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Characterization of Wastewater in School Environments for an Ecological Treatment Solution: A Case Study of Ndiebene Gandiol 1 School

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Abstract

The study conducted at Ndiebene Gandiol 1 school in Senegal has unveiled serious environmental and public health challenges. The wastewater analysis revealed high levels of Biochemical Oxygen Demand (BOD5), Chemical Oxygen Demand (COD), and fecal coliforms, signaling potential risks to the well-being of students and staff. This situation mirrors a wider issue in rural educational settings, where inadequate sanitation persists. Intensive wastewater treatment options are known for their effectiveness against high pollutant loads but are resource-intensive in both energy and cost. Conversely, extensive treatment systems, while requiring more land, provide a sustainable alternative by harnessing natural processes for pollutant removal. The research suggests a hybrid treatment approach could serve the school's needs, balancing the robust capabilities of intensive methods with the ecological benefits of extensive systems. Such a solution would need to be tailored to the specific environmental, financial, and logistical context of the school, based on comprehensive feasibility studies and stakeholder engagement. This study's findings underscore the urgency of addressing sanitation in schools, as it is intrinsically linked to the health and academic success of students. Quick, effective, and long-term strategies are vital to secure a healthier and more prosperous future for the youth. With proper implementation, the school can transform its sanitation facilities, setting a precedent for rural educational institutions in Senegal and similar contexts globally.

Keywords

Wastewater Characterization, Ecological Treatment, School Sanitation, Phytoremediation, Rural Infrastructure, Environmental Health

1. Introduction

The achievement of the Sustainable Development Goals (SDGs) lies at the heart of global concerns. In particular, SDG 6, which aims to ensure access to water and sanitation for all, is of paramount importance. The sanitation policy of Senegal (2016-2025) aligns with these objectives and targets the improvement of access to drinking water, sanitation, and sustainable management of water resources [1] [2]. However, an analysis of the situation reveals a gap between the political vision and the reality on the ground. As of 2021, only 56% of the Senegalese population had improved sanitation services. The majority of sanitation infrastructure is concentrated in urban regions, leaving rural areas, including educational institutions, in a precarious situation. With a stark deficiency in wastewater treatment, the ecological and health consequences are severe, heightening public health challenges [1] [2] [3]. Effective wastewater management is vital for environmental protection and public health [4]. Wastewater treatment in Africa, particularly in Sub-Saharan Africa, remains underdeveloped [5] with notable disparities between North Africa and Sub-Saharan countries [6]. Focusing on Senegal's sanitation, over a third of the population lacks access to improved toilets, with 15% practicing open defecation. Most households use improved toilets, like flush toilets connected to septic tanks (24%) or pit latrines with slabs (31%). Only about 8% are connected to sewer systems [7]. Toilet access varies by wealth, residence area, and urban or rural settings, with rural areas having lesser access to modern toilets. Only 12.5% of Senegal's population has access to collective sanitation. Most rely on autonomous systems like septic tanks with sludge treatment stations. There are nine functional treatment plants, four in Dakar and five regionally. The largest, operational since 1989, is in Cambérène, Dakar [7]. These data highlight ongoing challenges in sanitation and infrastructure, especially in rural areas and for low-income households, necessitating improved access to adequate sanitation facilities [8]. School sanitation in Saint Louis faces significant challenges. Only 59% of schools have access to drinking water, highlighting the need for considerable efforts to connect the remaining 326 schools, especially in remote rural areas [9]. There are disparities in water coverage between departments and urban vs. rural areas. For sanitation access, 70% of primary schools have latrines, slightly below the national rate of 72.8% [9]. However, rural areas struggle with inadequate sanitation infrastructure. Even schools with sanitation facilities often do not meet the standard of one sanitary box per 50 students, and many latrines are old or unusable. Substantial efforts are needed to renovate existing facilities to ensure adequate sanitation access for students and teachers [3]. Alternative wastewater treatment methods, such as constructed wetlands with reeds, have been studied in various contexts, including developing countries [10]. These methods have proven effective, but their application requires specific local adaptation. Thus, faced with the unique challenges of Senegal, how can systems based on phytoremediation be adapted and optimized for wastewater treatment? In this context, constructed wetlands with reeds emerge as a promising solution. These systems, which use aquatic plants to remove pollutants, are recognized for their effectiveness, low cost, and durability [5] [11] [12] [13] [14]. In Africa, they are considered as potential solutions for areas with limited infrastructure. The school environment presents a unique context. Schools, especially in rural areas, are often devoid of adequate infrastructure. Thus, an evaluation of wastewater specific to these environments is essential to contemplate suitable solutions. The ambition of this study is to characterize wastewater in Senegalese schools and propose an ecological treatment solution. It aims not only to fill gaps in the existing literature but also to contribute to the implementation of effective sanitation policies. To achieve this goal, the study will adopt a multidimensional approach:

