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# Assessment of Risks Associated with Hospital Effluent from Kara University Hospital (Kara U.H.) in Togo

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**Abstract:** The Kara University Hospital generates an average of 17133.1 $m^3$ of wastewater per year. These hospital effluents contain specific substances likely to disseminate pathogenic germs. The objective of the study is to assess the risks associated with the poor management of hospital effluents from the Kara University Hospital. The study involved the characterization of the effluents. The results obtained show that in addition to the temperature and the hydrogen potential (pH), the values of the other physico-chemical parameters in particular, suspended solids (SS) (58.07 mg/L) and nitrates (84.79 mg/L) exceed the discharge standards of World Health Organization (WHO). The values of the microbiological parameters sought, in particular total coliforms (1.106 CFU/100 mL), thermotolerant coliforms (4.105 CFU/100 mL), sulphite-reducing anaerobes (3.6103 CFU/100 mL) and faecal streptococci (5.103 CFU/100 mL) exceed the discharge standards accepted by the WHO. Exposed individuals were identified through an exposure level assessment matrix. The analysis shows that at the production stage, healthcare personnel are the most exposed with a critical rate of 64% (16/25); at the evacuation stage, the workers in charge of evacuation show a moderate exposure level of 48% (12/25). After disposal in nature, populations living near landfill areas are the most exposed with a rate of 48% (12/25). After disposal in nature, populations living near landfill areas are the most exposed with a rate of 48% (12/25). The wearing of personal protective equipment by staff and the establishment of a treatment plant will reduce the risks and ensure sustainable management of effluents from the Kara University Hospital.

**Keywords:** Hospital effluents; Environment; Health risks; Management; Assessment

## 1 Introduction

Hospital establishments generate large volumes of liquid effluents which contain specific substances (drug residues, chemical reagents, disinfectants, detergents, radiographic developers and fixers) are likely to disseminate pathogenic germs [1, 2]. The World Health Organization (WHO) estimates water consumption at 40 to 400 liters per bed per day with a discharge rate of around 80% [3]. In this context, the problem of hospital effluent discharge is becoming increasingly important. These effluents are generally evacuated without prior treatment, in the same way as conventional domestic wastewater. The management of hospital effluent has become a critical issue as it poses potential health risks and environmental damage attracting considerable international interest. Thus, indiscriminate and unscientific management of biomedical waste poses serious threats to the environment and human health.

The effective management of hospital effluents must be a preoccupation of hospital administrations and all stakeholders. This will minimize risks for the environment and public health [3–5].

The complex composition of these effluents, including pathogens, pharmaceutical residues, disinfectants, heavy metals, and sometimes radioactive elements, makes them a significant public health and global environmental safety issue.

When hospital effluents are not properly handled, they can cause significant contamination of water resources, affecting quality of life and raising health risks for surrounding populations, especially in low- and middle-income countries where hospital waste management systems are often deficient or non-existent [6, 7]. In recent years, research on hospital effluents has increasingly focused on emerging contaminants, particularly antibiotic resistance genes (ARGs), pharmaceutical residues, and microplastics, which pose significant environmental and health concerns. Studies such as [8, 9] have demonstrated that untreated effluents can act as reservoirs and dissemination routes for resistant bacteria and residual pharmaceuticals in aquatic environments across Africa. Integrating these emerging pollutants into the hospital wastewater monitoring framework would strengthen the understanding of multi-contaminant risks.

Public health and environmental pollution issues linked to hospital effluents have been exacerbated in recent years with the increase in hospital effluent in quantity and complexity, linked to the increase in production sources such as public and military hospitals, semi-public and private clinics, clinical and epidemiological laboratories; veterinary centers, etc., the strengthening of technical platforms and the advent of emerging and re-emerging diseases (Covid-19, viral hemorrhagic fevers, etc.). Indeed, hospital liquid effluents may contain dangerous chemical substances, pathogens and radioisotopes which may constitute a chemical, biological and physical risk for public health and the environment [10, 11].

