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Design and Sizing of an Ecological Wastewater Treatment System in a School Environment: A Case Study of Ndiebene Gandiol 1 School

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Abstract

The primary objective of this study was to design and size a sustainable sanitation solution for the Ndiebene Gandiol 1 school located in the eponymous commune in northern Senegal. Field investigations led to the collection of wastewater samples. Their analysis revealed specific pollutant loads, including loads of BOD5 3.6966 kgO_2/day and COD of 12.8775 kgO_2/day, which were central to the design phase. Following a rigorous assessment of the existing sanitation infrastructure, constructed wetland (CWs) emerged as the most appropriate ecological solution. This system, valued for its ability to effectively remove contaminants, was tailored to the specific needs of the site. Consequently, the final design of the filter extends over 217.16 m^2, divided into two cells of 108.58 m^2 each, with dimensions of 12.77 m in length and 8.5 m in width. The depth of the filtering medium is approximately 0.60 m, meeting the standards while ensuring maximized purification. Typha, an indigenous and prolific plant known for its purification abilities, was selected as the filtering agent. Concurrently, non-crushed gravel was chosen for its proven filtration capacity. This study is the result of a combination of scientific rigor and design expertise. It provides a holistic view of sanitation for Ndiebene Gandiol. The technical specifications and dimensions of the constructed wetland filter embody an approach that marries in-depth analysis and practical application, all aimed at delivering an effective and long-lasting solution to the local sanitation challenges. By integrating precise scientific data with sanitation design expertise, this study delivers a holistic solution for Ndiebene Gandiol. The detailed dimensions and specifications of the constructed wetland filter reflect a methodology that combines meticulous analysis with practical adaptation, aiming to provide an effective and sustainable response to the challenges of rural and school sanitation in the northern region of Senegal.

Keywords

Water Review, Hydraulic Engineering, Water Treatment, Agricultural Irrigation, Sanitation, Engineering, Environment

1. Introduction

Senegal's latest sanitation policy (2016-2025) explicitly aims to contribute to the achievement of the Sustainable Development Goals (SDGs) to ensure universal access to safe drinking water and sanitation by 2030 while guaranteeing integrated water resource management. The policy emphasizes the key elements of SDG 6, namely: 1) household access to sustainable sanitation, 2) wastewater and stormwater management, and 3) the eradication of open defecation. When this ambition is measured against the reality on the ground, a significant gap is apparent. According to data available up to 2021, about 56% of the Senegalese population had access to improved sanitation services, such as toilets connected to a sewage system. This indicates that a large portion of the population still lacks access to adequate sanitation facilities. Sanitation networks, such as sewers, are still limited in many regions of the country, particularly in rural areas. The majority of sanitation systems are concentrated in urban areas, especially in the capital, Dakar. Wastewater treatment is still inadequate in Senegal. Most of the existing wastewater treatment facilities are located in large cities, while rural areas are largely lacking. This results in pollution of water bodies and aquifers by untreated wastewater. The Senegalese government has taken measures to improve sanitation and wastewater treatment. It launched the Millennium Sanitation Program (PAM) in 2009, aiming to extend access to sanitation across the country. Additionally, the National Sanitation Plan (PNA) has been established to improve wastewater management and develop sanitation infrastructure. Senegal also benefits from the support of international bodies, such as the World Bank, the African Development Bank, and NGOs, which collaborate with the government to strengthen capacities in the sanitation sector. Like many countries, Senegal has committed to achieving the Sustainable Development Goals (SDGs) set by the United Nations General Assembly in 2015 [1] These commitments cover various aspects related to water and sanitation. Despite ongoing efforts and national and international initiatives, challenges in sanitation, especially in rural areas, persist [2]. Effective wastewater management is vital for environmental protection and public health [3]. Wastewater treatment in Africa, particularly in Sub-Saharan Africa, remains underdeveloped [4] with notable disparities between North Africa and Sub-Saharan countries [5]. 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 [6]. 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 [6]. 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 [7]. 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 [8]. 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% [8]. 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 [9]. 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? Our study explores this question, seeking to identify gaps and opportunities for improvement. It also aims to make recommendations, focusing on sustainable solutions tailored to local needs, with a particular interest in school wastewater. The main stages of our study are:

- Conducting a field survey to understand the site's specifics.
- Analyzing wastewater samples in the laboratory to determine pollutant load.
- Evaluating existing sanitation infrastructures and identifying relevant ecological treatment methods.
- Designing and calibrating an ecological treatment system that meets the identified needs.