- Conducting field surveys to assess the quality of wastewater.
- Laboratory analyses to determine the exact composition of wastewater.
- Evaluations of existing facilities and current treatment methods.
- Comparisons with the best international practices to identify the most effective techniques.
- Exploration of sludge management and water pollution reduction.

The remainder of this article is organized as follows: section 2 presents the adopted methodology, section 3 presents the results obtained and provides an in-depth discussion of the implications of the results, and finally, section 4 concludes and offers recommendations for the future.

2. Materials and Methods

2.1. Study Area

Ndiebene Gandiol is a Senegalese municipality situated approximately 20 kilometers from Saint-Louis city, near the Senegal River estuary. It forms part of the Rao district within the Saint-Louis department and region. Its geographical location places Ndiebene at the historical center of the Gandiol area. Following the implementation of the third act of decentralization in 2014, Ndiebene Gandiol has been designated as the administrative center of the Gandiol municipality. Within the Gandiol municipality, several schools have been examined. However, our study will focus primarily on the Gandiol school, which is considered for the implementation of an ecological wastewater treatment system. The location and size of the establishment are illustrated in **Figure 1**. The specifics of the selected site are recorded in **Table 1**. This table highlights the sanitary situation and the infrastructure of the "Ndiebene Gandiol 1" school. The institution accommodates 505 students, aged between 7 and 14 years, distributed across 12 classrooms. Despite this significant number of students, the school has only 4 latrines for student use and one reserved for teachers. The latrines are often non-operational. Moreover, the school lacks any functioning water points. Its sanitation system is deemed non-compliant. Lastly, the toilets are in poor condition, frequently blocked, and thus unusable for students and teachers most of the time. To design an appropriate wastewater treatment system, it is imperative to carry out sampling to determine the quality of the wastewater.

Figure 1. Location of the study site: Ndiebene Gandiol School. In yellow, the boundary of the study site.

Table 1. General information on the study site.

Criterion	Information
Name of the school	Ndiebene Gandiol 1
Number of students	505
Age range of students	7 to 14
Number of classrooms	12
Latrines for students	4
Latrines for teachers	1
Functional latrines	0
Sanitation system	Non-compliant
Water points (faucets)	Non-existent
Condition of the toilets	Dilapidated, blocked, not used

2.2. Wastewater Characterization

To determine the wastewater quality of the studied site, a characterization methodology was developed. The goal is to assess the main physicochemical and microbiological characteristics of these waters to propose suitable treatment solutions.

