



Assessment Of A Cost-Effective Local Sewage Treatment Facility: A Case Study From The Egyptian Countryside

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Abstract: This research provides a comprehensive performance assessment of an integrated anaerobic-aerobic decentralized wastewater treatment facility situated in a rural Egyptian community. The system configuration comprises an Up-flow Septic Tank/Baffled Reactor (USBR) followed by an aeration unit to facilitate biological polishing. Throughout a rigorous six-month longitudinal monitoring phase, the facility exhibited high treatment stability, yielding mean removal efficiencies of 87% for COD, 86% for BOD, 91% for TSS, and 86% for Oil & Grease (O&G). Analytical data confirm that the final effluent parameters consistently align with the regulatory thresholds established by the Egyptian Code of Practice. Critical operational phenomena, such as surface scum formation within the anaerobic reactor and sludge bulking in the aerobic stage, were systematically managed through technical maintenance and community-based participatory interventions. The empirical findings underscore that the anaerobic stage serves as the primary mechanism for pollutant degradation, while the subsequent aerobic phase ensures effluent stabilization. The study validates the Upgraded USBR as a technically viable, energy-efficient, and economically sustainable paradigm for rural sanitation infrastructure.

Index Terms - USBR, up-flow, wastewater treatment, decentralized, low cost.

I. INTRODUCTION

Decentralized wastewater treatment systems (DEWATS) are indispensable for rural regions and small settlements where centralized infrastructure is economically or technically unfeasible. Currently, approximately 38% of such villages in Egypt possess adequate sanitation facilities (Ménard, 2022).

The absence of centralized connections in these remote areas leads to untreated wastewater discharge, resulting in groundwater contamination critical environmental threat that has garnered significant national media attention. Consequently, the Egyptian government is under substantial pressure to implement affordable and efficient sewage treatment technologies.

The establishment of conventional wastewater systems in rural zones has been hindered by prohibitive construction, operational, and maintenance expenditures. Thus, the government is prioritizing low-energy, cost-effective, and user-friendly technologies capable of serving medium-sized villages while achieving regulatory effluent standards to safeguard environmental and groundwater health (Sabry, 2010). To meet these stringent specifications, various technologies, including Anaerobic Baffled Reactors (ABR), modified septic tanks, and Up-flow Septic Tank/Baffled Reactors (USBR), have been developed and evaluated.

Julliana and Arnaldo evaluated an integrated system comprising a laminar settling tank, three anaerobic chambers, and an aerobic chamber (AC) for treating low-strength wastewater. Over a 30-week period with hydraulic retention times (HRT) ranging from 8.25 to 33 hours and influent COD between 105 and 381 mg/L, the system achieved a 78% COD removal rate. The synergy of anaerobic and aerobic stages is expected to yield even higher efficiencies with high-strength wastewater (Da Silva *et al.*, 2017).

To optimize biological treatment and comply with rigorous discharge limits, there is a shift toward Fixed Biofilm Reactors (FBR). These systems offer enhanced stability and shock-load resistance by maximizing microbial concentrations. Recent research highlights the efficacy of using polyvinyl chloride (PVC) honeycomb structures as carrier media. These low-cost polymers significantly increase the surface area for biomass immobilization, accelerating kinetic rates and achieving COD removal efficiencies of up to 90.26% in anoxic fixed-film systems (Fauzi *et al.*, 2025).

Panswad and Komolmethee tested a modified anaerobic septic tank coupled with an anaerobic filter to examine hydraulic shock load impacts. Their findings indicated that varying feeding periods (8 to 24 hours/day) had minimal effect, with BOD removal slightly decreasing from 85% to 81%. However, efficiency was highly sensitive to tank volume and retention time; SS and BOD removal ratios declined as HRT decreased, suggesting that a retention time exceeding 48 hours is necessary for adequate nutrient elimination (Panswad and Komolmethee, 1997).

The Up-flow Septic Tank/Baffled Reactor (USBR) represents an innovative, low-cost modification pioneered by Tarek Sabry in rural Egypt. Initial results showed the ABR compartment was the primary treatment unit during start-up. After one year, the system reached a steady state with COD, BOD, and TSS removal efficiencies of 84%, 81%, and 89%, respectively. Notably, temperature drops from 3 summer (35°C) to winter (22°C) only reduced BOD and COD removal by 9%, while TSS removal remained unaffected (Sabry, 2010).

