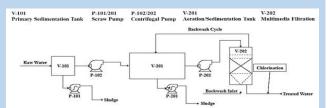


Conceptual Feasibility of a Portable Containerized and Decentralized Wastewater Treatment System for Rural Regions: A Case Study in Palestine

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Abstract: The necessary implementation of decentralized wastewater treatment systems in densely populated rural regions is a viable alternative to constructing a large centralized system. Therefore, this study aims to assess the conceptual feasibility of implementing a portable containerized and decentralized wastewater treatment system as a case study in Palestine that can help in treating wastewater in rural areas efficiently generated by up to 4,000 individuals. The conceptually proposed system is comprised of two stages. The initial stage includes a standalone



primary sedimentation tank located outside the container. The subsequent stage consists of a container housing all the equipment utilized in the treatment process beginning with aeration, followed by secondary sedimentation, and ending with filtration and chlorination. Although the system is designed as a single container, in practice, it will consist of two containers with identical units. The second container will ensure continuous operation mode in case of maintenance in the first container. An initial cost evaluation was conducted, and the projected cost for one container is roughly \$9,800, which is reasonable. Indeed, adopting this proposed system would result in a significant cost-saving of approximately 40 million dollars compared to the current west wastewater treatment plant in Nablus. Additional research can be undertaken to explore the running cost and the level of efficacy attained.

Keywords: Portable, Wastewater treatment, Rural, Decentralized, Containerized.

Introduction

Wastewater is a mixture of liquid and water-borne waste materials that are gathered from residential, commercial, and institutional structures, as well as from groundwater, surface water, and stormwater. Typically, it is rich in substances that deplete oxygen, disease-causing pathogens, organic substances, nutrients that encourage plant growth, inorganic minerals and chemicals, and sediment particles. Additionally, it has the potential to contain hazardous elements (1). There are four main types of wastewater effluents: domestic, industrial, infiltration/inflow, and stormwater.

This research proposes an on-site treatment system for domestic wastewater in a small town in Palestine. The term domestic wastewater (DWW) refers to wastewater generated by household activities such as clothes washing, bathing, and other activities that use water in the house (2).

As a type of wastewater treatment, DWW treatment involves removing contaminants from water, producing effluent that can be discharged into the surrounding environment or reused, and preventing water pollution caused by raw wastewater discharge (3). Household and business wastewater, as well as pretreated industrial wastewater, are contained in wastewater. While many recent unconventional treatment processes are proposed in the open literature such as adsorption and photodegradation (4-6), yet, various conventional wastewater treatment processes are available including sedimentation, biological and chemical processes (such as oxidation and aeration) (7), and filtration which are common wastewater treatment processes (3). However, sludge is one of the major by-products of wastewater treatment plants that are usually treated at the same plant or just disposed of in landfills (8).

Sedimentation

Primary sedimentation is a physical method that removes suspended solids in wastewater treatment, typically employed before the aeration stage. Once treated wastewater is introduced into a clarifier, any remaining organic sediment settles out of the water flow. Typically, primary sedimentation can eliminate around 50-70% of the total suspended solids (9). The discharge from this phase will proceed to the aeration stage (which will be covered in section B) and subsequently be introduced to the secondary sedimentation. When the influent exits the aeration phase, it enters a clarifier where tiny solids, or fines, settle into the tank's bottom. These solids mainly comprise active bacteria,

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and a portion of them is reintroduced into the aeration tank to increase bacterial concentration, facilitate propagation, and hasten the breakdown of organic substances (10). The sedimentation process produces biosolids (or sewage sludge) as a result of water pretreatment. Sludge primarily consists of microbial cells and biomass. To be precise, the biomass is composed of roughly 40% carbohydrates, 30% proteins, and 30% lipids in the particulate state (11). Handling biosolids poses a substantial challenge. Conventional methods for disposing of biosolids include landfilling, incineration, and ocean dumping (12). A recent trend in sludge management involves utilizing it as a feedstock for biodiesel production. This is because sludge is enriched with fatty acids, which constitute the primary material used in the production process (13). Given that sludge poses a significant environmental concern, the prevailing approach involves utilizing it as a feedstock for biodiesel production. It is feasible to gather sludge from this system and conduct further research on its treatment process. In this study, we propose collecting and repurposing it for biodiesel production. In this system, both sedimentation and aeration processes take place within the same tank due to land/space limitations.