2.2.1. Sample Collection

As part of our analysis of the wastewater characteristics of the site, we implemented a rigorous sample collection methodology. Our aim was to obtain representative data by sampling at strategic times to capture potential variations in wastewater composition depending on the time of day, season, and school activity. The timing of sample collection is crucial to reflect seasonal variability. According to [15], wastewater characteristics, such as pollutant load, vary significantly with the seasons. Additionally, the impact of weather on wastewater composition has been demonstrated in previous works [16]. Furthermore, collecting samples at different times of the day allows capturing fluctuations related to the usage habits of the sanitation facilities. Wastewater characteristics vary considerably during peak toilet usage hours. On the studied site, the use of toilets contributes to fulfilling the basic needs of Maslow's hierarchy. The first sample was taken on June 10, 2022, at 11:00 AM. It was collected during a period of intense heat, with a temperature of 36˚C. At that time, the students were fully using the toilets during the break. The relevance of this sample lies in the fact that it was taken when the weather conditions were hottest, which can impact the composition of the wastewater. Moreover, it was collected during the school year, thus providing data on the use of sanitation facilities on hot days. The second sample was collected on November 20, 2022, at 5:00 PM, during a period of moderate temperature, at 25˚C. This time corresponded to a cooler period of the school year when students were also very active in using the toilets. The relevance of this sample lies in the fact that it was taken on a normal school activity day, at a more moderate temperature, which provides data on wastewater under more typical conditions. The sample collection process was as follows:

- Identification of the inlet and outlet points of wastewater at the septic tanks: This step is crucial to ensure that samples are collected representatively. Previous work [17] emphasizes the importance of precise location of sampling points.

- Wearing protective equipment: Wearing protective gear is in line with safety standards recommended by the Occupational Safety and Health Manual [18].

- Spreading and numbering of bottles: Numbering the bottles allows for precise tracking of each sample, thus ensuring data traceability [19].

- Opening of manholes and inspection holes of the pits: This step must be carried out in accordance with good safety practices, as recommended by the World Health Organization's guidelines on sanitation and health [20].

- Immersion of a container inside the pits: Immersion must be performed at a specific depth to minimize sedimentation effects [21].

- Measurement of pH and temperature: Measuring pH and temperature conforms to protocols recommended by the World Health Organization for wastewater analysis.

- Filling the bottles: Bottle filling must be carried out in a way to minimize cross-contamination [22].

- Placing bottles in a thermostat containing ice packs: Maintaining the temperature at 4 degrees Celsius is important for preserving sample stability [17].

- Tests were conducted within the following 24 hours. This practice is in accordance with recommendations of [19] [22] to ensure data validity.

- Sending the samples to Dakar for analysis: Analyzing the samples by an external laboratory, [23] reinforces the reliability of the results.

- Thus, these samples were meticulously collected to provide an accurate picture of the wastewater characteristics of the studied site at the most representative moments of their use, allowing a thorough assessment of the wastewater treatment needs of the establishment.

2.2.2. Sample Analysis

The collected samples were subjected to detailed analysis to estimate the concentration of the following parameters:

- BOD5 (mg/l): Biochemical Oxygen Demand over a period of 5 days (BOD5) is used to quantify the oxygen required for the biological degradation of organic materials in the sample [24] [25].

- COD (mgO/l): Chemical Oxygen Demand (COD) is used to determine the total amount of oxygen that would be needed to chemically oxidize the organic and inorganic compounds present in the water [24] [25].

- SS (mg/l): Suspended Solids (SS) refer to solid particles that are not dissolved in water [26].

- Nitrates (mg NO_3^-/l): Nitrates indicate a form of nitrogen available in water, usually stemming from the degradation of organic substances or agricultural runoff [27].

- TKN (mg/l): Total Kjeldahl Nitrogen (TKN) represents the combined concentration of organic nitrogen, ammonia, and ammonium [28].

- Phosphates (mg PO_4^{3-} /l): Phosphates, often derived from detergents, fertilizers, and natural decomposition processes, are a primary source of nutrients [29].

- Fecal coliforms (CFU/100 ml): Fecal coliform counts serve as an indicator of fecal contamination and inform about the microbiological quality of water. It provides crucial information about water safety and microbiological quality [30].

2.2.3. Data Processing

After the completion of the analyses, the data were gathered and subjected to statistical processing. Averages for each parameter were calculated. Subsequently, these results were compared to established standards to assess the quality of the school's wastewater and to identify necessary treatment requirements. This thorough methodology not only establishes a precise state of the school's wastewater quality but also suggests appropriate solutions for their treatment and enhancement.