Comparative economic studies of wastewater technologies in Egypt indicate that USBR operation and maintenance (O&M) costs are only 10% of those for activated sludge (AS) systems, while construction costs range between 40% and 60% of AS costs (Sabry and Gendy, 2007). While USBR is a promising decentralized alternative regarding area, energy, and cost, further performance upgrades are required for safe, unrestricted irrigation use.

To leverage the USBR's advantages, a new decentralized plant was implemented in Kafr Mohsen, Sharqia. This facility features upgrades such as a plate settler between the up-flow and ABR units, followed by aeration and sedimentation tanks for effluent polishing. This study monitors the plant over 168 days to investigate unit performance and develop optimization strategies.

II. MATERIALS AND METHODS

Upgraded USBR Components

The modified USBR utilizes two primary treatment stages, each containing two parallel compartments. The anaerobic stage consists of an up-flow septic tank followed by an ABR arranged in series. The ABR is divided into four consecutive sections. The volumes for the up-flow and ABR units are 235 m³ and 680 m³, respectively. This stage removes suspended solids via gravitational settling in the up-flow tank, where a sludge blanket entraps smaller particles. The vertical flow forces volatile fatty acids and oil/grease (O&G) to form a 5-10 cm scum layer at the surface. Vertical weir and plate settlers at the effluent port prevent scum and solids from escaping. The flow then enters the ABR, where vertical baffles facilitate the conversion of organic matter into biogas.

Perforated pipes on the up-flow tank surface facilitate scum and grease removal through valve operations two to three times daily for 10-minute intervals.

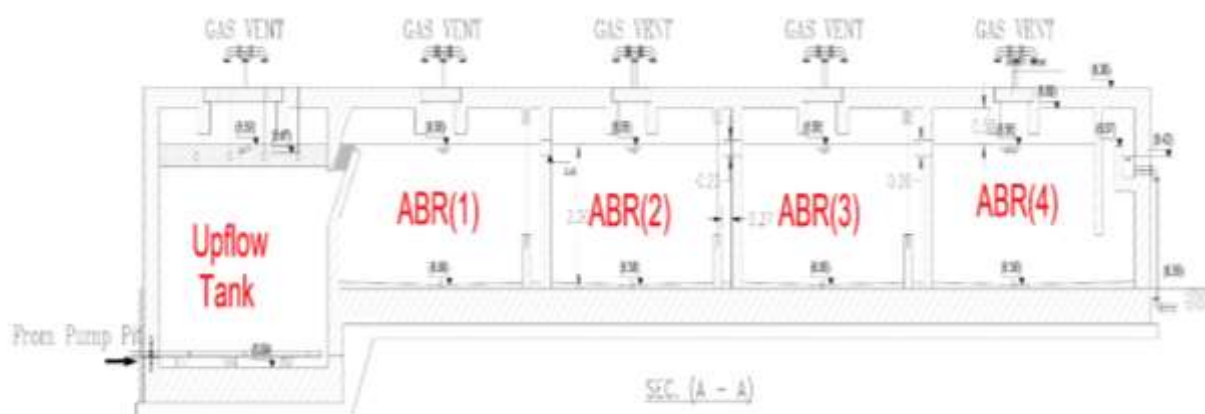


Figure 1: Cross section for the first stage (anaerobic treatment).

The aerobic stage comprises an aeration tank and a sedimentation tank. This stage acts as a polishing unit, converting residual BOD into stable matter, which is settled. Sludge is collected via a telescopic valve mechanism and recycled to the aeration tank to maintain high concentrations of activated microorganisms.