The structure of this article is as follows: Section 2 details our methodology, Section 3 presents our results, Section 4 discusses their implications, and Section 5 concludes by suggesting future recommendations.

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 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.

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 [11], 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 [12]. 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

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
Teaching staff	8
Latrines for students	4
Latrines for teachers	1
Functional latrines	0
Sanitation system	Improper
Water points (faucets)	Non-existent
Condition of the toilets	Degraded, clogged, unused

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 [13] 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 [14].
- Spreading and numbering of bottles: Numbering the bottles allows for precise tracking of each sample, thus ensuring data traceability [15].
- 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 [16].
- Immersion of a container inside the pits: Immersion must be performed at a specific depth to minimize sedimentation effects [17].
- 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 [18].
- Placing bottles in a thermostat containing ice packs: Maintaining the temperature at 4 degrees Celsius is important for preserving sample stability [19].
- Tests were conducted within the following 24 hours. This practice is in accordance with recommendations of [15] [18] to ensure data validity.

- Sending the samples to Dakar for analysis: Analyzing the samples by an external laboratory, [19] 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 [20] [21].

- 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 [20] [21].

- SS (mg/l): Suspended Solids (SS) refer to solid particles that are not dissolved in water [22].

- 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 [23].

- TKN (mg/l): Total Kjeldahl Nitrogen (TKN) represents the combined concentration of organic nitrogen, ammonia, and ammonium [24].

- Phosphates (mg PO_4^{3-}/l): Phosphates, often derived from detergents, fertilizers, and natural decomposition processes, are a primary source of nutrients [25].

- 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 [26].

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.

2.3. Sizing Parameters

According to [27], the Population Equivalent (PE) is a standardized unit used to compare the pollutant load produced by various users in an area (residents, workers, students, etc.) to that of a typical inhabitant. This unit is frequently used to size sanitation facilities. To determine the Population Equivalent for our study site, it is crucial to quantify the pollutant load generated by the students and staff, in relation to the activities on site. However, for an accurate assessment, detailed information on waste generation, water consumption, and other factors is required. In the absence of this information, we can still establish an estimate based on certain criteria stated in **Table 1**.

2.4. Pollutant Load References

When considering an ecological wastewater treatment, such as CWs, it is essential to have references 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 being considered. However, here are some general and recommended values for various parameters, widely recognized in the sanitation field (cf **Table 2**) according to [28]. It is important to note that these values are general and may vary based on local regulations, environmental context, and other factors. Furthermore, several organizations and publications provide guidelines on this matter, such as the World Health Organization (WHO) [29], the United States Environmental Protection Agency (EPA) [15], or European standards [30]. For specific applications, it is recommended to consult local regulations and the recommendations of experts in the field.

3. Results

3.1. Wastewater Quality

Following observations and site visits at the Ndiebene Gandiol 1 school, wastewater samples were collected for in-depth analysis. The results of these analyses are presented in **Table 3**. For biological oxygen demand (BOD5), the values obtained were 439 mg/l for the first sample and 293 mg/l for the second, with an overall average of 366 mg/l. Regarding chemical oxygen demand (COD), the first sample had a concentration of 1070 mgO_2/l, while the second showed 1480 mgO_2/l, for an average of 1275 mgO_2/l. For Suspended Solids (SS), the concentrations were 254 mg/l and 162 mg/l for samples 1 and 2 respectively, 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. In terms of Total Kjeldahl Nitrogen (TKN), the concentrations observed were 486.2 mg/l and 390.3 mg/l for samples 1 and 2 respectively, giving an average of 438.25 mg/l. Phosphates showed a concentration of 344 mg PO_4^{3-}/l in the first sample and 420 mg PO_4^{3-}/l in the second, for an average of 382 mg PO_4^{3-}/l. Finally, regarding Fecal Coliforms, the first sample recorded a high concentration of 1.03E+06 CFU/100 ml, while the second reached an even more concerning level of 4.00E+07 CFU/100 ml. The average for this parameter for the two samples was 2.05E+07 CFU/100 ml. These results come directly from the analyses performed at [31] and are essential for understanding the wastewater quality within the Ndiebene Gandiol 1 school.