3. Results and Discussion

3.1. Wastewater Analysis Results

Subsequent to site visits and observations, samples of wastewater were taken for comprehensive analysis. The findings from these analyses are outlined in **Table 2**. Pertaining to Biochemical Oxygen Demand (BOD5), values of 439 mg/l for the first sample and 293 mg/l for the second were recorded, averaging to 366 mg/l. In terms of Chemical Oxygen Demand (COD), the first sample exhibited a

Table 2. Wastewater analysis results.

Parameters	Sample No. 1	Sample No. 2	Average
BOD5 (mg/l)	439	293	366
COD (mgO/l)	1070	1480	1275
SS (mg/l)	254	162	208
Nitrates (mg NO_3^-/l)	60	40	50
TKN (mg/l)	486.2	390.3	438.25
Phosphates (mg PO_4^{3-}/l)	344	420	382
Fecal Coliforms (CFU/100 ml)	1.03E+06	4.00E+07	20.515E+06

concentration of 1070 mgO/l and the second 1480 mgO/l, averaging to 1275 mgO/l. For Suspended Solids (SS), concentrations of 254 mg/l for the first sample and 162 mg/l for the second were observed, with an average of 208 mg/l. Nitrate levels were 60 mg NO_3^-/l for the first sample and 40 mg NO_3^-/l for the second, leading to an average of 50 mg NO_3^-/l. Regarding Total Kjeldahl Nitrogen (TKN), observed concentrations were 486.2 mg/l for the first sample and 390.3 mg/l for the second, resulting in an average of 438.25 mg/l. Phosphate concentrations were 344 mg PO_4^{3-}/l in the first sample and 420 mg PO_4^{3-}/l in the second, with an average of 382 mg PO_4^{3-}/l. Lastly, for Fecal Coliforms, the first sample registered a high concentration of 1.03E+06 CFU/100ml, while the second showed a more alarming level of 4.00E+07 CFU/100ml. The average for this parameter across both samples was 20,515,000 CFU/100ml. These results derive directly from the analyses performed at [23] and are crucial for an understanding of the wastewater quality of the site.

3.2. Wastewater Quality

The wastewater analysis from the site, presented in **Table 2**, highlights several significant challenges to address. An average BOD5 of 366 mg/l, which is relatively high, indicates a substantial amount of biodegradable organic matter, usually associated with the presence of organic contaminants. This is corroborated by an average COD of 1275 mgO/l, signaling a significant presence of organic materials. Even more concerning is the high concentration of fecal coliforms, with an average of 20,500,000 CFU/100ml, indicative of major bacterial contamination, posing a serious public health risk. Considering that the BOD measured over 5 days (BOD5) represents only a part of the total BOD (or ultimate BOD), the use of the COD/BOD ratio, or more precisely the COD/BOD5 ratio (to stay with the measured parameters), provides a realistic idea of the biodegradability of an effluent according to [31]. The COD/BOD5 ratio is 3.48, falling between 3 and 5, which classifies the effluents in the category of moderately biodegradable according to the results of [31]. These analyses, conducted by the renowned laboratory [23], attest to the credibility of the results. The breadth of parameters analyzed provides a comprehensive view of the water quality situation. Several of them, especially the high concentration of fecal coliforms, alert us to the severity of the contamination. These data, coupled with the school's deficient sanitary infrastructure, are all the more concerning. These findings, when placed within the broader context of sanitation in schools and public health issues, underscore the urgent need for targeted sanitation interventions. Indeed, students and teachers are exposed to considerable health risks, which can impact not only their health but also their attendance and academic success. Faced with such a situation, immediate measures are imperative to enhance the water quality at Ndiebene Gandiol school, namely:

- Establishment of an effective wastewater treatment system.

- Organization of educational sessions focused on hygiene for students and staff.

- Implementation of modern sanitary infrastructure that meets current standards.

- Strengthened collaboration with local authorities and specialized entities for regular monitoring and maintenance.

- In summary, the data collected highlight the urgency of implementing corrective measures to improve water quality at this institution. It is crucial to take vigorous measures to ensure a healthy study environment conducive to the students' well-being.