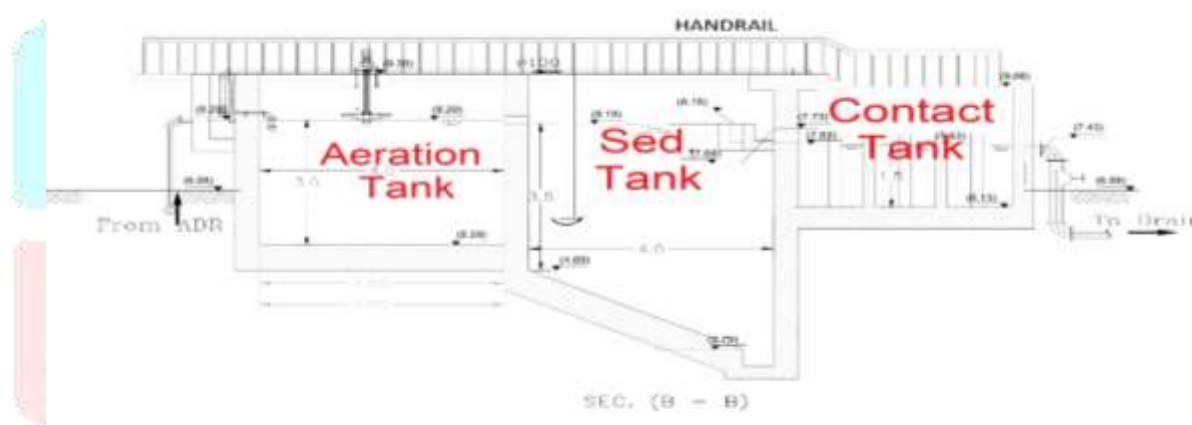


Figure 2: Cross section for the second stage (aerobic treatment).

Samples

Plant performance was evaluated through weekly or monthly sampling of influent, effluent, and intermediate stages. Parameters measured included BOD, COD, TSS, O&G, and MLSS (in the aeration and return sludge tanks), following the "Standard Methods for the Examination of Water and Wastewater" (American Public Health Association, American Water Works Association and Water Environment Federation, 2023). Key data during the investigation included:

1. Influent flow: 534 to 2,263 m³/day (average 1,088 m³/day).
2. Up-flow tank HRT: 2.5 to 10.5 hours (average 5.2 hours).
3. ABR HRT: 7.2 to 30.5 hours (average 15 hours).

III.RESULTS

Following three years of continuous operation since December 2021, the plant has surpassed the start-up phase and reached a steady state.

Influent Characteristics

Influent and effluent samples were collected over six months to assess system efficiency under diverse conditions. Influent COD, BOD, TSS, and O&G concentrations are detailed in Figure 3.

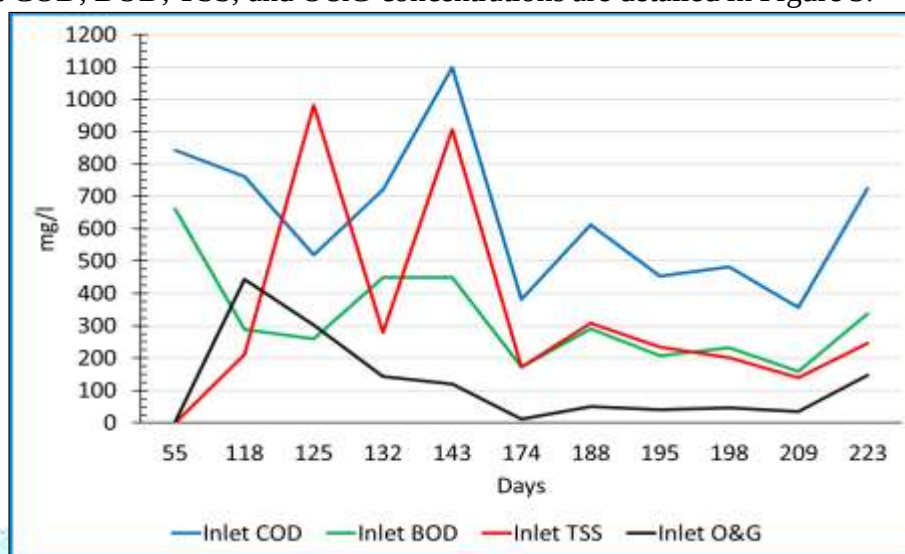


Figure 3: influent wastewater Characteristics.

Average concentrations were 616, 319, 328, and 122 mg/L, respectively, indicating high-range loading (Tchobanoglous *et al.*, 2014). This is attributed to local livestock farming, where animal waste and residues are frequently discharged into the sewer system. This practice increases organic loading and promotes floating scum accumulation.