The various problems resulting from liquid discharges from health services without any appropriate prior treatment raise questions about the chemical, biological characteristics and the future of hospital pollutants in the environment as well as the need to develop tools for sustainable waste management from these establishments.

In Togo, as in many developing countries, liquid effluents do not undergo any treatment before being discharged into nature with all the negative impacts that these raw effluents have on the environment and on human health.

The producing structures do not take full responsibility for the ecological and safe elimination of waste from their structures as an integral step in the process of providing quality care. Indeed, despite international conventions relating to hazardous waste (Basel Convention, Stockholm Convention, Rotterdam Convention) and especially national regulatory provisions in particular Law No. 2009-007 establishing the Public Health Code of the Togolese Republic and Law No. 2008-005 of May 30, 2008 relating to the framework law on the environment, sanitary structures continue to reject wastewater without prior treatment.

Hospital effluents need to be managed more carefully and quickly to avoid many public health risks associated with poor practices, including exposure to infectious agents and toxic substances [1, 12]. Their processing is necessary in order to protect the environment and human health.

The objective of the study is to assess the risks associated with the management of hospital effluents from the Kara University Hospital.

The microbiological parameters sought are total coliforms, thermotolerant coliforms, sulphite-reducing anaerobes and fecal streptococci. The chemical parameters sought are temperature, conductivity, hydrogen potential (pH), suspended solids (SS) and nitrates.

## 2 Materials and Methods

### 2.1 Study Framework

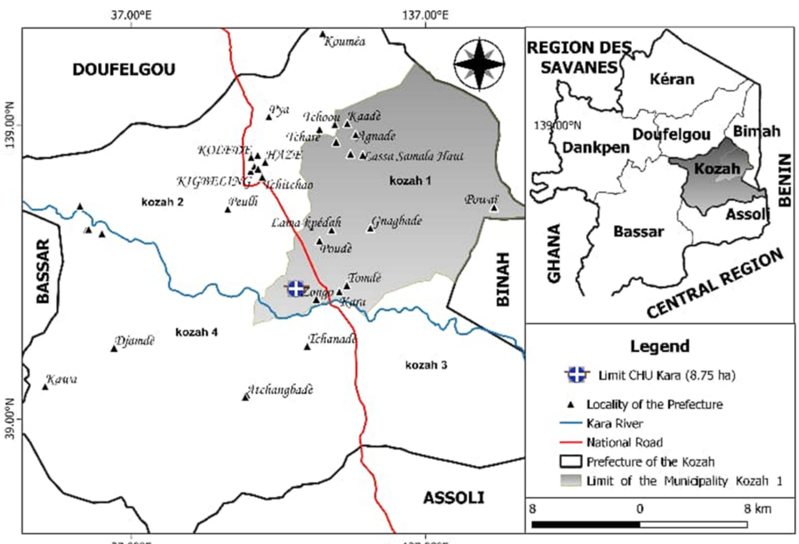


**Figure 1.** Map of the commune Kozah 1 showing the location of Kara University Hospital

The study was performed at the Kara University Hospital located in the commune of Kozah 1, Kozah prefecture, Kara region. Built in the 1970s, Kara University Hospital has a capacity ranging from 210–239 beds. It is called upon to serve the entire population of Togo in general and in particular that of the three northern regions of Togo whose population is estimated at more than 2.924.561 inhabitants according to the fifth General Population and Housing Census (RGPH-5) in 2022.

In terms of hospital wastewater management, Kara University Hospital uses a non-separative autonomous system which consists of storing wastewater in septic tanks and drainage pits. The pits receive water from the toilets, and the sumps receive specifically hospital effluent. The emptying frequency is not defined. It is carried out according to the filling frequency according to the analysis of the oil change book. The maternity septic tanks are those which are most frequently emptied. Wastewater is drained by trucks from the Kozah 1 commune town hall (Figure 1) as part of a partnership. The septic tanks and cesspools are functional and well-sealed with PVC pipes and concrete collectors with a diameter of 200 mm. The flow of effluent in the pipes is monitored using manholes. The minimum interior section of a manhole is 80×80 cm; the reinforced concrete pad, placed in the rebate, is visible for certain views and buried for others.

