Prototype Design of a Wastewater Collection System for Selected Households

Eunice Mac Pepple and Celestine Egwuonwu

Department of Agricultural and Bioresources Engineering, Federal University of Technology, Owerri, Imo State, Nigeria

***Abstract*- A prototype design of a gravity sewage collection system was achieved for selected households in Opobo town, Rivers State, Nigeria. This was done as a bid to mitigate the present practice of direct disposal of domestic wastewater into the surrounding waters of the study area, due to very limited modern sanitary facilities. SewerCAD was used to design the gravity sewer system with constraints for velocity, slope and depth of cover. The total design flow was 56,858 litres/day,and the total pipe length 208.3 m. The designed manholes are 8 in number with a lone outfall. The outcome of the design established that a gravity sewer network can be constructed for low-income densely populated rural or peri-urban communities. It is recommended that an efficient wastewater collection system for sewage and sullage be designed and implemented not just for selected households in the study area, but for the entire town.**

***Keywords:* Wastewater; Collection system; Raw sewage; Riverine communities; Opobo Town; gravity sewer.**

I. INTRODUCTION

Forty per cent of the world's population live within 60 km of the sea, thus the potential for adverse human impacts on the marine environment is very high. This occurs because among other impacts,wastewater from coastal cities and towns are often discharged, most times without any form of treatment, into the sea or an estuary via an outfall pipe [10].

According to [10], domestic wastewater is the water that has been used by a community and which contains all the materials added to the water during its use. It is thus composed of human body wastes(faeces, blood and urine) together with the water used for flushing toilets, and sullage, which is the wastewater resulting from personal washing, laundry, food preparation and the cleaning of kitchen utensils.

Faecal matter affects the economic and ecological health of any water body [12].Feaces and, to a lesser extent, urine contains many millions of intestinal bacteria and smaller numbers of other organisms. Other organic and inorganic substances present in domestic wastewater are carbohydrates, fats, proteins, amino acids, volatile acids, oil and grease, soaps, detergents, food substances, sodium, calcium, potassium, magnesium, chlorine, sulphur, phosphate, bicarbonate, ammonium salts and heavy metals[11] and [1].

In every community or area inhabited by humans, generated solid and liquid waste have to be hygienically collected and safely disposed of, in the absence of which diseases and epidemics would be birthed. References [8] and [1] reported that wastewater disposed into rivers, streams and oceans have resulted in the outbreak of excreta-related diseases like cholera, dysentery, diarrhea, etc, and even death. Most susceptible to these diseases are children under 3 years [8]. Deaths resulting from diarrhea are estimated to be between 1.6 and 2.5 million persons every year worldwide; and most of the affected are young children below the ages of five [9].Wastewater have also been reported as an important determinant in diseases like schistosomiasis, trachoma, ascariasis, trichuriasis and hookworm disease, malaria, yellow fever, filariasis, dengue, hepatitis A and hepatitis B, typhoid, arsenicosis, fluorosis and legionellosis[2].

This research designed a prototype wastewater collection system for selected households in Opobo town, as a bid to control and eventually mitigate the current unhealthy sanitary practice in the study area and its environs.

A. Wastewater Management in Opobo Town - Present Practice

Managing domestic wastewater in riverine or coastal communities is very important especially for the protection of public health, the environment and aquatic life. Reference [7] reported that right from 1870 till date raw sewage is being discharged directly into the water bodies surrounding Opobo town. In recent times some households have developed some form of acceptable sanitary systems, but most of these sanitary systems still channel raw wastewater through pipes and gutters directly into the surface waters.

1. Wastewater Collection: To address the poor sanitation practice in the study area, the domestic wastewater generated by the residents have to be properly collected, treated and disposed of safely. The transportation needs to be done quickly to prevent the development of septic conditionsand settling of solids. Artificial conduits, called sewers, are normally used to convey wastewater and sometimes surface water, from one point to another, usually located underground. They could be pipes, open channels or tunnels.