Winter influent concentrations were significantly higher than summer values. Field visits and interviews revealed that during winter, livestock is kept in barns, and waste is disposed of in the sewage network. In warmer months, livestock graze on agricultural land, where waste is naturally distributed, reducing the organic load on the WWTP.

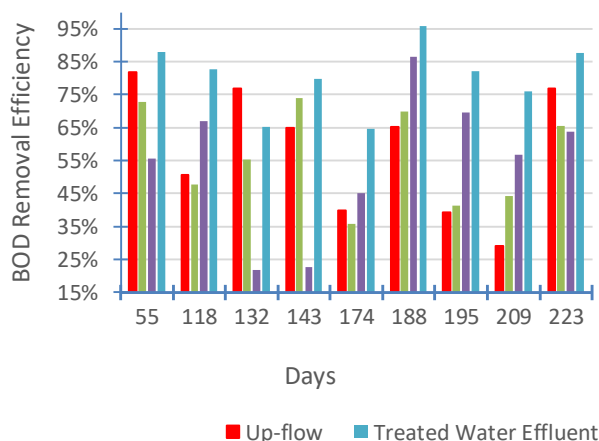


Figure 4: BOD Removal Efficiency.

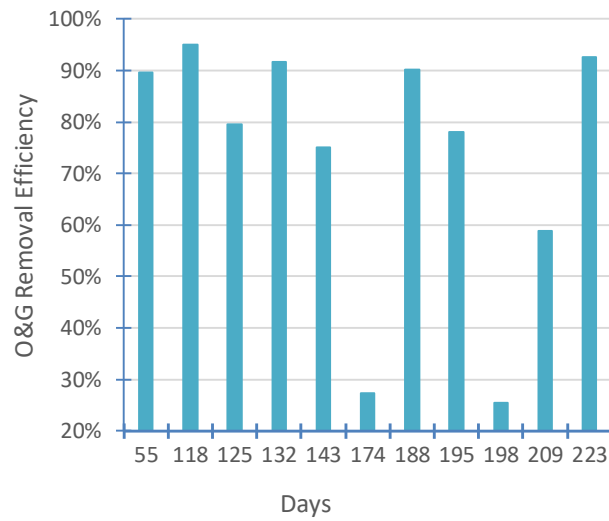


Figure 5: COD Removal Efficiency.

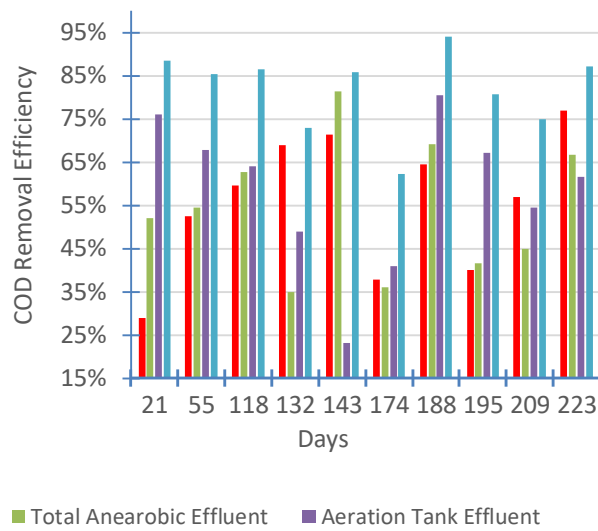


Figure 6: TSS Removal Efficiency.

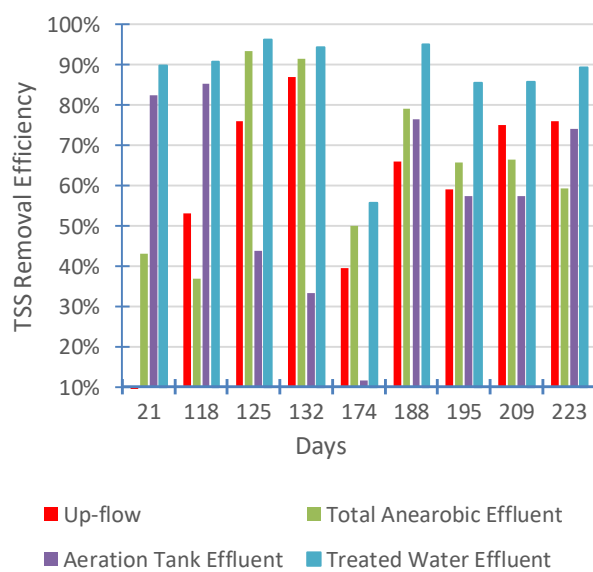


Figure 7: O&G Removal Efficiency.