Figure 2 shows a google map with the location of Kara University Hospital.

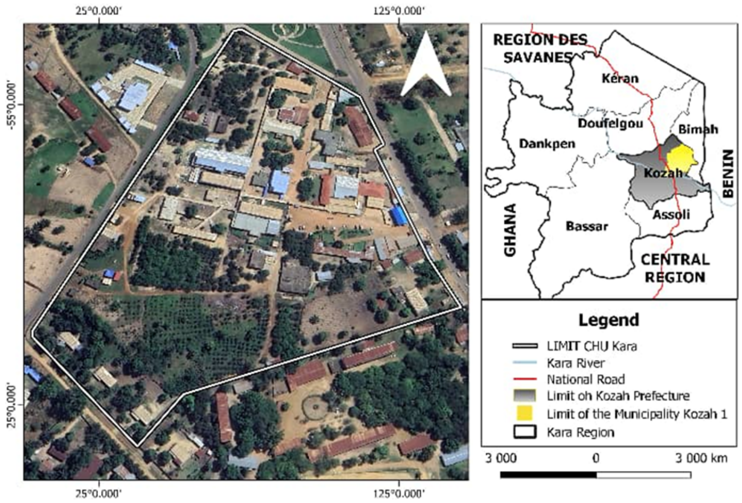


**Figure 2.** Map of the delimitation of Kara University Hospital

## 2.2 Ecological Context of Kara

The Kara region, located in northern Togo, has a generally hilly terrain with altitudes ranging from approximately 200 to 400 metres above sea level. The landscape consists of chains of hills (notably Séméré, Farendè, Boua Falé and Lassa), gently rolling plateaus and peneplains with moderate slopes of between 2 and 5%. This topographical configuration is conducive to both agricultural activities and human settlement, although some areas remain vulnerable to seasonal water erosion. In terms of soil, the dominant types belong to the tropical ferruginous, ferralitic, and poorly developed units. They have a sandy-clay to clay-sandy texture, average fertility, and are widely used for both food and cash crops such as millet, sorghum, and yams. The local agrarian system is based mainly on rain-fed agriculture, fallow land and slash-and-burn farming, combined with extensive livestock farming during the dry season.

From a hydrological perspective, the region belongs to the Volta River basin and is drained by several major rivers, including the Oti, Koumongou, Kéran, Kara, Mô and Binah. These rivers, several of which remain perennial during the dry season, are essential resources for domestic and pastoral supply, but remain exposed to diffuse pollution from domestic waste and the use of agricultural inputs. Groundwater resources come from a fractured crystalline bedrock forming discontinuous aquifers located in areas of fissures and joints. The aquifers are generally found at depths of between 30 and 70 metres, with an average drilling depth of around 160 metres. All of these soil, hydrological and topographical characteristics make the Kara region both productive and ecologically fragile, requiring integrated management to prevent soil degradation and protect the quality of water resources [13–15].

The Kara University Hospital is located in an area that is slightly elevated above the city, but not directly bordered by a watercourse. This geographical position limits the immediate risks of direct effluent discharge into neighbouring rivers, but does not eliminate them entirely. In fact, the areas where sludge from the university hospital's sanitation systems is spread and dumped are often located in rural outlying areas, sometimes in topographically depressed areas. These areas are prone to temporary stagnation of runoff water, particularly during the rainy season, thus promoting the infiltration of organic, chemical and microbiological contaminants into the surface soil and potentially into the groundwater.

## 2.3 Sample Collection and Conditioning

The analyzes focused on hospital effluent. These effluents were taken from the sumps of six (06) departments including maternity, medicine, surgery, emergency, pediatrics and the laboratory. The samples were taken in these departments because 94% of the effluent from Kara University Hospital comes from these departments. The samples were taken from the sumps to obtain effluents with characteristics closest to specifically hospital effluents (Figure 3).

**Figure 3.** Exterior of a pit showing the evacuation pipe for specifically hospital effluents

Instant manual sampling method was used for sample collection. The samples were collected in plastic bottles sterilized by heat autoclave at 120 °C for 1 hour (Figure 4 and Figure 5).