Reference [2] explored the potentials of using sanitary sewerage system for the collection, transportation, treatment and disposal of wastewater from Malali housing estate, Kaduna, Nigeria. Their research showed that sanitary sewerage (Simplified Sewerage) with a Waste Stabilization Pond (WSP) could be more cost effective than the use of septic tanks systems, especially in swampy areas in urban and peri-urban settings. Simplified sewerage has also been successfully employed in countries like Brazil and Latin

America; also in Bolivia, Colombia, Nicuagua, Paraguay and Peru.

In Africa it has been implemented in South Africa, and in Asia,it has been verysuccessfully used since the mid 1980s by the National Housing Development Authority in Sri Lanka, with over 20 schemes now in operation. It has also been used in Karachi, Pakistan and Malang, Indonesia [8].

*2. Choice of Sewer:*There are basically three types of sewers with respect to a hydraulic system network. These are gravity sewers, pressure sewers and vacuum sewers. On choice of sewer based on applicability, the gravity sewer system when compared with the pressure and vacuum systems is the most applicable to the study area based on the morphology, user demand, sustainability andcost factors. Another very important aspect in this consideration is the area of power supply. The pressure and vacuum sewer systems require constant electricity power supply to power the pumps and force mains on a daily basis, which is not possible for developing countries where power is unreliable.

II. MATERIALS AND METHODS

A. Study Area

Opobo Town is the headquarters of Opobo/Nkoro Local Government Area of Rivers State, Nigeria. It is located at the southern part of Nigeria just beneath Ikot Abasi, Akwa Ibom State. It lies between latitude 4° 30' 41.11" N and longitude 7° 32' 24.32" E. The town is inclusive in the total area of 130 km^2 of the local government area, and has an average elevation of 4m above sea level.Opobo town is bounded on the south by the Atlantic Ocean, on the north by Khana, east by Ikot Abasi and west by Andoni.A map of Opobo Town is shown in figure 1. Opobo Town as part of the Opobo Kingdom was founded in 1870 as a city state and played an important role in the palm oil trade because of her geographical location. The Opobo people are mainly farmers and fishermen who historically exchanged their smoke-dried fish and salt with the people of the hinterland for bulk foodstuffs, tools, clothing and domestic gear [6]. Opobo as an ancient Kingdom is made up of several Islands and communities, namely Opobo Town, Queenstown, Kalaibiama, Minima, Kala Sunju, Iloma, Ekereborokiri, Downbelow, and Epellema; while a part of the old city state, comprising of Ikot Abasi and Kampa, is now in Akwa Ibom State[5].

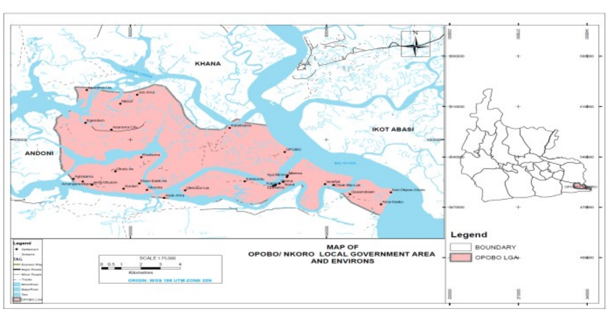


Fig. 1 Map of Opobo

Source: MacPepple *et al. (*2017)

*1. Study Area Survey:*The topography of the town in general is flat with an elevation of 4m above sea level. The houses in the town are very closely built with mostly earth-packed pathways for access. Only one major paved road exists in the town, and this runs from the main waterfront to the outskirts of the town towards Kalaibiama town. The town is very densely populated at two different times of the year (between March and April, and between December and January) each year. It is estimated that at these periods the population triples in number. The population of Opobo/Nkoro local government area according to the 2010 national population census is 170, 527 persons. Based on the 2006 census, a 3% increment between these years was used to estimate that the population for 2015 is 197,687 persons [4]. Since there is no existing record of the population of the individual settlements in the local government area, an estimate was done by MWRRD for Opobo town using the present voting population in 2015. Based on the six political wards in the town, it was established that the population of Opobo town in 2015 is 107, 829 persons. However from the questionnaire assessment, the population of the study area for the households' in-situ is 540 persons.