Anaerobic tanks (Up-flow Tank + ABR) performance

The up-flow tank's vertical flow facilitates a sludge blanket for SS entrapment. Positioning the outlet below the water surface prevents O&G discharge. However, a thick scum layer caused a 50 cm water level differential between parallel compartments, leading to hydraulic overloading. The first compartment showed 15% lower efficiency due to scum. Corrective measures included removing roof slabs for manual scum extraction, conducting villager education workshops, and repairing clogged valves.

The current scum collection system using perforated pipes proved inefficient under high loads due to waste density and hydraulic blockages. Proposed modifications include:

1. **Mechanical Scraper System:** An automated surface scraper for periodic scum removal.
2. **Open Channel Design:** Inclined open channels to improve waste mobility and accommodate higher loads.

Post-maintenance, up-flow tank COD and BOD removal efficiencies increased by 15%. The anaerobic stage achieved average removal rates of 66%, 69%, 77%, and 83% for COD, BOD, TSS, and O&G, respectively, serving as the primary pollutant removal mechanism. While the up-flow tank showed higher steady-state removal than the ABR, the ABR proved vital as a buffering unit during hydraulic shock loads (Sabry, 2010).

Aerobic Stage (Aeration Tank + Sedimentation tanks) performance

During the first three months, low MLSS in return sludge and sludge bulking (floating solids) hampered aeration tank performance. Floating solids were likely caused by anaerobic reactions at the tank bottom, fostering filamentous bacteria. Inefficiencies in the telescopic sludge return system were identified, specifically inadequate pipe reach (1.5m above the bottom) and frequent blockages. These factors increased sludge retention time, causing gas production (methane, H₂S) that buoyed solids.

To solve this, replacing the telescopic system with low-vibration submerged pumps at the tank base is recommended to prevent vortex effects and ensure continuous sludge return. Despite these hurdles, the aerobic stage achieved removal rates of 62% COD and 55% BOD relative to the anaerobic effluent. This confirms the aerobic stage is a critical component for stable plant operation and environmental compliance.

Overall results and performance

Initial non-compliance with ECP limits (80 ppm COD, 60 ppm BOD) was due to an 80 cm scum layer in the up-flow tank. After addressing this, the system achieved average removal efficiencies of 87% COD, 86% BOD, 91% TSS, and 86% O&G. Peak efficiencies reached 94-96%, demonstrating the plant's high potential under optimal management.

The following figures show the influent and effluent characteristics for COD, BOD, TSS and O&G.

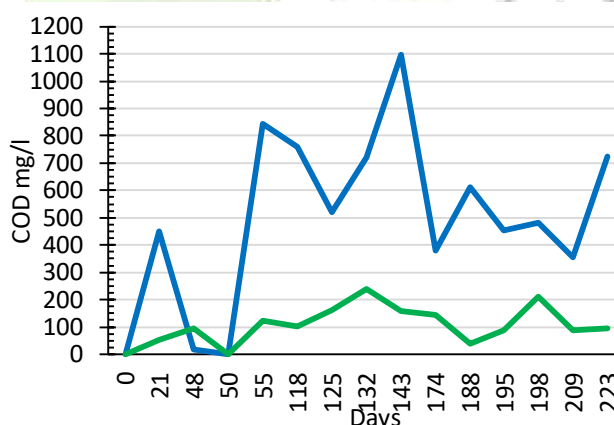


Figure 8: Inlet and Outlet COD concentrations.