Aeration

The natural breakdown of organic material by bacteria is key to the wastewater treatment process, and this process begins in the aeration tank. The primary purpose of the aeration tank is to introduce oxygen into the tank to facilitate the breakdown of organic material and promote the growth of bacteria (14). Sufficient time is also provided for the organic material to decompose. Aeration can be achieved through air pumping and diffusion or through intense agitation that adds air to the water (14). This process is carefully managed to provide the ideal conditions for bacterial growth. Maintaining oxygen gas [O₂] levels above 2 ppm is crucial as anything below this level can kill off bacteria, reducing the plant's efficiency (3). Therefore, dissolved oxygen monitoring is critical at this stage. Additionally, measuring ammonia and nitrate levels is common practice to assess how efficiently bacteria are converting NH₃ to N₂ (15).

Filtration

Filtration is a crucial stage in wastewater treatment systems, and selecting the appropriate system requires careful consideration. This process involves physically separating solid particles from a liquid or gaseous fluid to eliminate or reduce the concentration of suspended particles, parasites, bacteria, algae, viruses, fungi, and other chemical and biological contaminants (16). One common type of filtration is multi-media filtration, which is utilized to capture suspended particulate matter like clay, sand, and silt that causes water to appear cloudy. Typically, it involves arranging several layers of media in ascending order of density, with the densest medium at the bottom and lighter media at the top (17).

Disinfection

Wastewater disinfection is the process of eliminating or deactivating pathogenic microorganisms, such as bacteria, viruses, and protozoa, that may be present in wastewater to prevent the spread of waterborne diseases (18). Chlorination has been the most widely used method of disinfecting wastewater globally since the 1940s, and it has played a crucial role in preventing waterborne diseases across the world (19). Different chlorine derivatives, including gaseous chlorine, hypochlorite, and chloramine compounds, can be used for disinfection purposes (19). Disinfection is necessary for treated wastewater that will be used in irrigation to ensure that any harmful pathogens or bacteria are eliminated, which can pose a risk to human health (20). Chlorination is the least expensive and systematically the simplest method of disinfection, but it can increase the salinity of the treated wastewater and affect the permeability of soils and crops. Dechlorination may be necessary to reduce the negative effects of chlorine on soil and crops. The proposed system will employ hypochlorite injection to disinfect the water discharged from the filtration process.

Problem Statement

Kafr Qallil is a town located in the Nablus Governorate of the State of Palestine with a population of ~3,366 as of mid-2023, according to the Palestinian Central Bureau of Statistics (PCBS) (21). The Palestinian Water Authority and the PCBS indicate that Palestine's daily water allocation for domestic use is 81.9 liters per capita (22). To treat the daily wastewater effluents in the village, a decentralized portable wastewater treatment plant is planned to be designed with consideration for all conceptual design parameters while keeping the costs low.

Proposed System

A proposed mobile wastewater treatment plant is designed to fit in a standard 40-foot container, with easy assembly and disassembly (plug-and-play) making it convenient for temporary use in Kafr Qallil village and other similarly sized villages. The container offers protection against all weather conditions and contains all necessary units, but it requires coating with a suitable material for corrosion protection, such as Amercoat 240 (Universal Epoxy Coating) (23). This surface-tolerant, direct-tometal universal epoxy provides optimal corrosion protection in immersion, non-potable, and corrosive chemical environments, making it ideal for use in the aeration tank (23). To ensure the treatment of wastewater is feasible, the proposed system can treat the daily effluent of the village, which amounts to about 275 m³/day. Conventional and non-conventional methods for treating this amount of water will be discussed in the following topics. The primary sedimentation process will occur outside of the container, with all subsequent stages taking place inside it. Figure 1 shows the Process flow diagram of the proposed system.

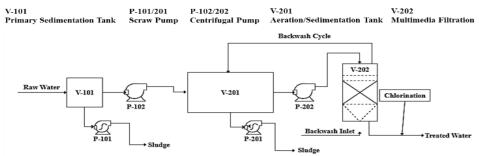


Figure (1): Process flow diagram of the proposed system.