2. Materials:

a) Questionnaires

b) Interviews

c) Maps

d) Total station

e) GIS

f) SewerCAD software

B. Methodology

The methodology employed for the study included survey and mapping of the study area, interview and questionnaire survey and SewerCAD collection system design.

1. Design of the Gravity Sewer System: Gravity sewer system design is based on long-term serviceability, design flow, minimum pipe diameter, slope, depth of bury, loads on buried conduits, appurtenances and site conditions [3]. The designed flows were developed using the tributary area, sanitary or domestic wastes, average daily flow, average hourly flowrate and extreme peak flowrate [13]. To design the sewer network to collect and convey the wastewater, an overall system layout thatincluded a plan of the area to be sewered was established, showing roads, streets, buildings and other utilities; topography, soil type and floor elevations. This followed the general guideline for sewer system layout and design by [14] involving a topographic map of the area to be served, identifying the location of the drainage outlet and a sketching of a pipe system to serve all contributors making allowances for maintenance, amongst other considerations.

2. Mapping of study area: Since there was no current infrastructural map of Opobo town, the overall layout of the study area was established by utilizing Google earth to retrieve geographical and infrastructural spatial data of the study area, including its morphological characteristics; and Esri's ArcGIS (ArcMap client) was used to establish descriptive details with cartographic accuracy in 2D. Onsite survey work was also carried out involving reconnaissance, establishment of points, traversing, detailing and leveling of the study area.

3. Questionnaire Design and Interviews: To determine the sanitary and domestic waste generated by the residents in the study area, questionnaires were distributed to the residents living within the study area. Thedesign of the questionnaire comprised of questions about water use habits such as daily water usage and consumption, wastewater generation and dietary habits, amongst other questions.

4. System Modeling: After establishing a preliminary layout of the area involving topographic analysis, system demand, morphology, pipe lengths and ground elevation, SewerCAD software was then used to design the gravity sanitary system. The following activities were done with design constraints for velocity, cover, and slope:

- Manhole locations were determined on the basis of changes in direction and junction of pipes.
- The street elevations at manhole junctions were determined from the survey result for the area.
- The distances between manholes were determined.
- Sanitary flows were loaded into the system based on the contributing areas.
- The system then determined the street slopes, pipe sizes, full sanitary flows, velocities, depth of cover, etc.

III. RESULTS AND DISCUSSION

A. Results

Table 1 shows the result of the questionnaire and personal interview survey, while table 2 shows the conduit and manhole data. Figure 2 shows the outcome of the on-groundsurvey investigation carried out in the study area. Figure 3 shows the aerial view of the study area using Google map and ArcGIS, figure 4 is the gravity sewer design showing the infrastructural details of the study area.

*1. Survey and Mapping of the Study Area:*The survey carried out of the study area (figure 2) produced point elevations and invert values as well as natural drainage points. The infrastructural and geographical details were also established. The lowest point at B01 was 8.87 meters and the highestpoint was at E4 (10.47m). The study area lies in a total area of 5631.242m^2 with a map scale of 1:1000. The geographical information system (GIS) in concert with Google earth produced the aerial view of the study area as shown in figure 3.

2. Questionnaire and Personal Interviews Survey:A total of 30 residents in the different households (mostly the house owners) were successfully reached. Also, 18 residents were reached for personalinterviews. It was established from the interviews that the residents in the study area liked the idea of a sanitary upgrade for their community.

B. Discussion

*1. System and User Demand:*The results of the interview and questionnaire survey established that the system was to be designed for a total of 540 persons with average water consumption and usage of approximately1, 419 litres/day/household and a total baseflow of 42,578 litres of wastewater per day. Table 1 shows the details of the water consumption and use in the selected households (study area) in Opobo Town, while Table 2 shows the systems total flow, sanitary loads and design flow capacity amongst other parameters.

