increase encountered in the analysis.

Mapping the situation in the area provided the picture of water scarcity and environmental degradation. As threats continue to escalate, urgent move is needed to secure an alternative water source to meet the growing water demand. This will sway the decision wing towards separate drainage system rather than combined one.

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