Primary Sedimentation

To remove large particles, the wastewater influent is subjected to primary sedimentation which will occur in a separate tank, and the resulting sludge is disposed of in a collecting container with clear water being pumped to the treatment tank for aeration. The treatment tank is comprised of three stages: aeration, secondary sedimentation, and filtration.

Aeration Phase

The initial stage of the treatment process in the container involves subjecting the settled water to aerobic treatment in the front section of the plant. The fine bubble aeration is facilitated by submerged membrane diffusers mounted on a stainless-steel pipe. These diffusers provide thorough mixing and ensure that the microorganisms of the activated sludge receive adequate oxygen for their metabolic activity, which is necessary for the decomposition of pollutants. The required compressed air is generated by an external air compressor installed in a control cabinet. The aeration process is usually intermittent, creating intensive contact between the wastewater and bacteria. The aeration typically lasts for 30-90 minutes, but in this design, the proposed detention time is 60 minutes. Figure 2 shows the aeration phase within the container (24).

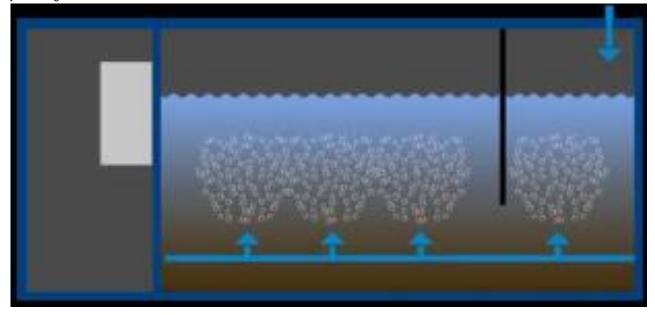


Figure (2): Aeration phase (*image adapted from* (24)). Secondary Sedimentation

Once the aeration process is complete, secondary sedimentation of the wastewater will occur within 1 hour, during which the activated sludge will settle to the bottom of the tank. After this, the clear water (the upper layer in the sedimentation part of the plant) will be pumped into the filtration system using a centrifugal pump. To remove the sludge, screw pumps will be utilized, which will dry for further use as a fertilizer ingredient. Figure 3 shows the secondary sedimentation phase.



Figure (3): Secondary sedimentation phase (image adapted from (24)).

Filtration

The multimedia filter tank will receive water from the top, and it is composed of four different layers, including anthracite, silica sand, zeolite, and gravel. These media have a different density than sand and can be sorted by size to create a layered structure during backwashing. This arrangement of varying particle sizes helps to prolong filter operation by preventing early clogging (25). Each layer is designed to serve a specific purpose in the filtration process.

- Anthracite (coal): It is used to eliminate color and odor and to reduce head loss resulting from increased flow rates, extended filter runs, and reduced backwash rates. Its density is 550 kg/m³.
- Silica Sand: It is utilized to eliminate suspended particles and has a high capacity to retain precipitates that contain impurities. It has a density of 800.9 kg/m³.

- Zeolite: It is characterized by a high surface area due to its significant pore density, allowing it to trap a significant amount of pollutants before requiring backwashing. Its density is 1,600 kg/m³.
- Gravel: It is used as a supporting layer for the filtration media. They have a density of 1,680 kg/m³.

All the information regarding the materials mentioned above, such as their density, is adapted from (26). Within the filtration tank, there exists a filter bed that contains the above materials and ends with strainers. These strainers are purposefully engineered to apprehend large, intermediate, and undesirable suspended particles present in the water, mainly to safeguard equipment downstream, such as pumps, from harm. Figure 4 shows the filtration media distribution.

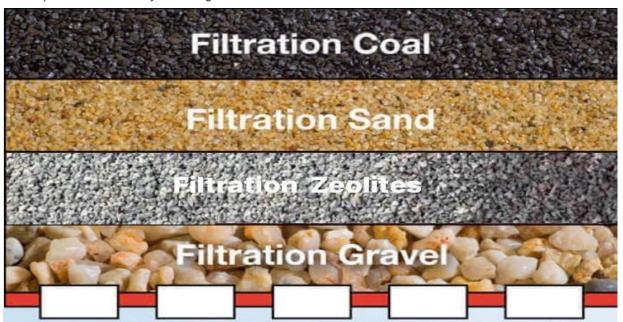


Figure (4): Diagram for the filtration media bed.