*2. Gravity Sewer System design:*Figure 4 shows the outcome of the design of the gravity sewer system using SewerCAD. This was feasible after needed data such as elevations, sanitary loads, infiltration rate, etc, were imputed into the software and constraints set. The most downward segment of the pipe was at an invert of 4.25m (downstream), while the minimum bury was 1.54m, exceeding the minimum standard of0.7m. The user-defined pipe lengths are between 10.8m to 50.1 m. The flow velocities satisfied the minimum value of 0.6m/s. The slope did not satisfy the minimum standard of 0.005m/m. The maximum flow however did not exceed 10% of the design capacity. The total length of pipe designed was 208.3m, with a total number of 8 manholes and 1 outfall.

IV. CONCLUSION

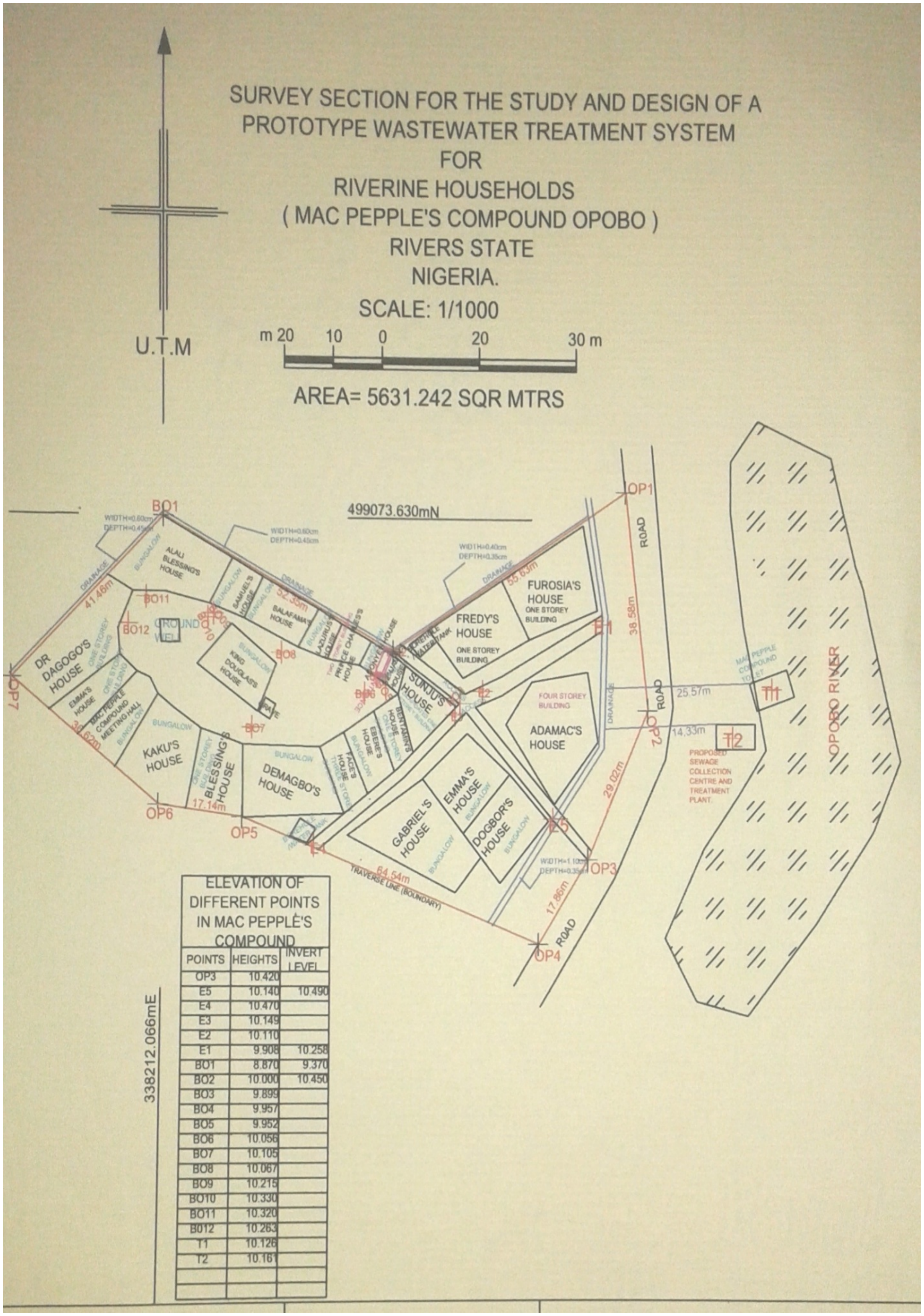
The prototype design of a sewage collection system using SewerCAD showed that a gravity sewer network can be achieved for low-income densely populated rural or peri-urban communities. This study recommends the development of an effective and efficient sewage and wastewater collection system for the entire town and not just for some selected households in Opobo. This is because the effect of direct disposalof raw sewage into the surrounding waters cannot be addressed efficiently by providing proper collection and treatment facilities for only a small percentage of the whole town. The prototype design will help the local and state government plan for an upgrade of the present sanitation practice in the town as well as other surrounding coastal communities. Policy makers and stake holders can also use the data to make policies concerning proper sanitation practices in riverine communities.