Table 2. Target values for effective treatment or acceptable discharge.

Parameter	Description	Target Value
BOD5	Indicator of the amount of organic matter in the water.	<25 mg/l
COD	Total amount of oxygen required to oxidize all organic matter.	<125 mg/l
SS	Can obstruct the treatment system and affect its efficiency.	<35 mg/l
Nitrates	High concentrations can cause eutrophication of water bodies.	<50 mg/l
Total Kjeldahl Nitrogen (TKN)	Sum of organic nitrogen, ammonia, and ammonium.	<30 mg/l
Phosphates	Can contribute to eutrophication, similar to nitrates.	<2 mg/l
Fecal coliforms	To prevent health risks.	<1000 CFU/100ml

Table 3. Wastewater analysis results for the school

Parameter	Sample 1	Sample 2	Average
BOD5 (mgO_2/l)	439	293	366
COD (mgO_2/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	2.05E+07

3.2. Sizing Parameters

Based on the data from **Table 1**, the school has 505 students. It can be assumed that a student produces a pollutant load less than that of an adult (let's say 50% of an adult's load). If one adult corresponds to 1 PE (Population Equivalent), then a student would be rated at 0.5 PE. The fact that all the latrines are out of service, combined with the dilapidated state of the toilets, means that the wastewater is not receiving proper treatment. While this does not directly influence the calculation of the PE, it highlights the inadequacy of current infrastructure in relation to the defined number of PEs. The lack of a water point suggests restricted water consumption or supply from other sources. This could reduce the volume of wastewater produced, but it is difficult to assess its impact on the PE without additional data. Assuming one teacher per class, which makes 8 teachers, and considering that a teacher generates a pollutant load equivalent to that of an adult, each teacher would be accounted for 1 PE.

4. Discussion

4.1. Wastewater Quality

The wastewater analysis of Ndiebene Gandiol school, as presented in **Table 3**, highlights several major challenges that need to be addressed. An average BOD5 of 366 mg/l, which is relatively high, indicates a significant amount of biodegradable organic matter, typically associated with the presence of organic contaminants. This is corroborated by an average COD of 1275 mgO/l, signaling a considerable presence of organic matter. Even more alarming is the high concentration of fecal coliforms, averaging 2.05E+7 (CFU/100 ml), indicative of major bacterial contamination posing a serious public health risk. These analyses, conducted by [31], attest to the credibility of the results. The range of parameters analyzed provides a comprehensive view of the water quality situation. Several, especially the high concentration of fecal coliforms, alert to the severity of contamination. These data, combined with the school's deficient sanitary infrastructure, are even more concerning. These findings, placed within the broader context of school sanitation and public health issues, underscore the urgent need for targeted sanitation interventions. Indeed, students and teachers are exposed to considerable health risks, potentially impacting not only their health but also their attendance and academic success. Faced with such a situation, immediate measures are imperative to enhance water quality within Ndiebene Gandiol school, namely:

- Establishing an effective wastewater treatment system.
- Organizing hygiene-focused educational sessions for students and staff.
- Implementing modern sanitary infrastructure that meets current standards.
- Strengthening collaboration with local authorities and specialized entities for regular monitoring and appropriate maintenance.