**Figure 4.** Opening a pit


**Figure 5.** Sampling of effluents

The samples were carefully labeled and stored at 4 °C. The wastewater samples analyzed were taken from the Kara University Hospital. sumps in sterile 500 mL bottles. The bottles, once filled, were labeled and placed in a cooler equipped with cold accumulators before being transported to the LAMICODA-ESTBA/University of Lomé laboratory. Bacteriological analyzes were carried out the same day.

### 2.4 Microbiological Analyzes

The research focused on certain indicators of the presence of pathogenic germs. The germs sought are those retained by the EU 2007 criteria. Table 1 presents the germs sought and the methods used.

**Table 1.** Germs research and analysis methods

| No. | Germs Wanted | Methods | Culture Zone | Cultivation Conditions |
|---|---|---|---|---|
| 1 | Total coliforms | NF V08-050, December 1992 | VRBL | 30 °C, 24 hours |
| 2 | Thermotolerant coliforms | NF V08-016, December 1992 | VRBL | 44 °C, 24 hours |
| 3 | Sulphite-reducing anaerobes | XP V08-061, October 1996 | TSN | 44 °C, 24 to 48 hours |
| 4 | Fecal streptococci | NF T90-416, October 1985 | Slanetz and Bartley | 37 °C, 24 to 48 hours |

### 2.5 Physic–Chemical Analyzes

The temperature and conductivity were measured in situ using the pH meter from the HANNA/HI/99300 multi-parameter kit. Meanwhile, the pH was determined in the laboratory using an electronic pH meter of the HANNA pH 210 brand. Furthermore, the suspended matter concentration was calculated by taking the ratio between the difference in masses and the filtered volume of the sample. Finally, the determination of nitrate ions ($NO_3^-$) was carried out by diazotization of sulfanilamide by nitrite ions ($NO_2^-$) in an acidic medium and in the presence of N-1 naphthyl ethylene diamine. This reaction resulted in a coupling process that led to the formation of a purple-colored complex, allowing for a colorimetric analysis, with the optical density readings taken at a wavelength of 543 nm.

### 2.6 Statistical Analysis of Data

Data processing was computerized. Data entry, clearance and processing, calculation of indicators, production of tables, graphs and standard error calculation were done with the Excel.

### 2.7 Health and Environmental Risk Assessment

The assessment of health and environmental risks was conducted using a semi-quantitative approach based on the WHO Environmental Health Risk Assessment framework. The criticality ($C$) of each hazard was determined according to the following relationship:

$$C = P \times G$$

where,

$P$: probability of occurrence or frequency of exposure to the hazard, and

$G$: the severity or magnitude of the potential consequences for human health or the environment.

Each parameter ($P$ and $G$) was scored on a scale from 1 to 5 (Table 2), with higher values indicating a greater likelihood or more severe consequence. The product of these two factors yields a criticality score ($C$) that reflects the level of risk associated with each exposure scenario. The resulting criticality was interpreted using the following classification.

**Table 2.** Indicative grid of criticalities

| Criticality Value ($C$) | Risk Level | Interpretation |
|---|---|---|
| 1–4 | Low | Acceptable: risk or controlled risk |
| 5–9 | Moderate | Requires monitoring and preventive actions |
| 10–15 | High | Significant risk requiring mitigation measures |
| 16–25 | Critical | Unacceptable risk: immediate intervention required |

The scoring of $P$ and $G$ was conducted through expert consultation involving hospital hygiene officers, sanitation technicians, and environmental health specialists, based on observed exposure frequencies, handling practices, and available protective measures. This method, widely used in risk management studies ISO 31000:2018 and WHO, 2017, provides a structured framework for prioritizing the most critical exposure situations even in the absence of quantitative microbiological data.

#### 2.7.1 Identification of groups of people exposed

The categories of exposed people were identified based on the stages of hospital effluent management and the actors who could be exposed. Table 3 presents the categories of people exposed by stages.