The interpretation of the data collected on the study site reveals crucial aspects to consider for a rigorous analysis [32]. The small number of samples could influence the representativeness of the results. A diversification of samples over a longer period would be ideal to obtain a more comprehensive overview of potential variations in water quality. Not considering the relief might skew the understanding of pollutant dispersion. Integrating this dimension could refine recommendations. The absence of climate variation analysis could affect the relevance of treatment methods, given local seasonal fluctuations. However, the study offers a complete perspective on water quality through the diversity of analyzed indicators. The results, derived from the laboratory [23], are highly credible. The study suggests recommendations based on both intensive and extensive solutions, allowing for effective wastewater treatment. The emphasis on health indicators, such as fecal coliforms, underscores the health issues associated with untreated wastewater. This study provides guidelines for future interventions. To improve the reliability of future studies, it would be wise to consider a more diverse sampling, to take into account topography, and climate conditions.

3.3. Potential Ecological Treatment Technologies

The population equivalent (PE) is a standardized unit used to compare the pollutant load emitted by various users in an area (residents, workers, students, etc.) to that of a typical inhabitant. This unit is often used to size sanitation facilities. To determine the population equivalent of our study site, it is crucial to quantify the pollutant load generated by the students and staff, related to on-site activities. However, for a precise evaluation, detailed information on waste generation, water consumption, among others, is required. In the absence of this information, we can still establish an estimate based on certain criteria stated in **Table 1**. The school has 505 students. We can assume that a student produces a lower pollutant load than an adult (say 50% of an adult's load). If an adult corresponds to 1 PE, then a student would be valued at 0.5 PE. The fact that all the latrines are out of service, combined with the dilapidated state of the toilets, means that wastewater does not receive proper treatment. While this does not directly influence the PE calculation, it highlights the inadequacy of current infrastructure relative to the defined number of PEs. The absence of a water point suggests limited water consumption or provision from other sources. This situation could reduce the volume of wastewater produced, but it is tricky to assess its influence on the PE without additional data. Assuming one teacher per classroom, *i.e.*, 12 teachers, and estimating that a teacher generates a pollutant load equivalent to an adult, each teacher would be counted for 1 PE. Thus, based on these estimates and the data provided, the study site would represent approximately 265 PEs. It is critical to note that this evaluation remains approximate and that a more detailed analysis would be necessary for refined results. With a population equivalent of 265, the site is positioned as a small to medium-sized entity in terms of wastewater sanitation. Various treatment solutions can be considered for a community of this size, as highlighted by [33].

3.4. Reference Values for Pollutant Loads

When considering an ecological treatment for wastewater, such as phytoremediation, it is essential to have reference values for permissible pollutant loads to ensure optimal system efficiency. These reference values can vary depending on national or local regulations, environmental conditions, and the type of ecological system envisioned. However, here are some general and recommended values for various parameters, widely recognized in the field of sanitation (see **Table 3**) according to [34]. It is essential to note that these values are general and may vary depending on local regulations, environmental context, and other factors. Moreover, several organizations and publications provide guidelines on this subject, such as the World Health Organization (WHO) [35], the United States Environmental Protection Agency (EPA) [19], and European standards [36]. For a specific application, it is recommended to consult local regulations and expert recommendations in the field.

3.4.1. Intensive Treatment Processes

When we refer to intensive (or conventional) wastewater treatment processes, we can list several techniques, including activated sludge, trickling filters, rotating biological contactors, and high-performance lagooning [33]. Each technique has its own advantages and disadvantages (**Table 4**). Compared to the results obtained for the studied site, an intensive process could be advantageous to ensure regular compliance with discharge standards, especially due to the high loads observed in BOD5, COD, and fecal coliforms. However, the choice between these techniques will depend on the specific constraints of the site, the budget, and the long-term objectives for the management of wastewater at the school.

3.4.2. Extensive Treatment Processes

The treatment of wastewater by extensive processes mainly refers to systems that require little or no energy to operate and rely largely on natural processes. Here are some extensive processes with their advantages and disadvantages, taking into account the results of the wastewater analysis of the studied site presented in Table 5. Based on the results of the wastewater from the site, the BOD5, COD, and fecal coliforms are particularly high. Reed bed filters and natural lagoon seem to be the most promising options to effectively treat these

Table 3. Target value for effective treatment or acceptable discharge.