In summary, the data collected highlight the urgency of undertaking corrective measures to improve water quality in this institution. It is essential to take vigorous steps to ensure a healthy study environment conducive to students' well-being. The interpretation of the data collected on Ndiebene Gandiol 1 school reveals crucial aspects to consider for a thorough analysis. The limited number of samples could influence the representativeness of the results. Diversifying samples over a longer period would be ideal to gain a more comprehensive overview of potential variations in water quality. Not taking the topography into account could distort the understanding of pollutant spread. Integrating this dimension could refine the recommendations. The absence of analysis of climatic variations may affect the relevance of treatment methods, given local seasonal fluctuations. However, the study offers a complete perspective on water quality thanks to the diversity of analyzed indicators. The results, from [31], are highly credible. The emphasis on health indicators, such as fecal coliforms, underscores the health issues associated with wastewater.

4.2. Feasible Ecological Treatment Technology

The combined analysis of the information contained in **Table 1** and the pollutant load of the wastewater classifies the study site 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 [27]. When we look at intensive (or conventional) wastewater treatment sectors, such as activated sludge, trickling filters, rotating biological contactors, and high-performance lagoons, their respective disadvantages (significant energy consumption, significant sludge production requiring proper management, regular monitoring and management required, larger installation space than for activated sludge, sensitivity to toxic shocks, need for mechanical equipment, risk of clogging, among others) make them less suitable. Wastewater treatment through extensive systems, whose advantages and disadvantages are presented in **Table 4**, mainly refers to systems that require little or no energy and largely rely on natural processes. These appear more suitable for the site in question. According to the analyses performed on the school's wastewater, BOD5, COD, and fecal coliforms are particularly high. CWs and natural lagoons emerge as the most suitable solutions for effectively treating these high concentrations. Taking into account the site constraints, available resources, and community preferences, the choice falls on constructed wetlands with reeds as recommended by the work of [32] in relation to the hot and dry climate of the area.

4.3. Design and Sizing of the Filter

According to [33] [34] [35], the process of sizing a planted filter, also known as a constructed wetland, for wastewater treatment is inherently complex and requires careful consideration of various critical factors. A primary element is the incoming hydraulic flow, defined by the amount of water that needs to be treated daily, which determines the required surface area of the CW from the hydraulic point of view. The organic load, that is, the level and nature of the contaminants present, directly influences the required level of treatment and determines the size and depth of the filter. The choice of vegetation is also strategic: although different plants have varying abilities to assimilate pollutants, reeds (Phragmites australis) are commonly used. The composition and granularity of the filtering media, whether sand or gravel, affect the water retention time and the efficiency of the treatment. CWs can have a horizontal or vertical flow configuration, each with its advantages and disadvantages. Climatic conditions, such as temperature or precipitation patterns, can impact the performance of the filter. It is also essential to define the maintenance frequency to ensure optimal system efficiency, as well as the duration the water is retained within the filter is critical for its effectiveness.

4.3.1. Incoming Hydraulic Flow

Based on international standards, water needs can vary depending on activities and regions. However, according to a simplified estimate from the World Health Organization (WHO), the water needs for essential domestic activities (such as drinking, cooking, and personal hygiene) amount to about 20 to 50 liters per person per day. In the context of a school where students neither cook nor sleep, this consumption would likely be at the lower end of this range. According to

Table 4. Advantages and disadvantages of extensive treatment systems.

Extensive Systems	Advantages	Disadvantages
Natural Lagoons	Low operational cost and little maintenance. Suitable for high pollutant loads. Good 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. Habitat for biodiversity. Low operational and maintenance costs.	Requires significant area. Less effective for high coliform loads. Sensitive to seasonal variations.
Vertical flow constructed wetlands	Effective in treating organic pollutants and nutrients. Low maintenance. Aesthetically pleasing.	Requires certain area. May require pretreatment for very high loads.
Infiltration Wells	Good for BOD5 reduction and solids filtration. Recharges groundwater.	Less effective for nutrients and pathogens. Risk of groundwater contamination.
Biological rotating contactors	Effective for reducing BOD5 and suspended solids. Compact footprint.	Requires mechanical equipment. Less effective for nutrient treatment.