**Table 3.** Categories of persons exposed by steps

| Hospital Effluent Management Steps | Category of People Exposed |
|---|---|
| Production | Nursing staff<br>Patients and accompanying persons |
| Kara University Hospital sanitation network | Nursing staff<br>Patients and accompanying persons<br>Populations living near Kara University Hospital |
| Evacuation | Nursing staff<br>Patients and accompanying persons<br>Populations living near Kara University Hospital<br>Workers involved in the operation |
| Using hospital effluent for Field Amendment | Populations living near landfill areas<br>Peasants responsible for cultivating the fields |

Source: Study report on the environmental and health management of hospital waste and effluents at the Kara University Hospital in 2018.

#### 2.7.2 Frequency or probability of occurrence

This involves defining objective criteria in order to evaluate the frequency of exposure of each category of exposed person. The exposure assessment will also take into account the contributing factors or resilience factors of the exposed agents such as the wearing of personal protective equipment. Exposure will be assessed in relation to its frequency or probability of occurrence. The definition of probability categories is specified in Table 4.

**Table 4.** Definition of probability categories

| Probability Category | Ranking | Definition |
|---|---|---|
| Almost certain | 5 | Once a day |
| Likely | 4 | Once a week |
| Moderately likely | 3 | Once a month |
| Unlikely | 2 | Once a year |
| Rare | 1 | Every 5 years |

#### 2.7.3 Severity level

The severity level measures the extent of a risk on the target. The objective criteria for its evaluation are defined in Table 5.

**Table 5.** Definition of severity level

| Severity Level | Ranking | Definition |
|---|---|---|
| Catastrophic | 5 | Impact on public health |
| Major | 4 | Regulatory impact |
| Moderate | 3 | Aesthetic impact |
| Minor | 2 | Impact on adherence |
| Insignificant | 1 | Absence of impact or detectable impact |

#### 2.7.4 Risk characterization

The combination of identification data, hazard characterization and exposure assessment enable assess the risk through its criticality which will be the product of the severity and the probability of occurrence.

### 2.8 Study's Limitations

Sampling was carried out exclusively during the rainy season, which coincides with increased hydraulic flow and significant dilution of pollutants. This hydrological context tends to reduce the apparent concentrations of suspended solids and microbiological parameters compared to periods of low water flow. The results presented in this study therefore correspond to a high-dilution scenario, representative of the rainy period in the Kara region. Seasonal variations in pollutant concentration and microbiological load should be considered when interpreting the data, as lower dilution during dry periods may amplify the environmental and sanitary risks identified.

The lack of specific epidemiological data on infections associated with inadequate management of hospital effluents. Indeed, the linkage of epidemiological data on pathologies related to hospital effluents would strengthen the link between microbial load and the actual incidence of disease among hospital stakeholders.

Also preserving the transfer chain and risks for downstream users, the environmental traceability of pollutants from the discharge point to the receiving environment remains to be completed for a complete risk assessment.

## 3 Results and Discussion

### 3.1 Physicochemical Analyzes

#### 3.1.1 Temperature

The effluent temperature varied between 27.4 °C and 28.3 °C, with an average of 27.87 °C and a standard deviation of 0.31 °C. These values are more or less equal to those of FAGNIBO who noted in 2012 at the Hubert Koutoukou Maga National Hospital Center in Cotonou (Benin) temperatures between 28.9 °C and 29.32 °C. Figure 6 shows the temperatures obtained per service.

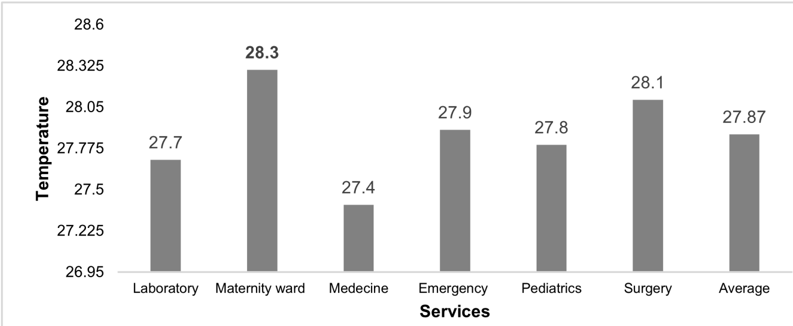


**Figure 6.** Temperature by service

The effluent discharge temperatures from Kara University Hospital comply with the discharge standards according to the WHO which sets the discharge temperatures of hospital effluents below 30 °C. Recent study by Ouédraogo et al. [1] shows that these values would be favorable to the maintenance of colonies of "mesophilic" microorganisms which thrive at a temperature between 20 °C and 40 °C.