Backwash system

Backwashing is an essential process used in wastewater treatment to pump water backward through filter media, including anything in a filter that changes the quality of water flowing through it. Moreover, performed at least once a week for 2-3 minutes to prevent clumping of the media. The backwashing process in this proposed system will be utilized through the filtration tanks equipped with connections for conducting the backwashing.

Disinfection

The last step of the treatment process involves using a chlorine injection pump to inject hypochlorite as a disinfection process through the discharge line after the filtration to enhance the treatment of the water. Then, outlet water can be used for irrigation purposes.

Initial Cost Study

The treated wastewater can be used for agricultural purposes, benefiting a wide audience including farmers. A portable and containerized wastewater treatment plant with a capacity of 30 cubic meters per hour is technically, financially, and environmentally feasible. A brief cost estimation was carried

out on this plant to assess its approximate cost, and the findings are outlined in Table 1. According to the analysis, the estimated cost of this system is \$9,760.

Equipment	Quantity	Price (\$)
Container 40ft	1	2,000
Micro Bubble Diffusers	12	131
AC Powered Aerator	1	189
Filtration Tanks	1	3,800
Centrifugal Pump	2	680
Screw Pump	2	1,000
Amercoat (L)	5	100
Chlorine Pump	1	180
Total	-	9,760

 Table (1): Prices of the equipment used in this system^{*}.

*All prices are taken from (27).

As per information from the Nablus Wastewater Treatment Plant (WWTP) website (28), the West Plant located near Deir Sharaf caters to approximately 150,000 Population Equivalent (PE) at an estimated cost of around 42 million US Dollars (40 million Euros). In contrast, our suggested system is designed to accommodate up to 4,000 PE at a cost of approximately 10 thousand dollars. To serve a population of 150,000 using our proposed system, the projected cost would be approximately 380,000 dollars, with about 38 units, each capable of serving 4,000 PE. Indeed, adopting this proposed system would result in a significant cost-saving of approximately 40 million dollars compared to the current West Plant in Nablus. This represents a substantial financial advantage.

From a feasibility point of view, the decentralized plant's design is moveable, portable, and transportable, which is a big improvement over traditional wastewater treatment facilities. Figure 5 summarizes all the steps included in this system.

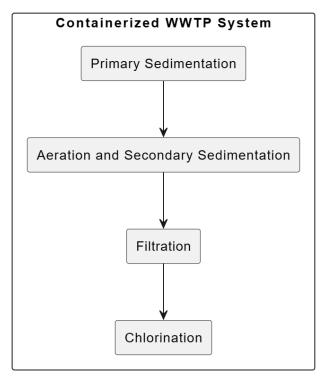


Figure (5): The steps will be used in the proposed system.

It is a more practical and efficient way to manage wastewater in rural areas because it is flexible and adaptable to variations in population and wastewater flow. The proposed plant is also an appealing choice for tiny rural communities with limited resources because of its low cost and simplicity. According to the cost estimate, building the plant will cost less than \$10,000 which is within the means of many rural towns or villages.

Conclusion

In conclusion, this conceptual study has presented a portable, containerized wastewater treatment plant that is technically, financially, and environmentally feasible. The proposed system provides a good solution for the treatment of wastewater anywhere and at any time. The system uses various processes for the treatment of wastewater, including the breakdown of organic waste by bacteria in a secondary treatment process. To enhance treatment effectiveness, a chlorine disinfection method will be employed in the final stage using a dosage injection system into the discharge pipes. The treated wastewater can be used for agricultural purposes, benefiting a wide audience. The economic study conducted for this plant showed promising results, with a capital cost estimate of approximately \$9,760 for a plant with a capacity of 30 m³/h. Overall, the proposed system has the potential to address the challenges of wastewater treatment in various settings and provide an effective solution for the sustainable management of wastewater. Futuristic attempts will focus on more detailed design aspects based on land and geographical aspects as well as on annual operation modes.

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The raw data required to reproduce these findings are available in the body and illustrations of this manuscript.

Author's contribution

AE: Idea conceptualization and supervision, MS, AY, and LR: data collection, literature review, and drafting the manuscript. All authors wrote and revised the final version of the manuscript.

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Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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