studies established by the [8], consumption (drink, hygiene and sanitation) is estimated at approximately 17.5 liters per student /d. However, it is important to take into account additional water needs, such as cleaning classrooms and toilets. Considering an average consumption of 21 liters per student each day (assuming that they are only present for a fraction of the day at school), the estimated incoming hydraulic flow for the Ndiebene Gandiol school would be approximately of 10.773 m^3 per day Equation (1). Only a part of this total flow will become wastewater, so a conversion factor should be used. It is advisable to estimate this factor based on local information and studies. However, when they cannot be carried out, which is this case, it is advisable to assume values between 0.80 to 0.85 (OPS, 2005). I our case, we take 0.833 as this factor, so the total average flow to the wastewater treatment plant is 8.97 m^3/d Equation (2):

$$(505\ \text{students} + 8\ \text{teachers}) \times 21 \frac{\text{L}}{\text{student} \cdot \text{d}} \times \frac{1\ \text{m}^3}{1000\ \text{L}} = 10.773\ \text{m}^3/\text{d} \tag{1}$$

$$10.773\ \text{m}^3/\text{d} \times 0.833 = 8.97\ \text{m}^3/\text{d} \tag{2}$$

[8] Nonetheless, it is important to consider additional water needs, such as cleaning classrooms and sanitary facilities. Considering an average consumption of 20 liters per student per day (assuming they are present only for a fraction of the day at school), the estimated incoming hydraulic flow for Ndiebene Gandiol school would be approximately 10.1 m^3 per day.

4.3.2. Organic Load

The organic load to be treated generally depends on the concentrations of contaminants in the wastewater and the total volume of this water produced. Table

3 provides concentrations of various parameters, which can be used to estimate the organic load. However, to estimate the total volume of wastewater generated, we must make some assumptions based on **Table 1**. As we previously estimated, the incoming hydraulic flow for Ndiebene Gandiol school would be about 10.1 m^3/day. Suppose the entirety of this volume converts into wastewater, although this may be an overestimation since not all consumed water necessarily becomes wastewater. The organic load can be determined using the BOD5 and COD parameters. These represent the biochemical and chemical oxygen demand, indicators commonly used to quantify organic matter in water. The estimation method involves multiplying their respective average concentrations by the hydraulic flow of wastewater. Following this methodology, the organic load in BOD5 is estimated at 3.2574 kgO_2/day and that in COD at 11.4417 kgO_2/day for the school. Assuming that the wastewater treatment plant has a septic tank as primary treatment, and this kind of process removes 1/3 of the organic load, BOD and COD loads to the CW will be 2/3 of these values (2.1716 kgO_2/d of BOD and 7.6278 kgO_2/d of COD). It should be emphasized that these assessments are based on assumptions and averages of the data provided. In practice, daily variations may occur. Therefore, it is advisable to take regular measurements to arrive at a more accurate estimate.

4.3.3. Types of Plants and Filtering Media

Different plants have varying abilities to assimilate pollutants. Generally, reeds (Phragmites australis) are commonly used, but other plants may also be suitable. The work of [32] suggests that uncrushed gravel and Typha sp. can offer better results. Given that these two elements are local, they should be preferred as filtering media and plants.