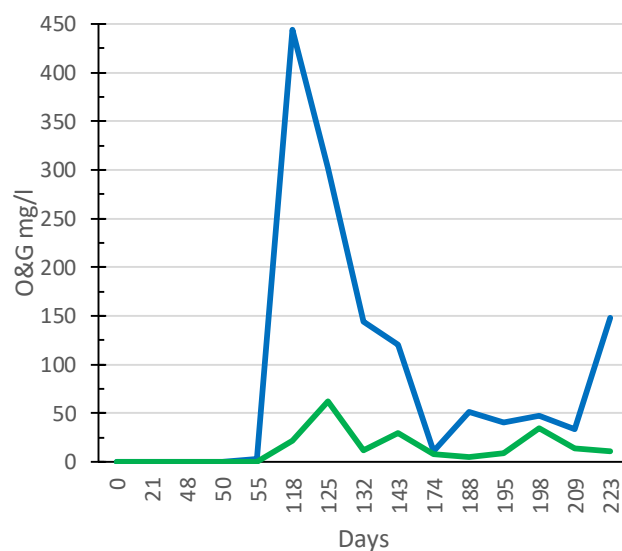


Figure 9: Inlet and Outlet BOD concentrations.

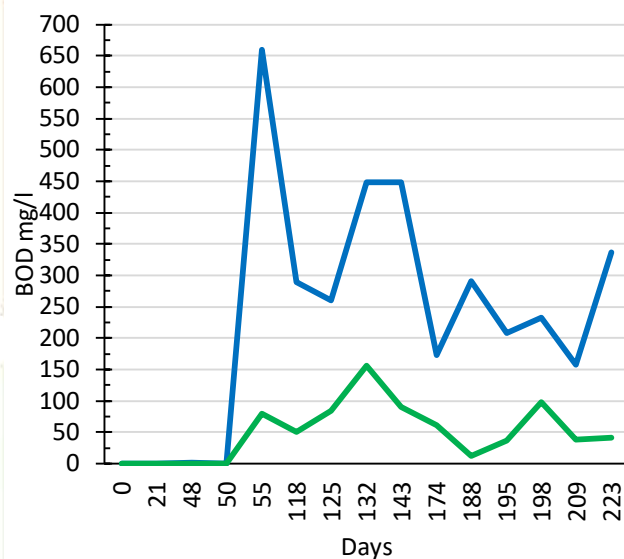


Figure 10: Inlet and Outlet TSS concentrations.

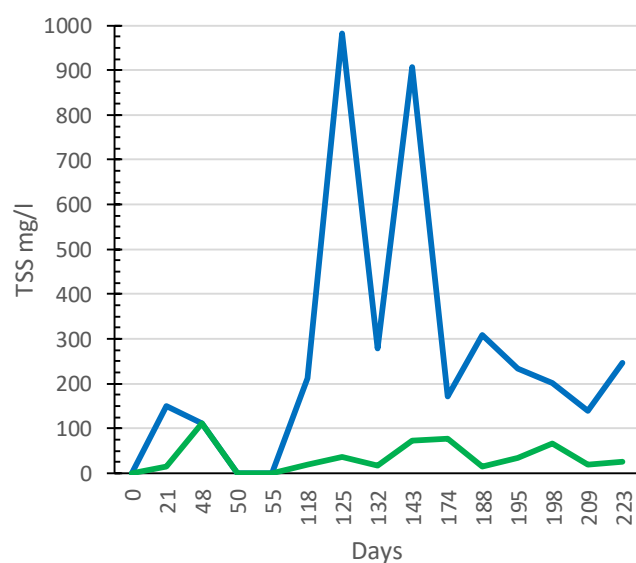


Figure 11: Inlet and O&G concentrations.

IV. CONCLUSION AND RECOMMENDATIONS

The upgraded USBR plant demonstrated robust performance, with effluent parameters meeting Egyptian Code standards. The up-flow tank is the primary unit for organic and solids removal (>75% TSS reduction), while the ABR stabilizes the system during shocks. The aerobic stage is essential for meeting final environmental thresholds.

Recommendations

1. **Sampling Ports:** Install ports in the up-flow tank at 0.5 m intervals to monitor sludge distribution.
2. **Scum System Upgrade:** Replace 4-inch pipes with 6-inch pipes, increasing opening diameters and frequency (30 cm apart) with higher slopes.
3. **Pre-Treatment:** Construct a gravity-based O&G trap upstream to reduce influent grease.
4. **Biofilm Media:** Integrate PVC rings in the ABR to enhance microbial attachment and removal rates [4].
5. **Solar Power:** Implement PV systems on the anaerobic stage's surface area to power the aeration stage, improving sustainability (Zacchei and Colacicco, 2022).
6. **Community Oversight:** Establish a village committee to regulate sewer usage and enforce disposal penalties.

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