TABLE 1 QUESTIONNAIRE SURVEY RESULTS

	No. of houses	Total (l/d)	Household average (l/d)	Per capita average (l/d)
Water used for food production (50 x 30)		1,500	50	2.8
Water used for washing clothes and utensils		4800	200	11.2
Water used for bathing		8210	342	19.1
Water used for flushing toilets (if all households own a flush toilet)		23640	788	44.78
Water used for flushing Public Toilet (Estimated: 6 households)		4728		
Total water used (Total base flow)		42878	1429	79
No. of houses surveyed	30			
No. of occupants(Base population)	540	(total)		
	18	(average)		

TABLE 2 CONDUIT AND MANHOLE DATA

Pipe No.	Manhole (From)	Elevation (m)	Manhole (To)	Invert Elevation (m)	Length (Scaled) (m)	Slope (m/m)	Pipe Size (mm)	Manning's Number	Total Flow (L/day)	Velocity (m/s)	Infiltration (Local) (L/day)	Cover (Average) (m)	Elevation Ground (Stop) (m)	Sanitary Load (L/day)	Design Flow capacity (L/day)
CO-1	MH-1	9.31	MH-2	7.77	19.9	0.065	100	0.01	8,988	0.6	472	1.54	10.26	4,258	437,244
CO-2	MH-2	7.77	MH-3	7.39	13	0.036	100	0.01	17,720	0.6	216	2.61	10.32	8,516	1,552,068
CO-3	MH-3	7.39	MH-4	6.68	19.8	0.029	100	0.01	22,465	0.6	488	3.06	10.07	12,774	1,514,843
CO-4	MH-4	6.68	MH-5	6.26	20	0.024	100	0.01	28,495	0.6	352	3.5	10.06	18,451	1,488,269
CO-5	MH-5	6.26	MH-6	5.94	16.8	0.019	100	0.01	35,921	0.6	330	3.83	10	25,547	1,464,253
CO-7	MH-7	5.05	Tmt	4.75	24.6	0.015	100	0.01	49,299	0.6	3,860	5.36	10.3	34,063	1,221,193
CO-6	MH-6	5.94	MH-7	5.05	58.9	0.018	100	0.01	39,762	0.6	1,002	4.62	10.42	28,386	1,405,424
CO-8	Tmt	4.75	Outfall	4.25	35.3	0.013	100	0.01	56,858	0.61	7,480	5.61	10.13	34,142	1,038,260



ELEVATION OF DIFFERENT POINTS IN MAC PEPPLE'S COMPOUND

POINTS	HEIGHTS	INVERT LEVEL
OP3	10.420	
E5	10.140	10.490
E4	10.470	
E3	10.149	
E2	10.110	
E1	9.908	10.258
BO1	8.870	9.370
BO2	10.000	10.450
BO3	9.899	
BO4	9.957	
BO5	9.952	
BO6	10.056	
BO7	10.105	
BO8	10.067	
BO9	10.215	
BO10	10.330	
BO11	10.320	
BO12	10.263	
T1	10.126	
T2	10.161	

Fig. 2 Survey of Household Cluster

Fig. 3 Aerial View of Study Area

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