Parameters	Description	Target value
BOD5	Indicator of the amount of organic matter in the water.	<25 mg/l
COD	Total amount of oxygen needed to oxidize all organic material.	<125 mg/l
SS	Can clog the treatment system and affect its efficiency.	<35 mg/l
Nitrates	High concentrations can cause eutrophication of water bodies.	<50 mg/l
TKN	Sum of organic nitrogen, ammonium, and ammonia.	<30 mg/l
Phosphates	Can contribute to eutrophication, just like nitrates.	<2 mg/l
Fecal coliforms	To prevent health risks.	<1000 CFU/100ml

Table 4. Advantages and disadvantages of intensive treatment processes.

Technique	Advantages	Disadvantages
Activated sludge	- Effective in treating a wide variety of pollutants. - Produces good quality effluent. - System is widely studied and well understood.	- Consumes a lot of energy (aeration). - Produces sludge that requires proper management. - Needs regular monitoring and management.
Trickling filters	- Requires less energy compared to activated sludge. - Limited sludge production.	- May require more space than activated sludge. - Sensitive to toxic shocks.
Rotating biological contactors	- Good removal of BOD and suspended solids. - Limited sludge production. - Low energy consumption.	- Requires mechanical equipment (which can fail). - Risk of clogging or fouling.
High-performance lagooning	- Provides effective treatment with low energy consumption. - Capable of absorbing load variations.	- Requires a large space. - Dependent on climatic conditions.

Table 5. Advantages and disadvantages of extensive treatment processes.

Extensive processes	Advantages	Disadvantages
Natural lagoon	- Low operational cost and maintenance. - Suitable for high pollutant loads. - Effective reduction of pathogens and organic matter.	- Requires a large area. - Sensitive to seasonal and climatic variations.
Horizontal flow constructed wetlands	- Effective in treating BOD5, COD, nitrates, phosphates. - Provides a habitat for biodiversity. - Low operational and maintenance cost.	- Requires significant area. - Less effective for high fecal coliform loads. - Sensitive to seasonal variations.
Vertical flow constructed wetlands	- Effective for treating organic pollutants and nutrients. - Minimal maintenance. - Aesthetically pleasing.	- Requires a certain area. - May need pretreatment for very high loads.
Infiltration wells	- Good for BOD5 reduction and solid filtration. - Recharges groundwater.	- Less effective for nutrients and pathogens. - Risk of groundwater contamination.
Biological rotating contactors	- Effective for reducing BOD5 and suspended solids. - Compact.	- Requires mechanical equipment. - Less effective for nutrient treatment.

high concentrations, but the final choice will also depend on the constraints of the site, available resources, and community preferences.

4. Conclusion

The Ndiebene Gandiol 1 school, through the analysis of its wastewater, has revealed a concerning situation. High concentrations of BOD5, COD, and fecal coliforms indicate a major health risk for students and teaching staff. Unfortunately, this reality is not isolated and underscores the need to adopt effective sanitation approaches, especially in educational contexts. While intensive treatment processes offer a robust and proven solution, particularly for high pollutant loads, they also require substantial resources, both financially and energetically. On the other hand, extensive treatment processes, although requiring more space, represent sustainable and ecological solutions, utilizing natural purification mechanisms. For the Ndiebene Gandiol school, a combined approach, perhaps an extensive process supported by elements of intensive techniques, could offer a solution that is adapted to both its needs and constraints. The final choice should be grounded in a detailed feasibility study, consultations with stakeholders, and consideration of local realities. In conclusion, the situation at the Ndiebene Gandiol school highlights the critical importance of sanitation in educational institutions. This is an issue that goes beyond environmental concerns to directly affect the health, well-being, and educational success of students. It is imperative to act quickly, effectively, and sustainably to ensure a better future for the younger generation.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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