#### 3.1.2 Conductivity

The electrical conductivity values range between 124 $\mu$S/cm and 187 $\mu$S/cm. The average value is 166.50 $\mu$S/cm with standard deviation of 22.46 $\mu$S/cm. These values are below those obtained by FAGNIBO who noted in 2012 [13] at the Hubert Koutoukou Maga National Hospital Center in Cotonou (Benin) with conductivities between 790 $\mu$S/cm and 891 $\mu$S/cm and SARHANE in 2014 [13] who noted an average value of 1500 $\mu$S/cm in the maternity ward of the Rabat Salé Zemmour Zaer regional hospital. Figure 7 presents the conductivity by service.

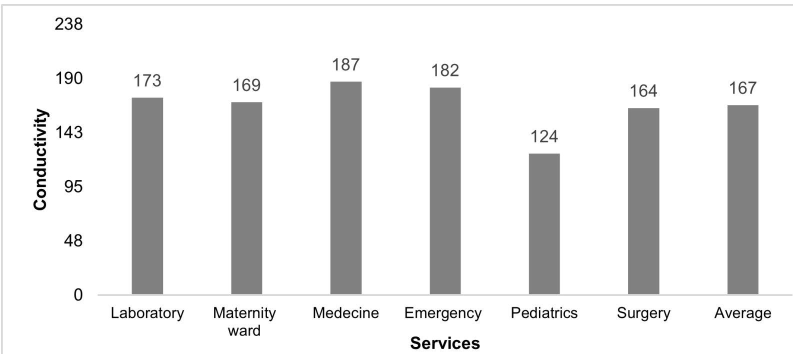


**Figure 7.** Conductivity by service

The low conductivities obtained during our study could partly be explained by the dilution phenomenon. Indeed, our study period coincided with the rainy season in Kara. According to study [1], during the rainy season, hospital effluents receive a large quantity of water resulting in a considerable dilution of the chemical elements present.

3.1.3 Hydrogen potential (pH)

Figure 8 shows a pH between 7.12 in maternity and 7.38 in medicine with a mean of 7.12 and a standard deviation of 0.1. This highlights the existence of a slightly alkaline medium. The variation in pH between different services is less than 1 unit of pH.

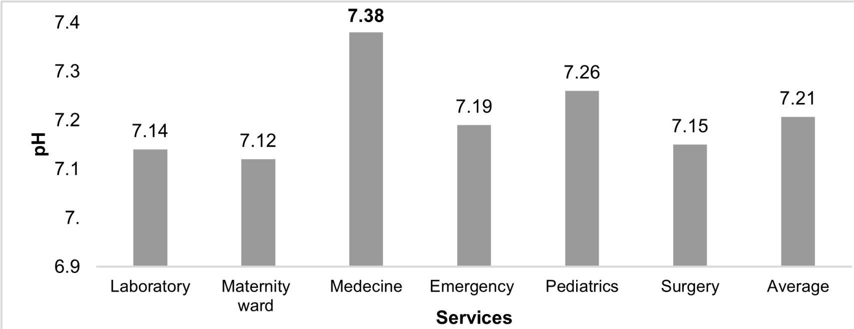


**Figure 8.** Hydrogen potential (pH) by service

This result agrees with that of the study by Fossou et al. [13] at the Hubert Koutoukou Maga National Hospital Center in Cotonou (Benin), a pH of around 7.02 and Nya [14] at the Lyon University Hospital which had also noted a pH of around 7.4.