4.3.4. Surface Area and Thickness of Filtering Media

The thickness of the filtering media in a reed-planted filter is a crucial component of the design and is closely linked to the organic load to be treated. Depending on the sources consulted, the specifications for sizing CWs may vary. According to [36], the substrate thickness for a vertical flow planted filter generally ranges from 0.5 to 1 m. These authors specify that the organic load plays a predominant role in determining this thickness, as well as in the choice of the type of filtering media and its granularity. The work of [10] suggests that the permissible organic load for a vertical flow planted filter varies between 50 and 150 g of BOD5/m^2/day, depending on climatic conditions, type of vegetation, and type of wastewater treated. The publication of [37] also supports the idea that the thickness of the filtering media and the surface area of the filter must be adapted to the organic load, taking into account other parameters such as the granularity of the media and the treatment objectives. According to the studies of [10] [35] [38], the thickness of the filtering media in a horizontal flow filter is generally determined based on the organic load and the hydraulic flow. The thickness can vary according to the specific design, the type of filtering media used, and local treatment requirements. For horizontal flow CWs, surface loads based on BOD5 and COD are usually suggested. Recommendations vary, but commonly, we consider values between 5 and 30 g/m^2 per day for BOD_5 and between 50 and 200 g/m^2 per day for COD [27]. Based on an average estimate for BOD_5 of 10 g/m^2 per day (Wallace & Knight), and considering the given BOD_5 load of 2.1716 kg/day, we deduce an approximate area of 217 m^2 Equation (3). Likewise, for COD, with an average estimate of 50 g/m^2 per day and a load of 7.6278 kgO/day, we obtain a surface area of approximately 152.5 m^2 Equation (4). The final surface area of the filter would then be based on the larger of the two estimates, *i.e.*, 217 m^2 based on the BOD5.

$$A = \frac{2171.6 \text{ g BOD}_5/\text{d}}{10 \text{ g BOD}_5/\text{m}^2 \cdot \text{d}} = 217.16 \text{ m}^2 \tag{3}$$

$$A = \frac{7627.8 \text{ g COD}/\text{d}}{50 \text{ g COD}/\text{m}^2 \cdot \text{d}} = 152.5 \text{ m}^2 \tag{4}$$

Regarding the thickness of the filter media, it is usually between 0.3 and 1.2 m for a horizontal flow CW. A choice of around 0.6 m would be a reasonable intermediate estimate, with 0.55 m of water level. Finally, to facilitate implementation and consider the physical reality of the field, the proposed filter is composed of two cells with a total surface area of 221 m^2, two cells of 110.5 m^2, 13 m long and 8.5 m wide each. These dimensions result in 232.25 $gBOD_5/m^2 \cdot d$ Equation (5) of organic loading rate (OLR) in the cross-sectional area.

$$\text{OLR}_{\text{BOD}} = \frac{2171.6 \text{ g BOD}_5/\text{d}}{2 \text{ cells} \cdot 8.5 \text{ m} \cdot 0.55 \text{ m water level}} = 232.25 \text{ g BOD}_5/\text{m}^2 \cdot \text{d} \tag{5}$$

4.3.5. Filter Configuration

The configuration of the horizontal flow planted filter is presented in **Figure 1**. A 3D representation is provided in **Figure 2**. The filter is composed of two filter bed cells, preceded by a septic tank. A reservoir collects the treated water. The dimensions and depth of the filter are presented in **Figure 3**.

4.4. The Cost of This Proposed Approach to Wastewater Management

The overall project encompasses various components, ranging from the construction of toilet blocks to the refurbishment of classrooms, the rehabilitation of ancillary structures, the construction of a perimeter wall, and finally, the implementation of a horizontal flow reed bed filter. However, our focus is specifically on the financial monitoring related to the construction of the reed bed filter. The financial summary of the project, breakdown in West African CFA franc (FCFA), is as follows: Initial site setup costs are 100,000, while terrain preparation and excavation work come to a subtotal of 253,000. Concrete and masonry work, including reinforced concrete and block masonry, total 1,031,600. Materials for transition layers and filtration in wet zones cost 343,000. Waterproofing, including preparation and hydraulic testing, comes to 350,075. Plant installation,

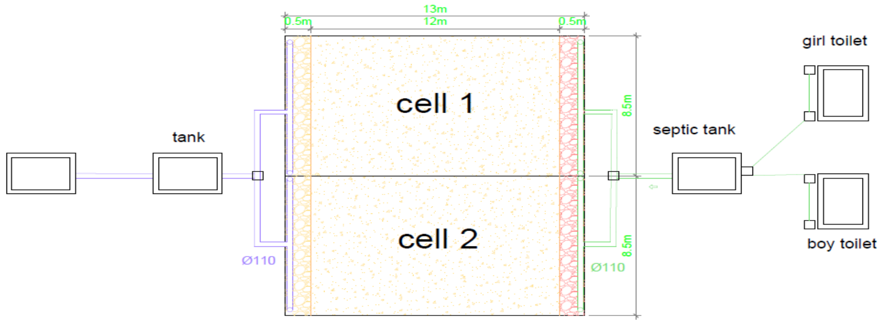

Figure 1. Configuration of the horizontal flow constructed wetland.

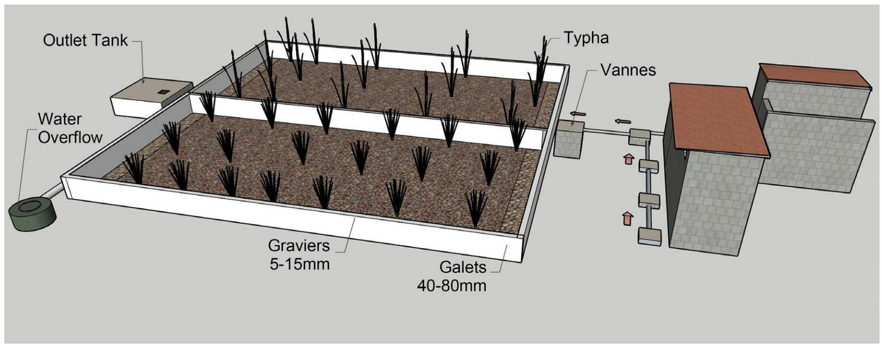

Figure 2. 3D plan of the filter.

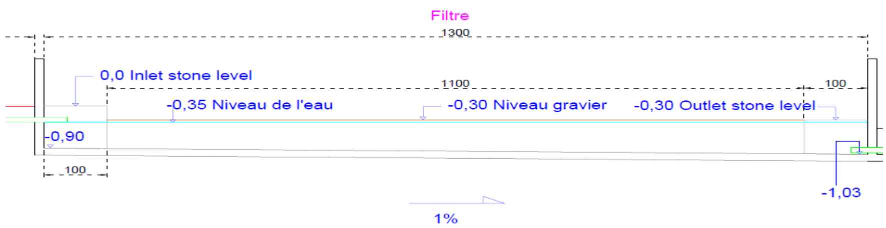

Figure 3. Dimensions and depth of the filter.

specifically Typha, adds 20,000. Sanitary plumbing reaches 188,000. Inspection chambers and connections cost 367,100. The total before tax is 2,652,775, with an 18% VAT of 477,500, leading to a grand total of 3,130,275. Converted to United States dollars (USD), using an approximate exchange rate of 608 FCFA to 1 USD, the amount is approximately $5148.48. Please note that exchange rates fluctuate constantly, so it is advisable to check the current rate for the most accurate conversion.

5. Conclusion

At the conclusion of this article, the significance of an integrated and methodical approach to wastewater management is highlighted. The comprehensive study of the Ndiebene Gandiol site not only provided an understanding of local specificities but also facilitated the adaptation of an optimal treatment solution to this particular context. The first operational objective, which involved conducting a field survey, was crucial for understanding the realities and constraints of the site. This approach gave us a clear perspective on the challenges and strengths of the site, allowing for effective guidance in subsequent stages. The laboratory analysis of the wastewater samples was pivotal. By determining the pollutant load, we were able to quantify the environmental and health threats posed by untreated wastewater. This phase also guided us towards the best treatment strategies, considering the composition of the wastewater. The assessment of existing sanitation infrastructure revealed opportunities for improvement, while research into ecological treatment methods directed our choice towards a sustainable and environmentally friendly solution. Finally, the design and calibration of an ecological treatment system, based on the CWs, were detailed. This system, tailored to the identified needs, represents a promising solution for Ndiebene Gandiol, offering an approach that meets the sanitation challenges while favoring an ecological perspective. This work underscores the importance of a holistic approach, where each step, from field reconnaissance to technical design, contributes to developing a suitable, efficient, and sustainable solution for wastewater treatment. It is hoped that this study will serve as a model for other regions facing similar sanitation challenges.

Conflicts of Interest

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

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