However, these effluents are less alkaline than the leachate from the Akouedo landfill in Ivory Coast according to the study [15] on the physic-chemical characterization of leachate from this landfill.

The pH of the waste effluent from the Kara University Hospital services that we analyzed complies with the wastewater discharge standards according to the WHO, which places the discharge pH between 5.5 and 8.5.

The pH values obtained in the effluents could be linked to the low concentration of volatile organic compounds. Indeed, during acid fermentation, the first phase of anaerobic decomposition of waste, young percolates are rich in volatile organic compounds. According to study [16], during this phase, the pH values recorded are generally below 4. As the landfill ages, the effluent becomes depleted in volatile organic compounds. According to study [17], this will then cause the pH to rise to 7 or more.

The composition of hospital effluents may fluctuate depending on operational and institutional factors. Variations in water quality parameters can result from the frequency of cleaning operations, the quantity of disinfectants and detergents used, and the number of patients treated in each department. These factors can modify the load of suspended solids, conductivity, and nitrate concentrations in the wastewater. In the Kara University Hospital, the increased use of detergents and bleaching agents, combined with variable water consumption, likely influences both the dilution and the chemical composition of the effluents. Accounting for these factors helps explain the intra-departmental variability observed in the results and strengthens the interpretation of pollutant dynamics within the hospital environment.

3.1.4 Suspended solids (SS)

Recent study by Owono et al. [18] showed that SS represent the mineral and organic particles contained in the effluent. SS oscillates between 41 mg/L and 72.3 mg/L with an average of 58.07 mg/L and a standard deviation of 14.59 mg/L. Figure 9 presents the SS values by service.

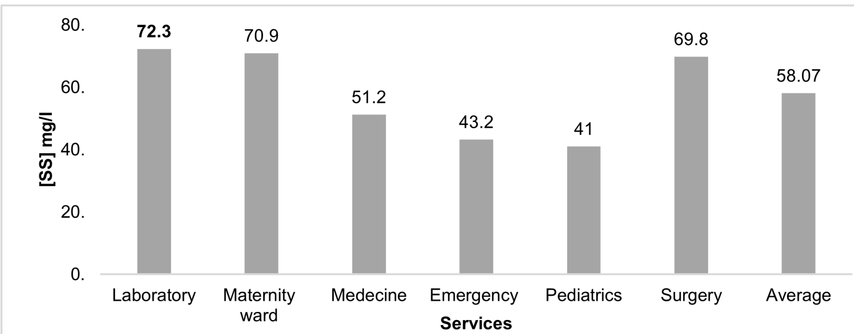


**Figure 9.** Suspended matter concentration by service

These SS loads measured at the Kara University Hospital are well beyond the WHO standards which set the SS load limit in discharge effluents below 30 mg/L.

These values agree with those found in research [19] that noted during the rainy season of 2012 at the Hubert Koutoukou Maga National Hospital Center in Cotonou (Benin) a suspended matter concentration load of 66 mg/L.

However, they are well below the SS load found during the same study carried out by Fossou et al. [13] in the dry season in 2012 which noted a SS load of around 116 mg/L. This difference observed between the loads could be explained by the dilution factor linked to the infiltration of rainwater into septic tanks and hospital wastewater sumps.

These values are also below the SS load found in domestic effluents. Indeed, Tattan et al. [20] noted in 2014 a SS value of around 917 mg/L in domestic wastewater from the town of Ouargla in Algeria.

#### 3.1.5 Chemical analyzes (nitrates $NO_3^-$)

Nitrates are the final stage of nitrogen oxidation, and are the highest oxidized form of nitrogen found in water. The levels recorded vary between 56.68 in the maternity ward and 112.90 mg/L in the medical area with an average level of 84.79 mg/L and a standard deviation of 20.53 mg/L. This value is well above the maximum concentration accepted by the WHO (2001) which is 50 mg/L.

Nitrogen is an essential element in the building of the cell. In the aquatic domain, nitrogen exists in molecular ($N_2$) or ionized form such as nitrates ($NO_3^-$), nitrites ($NO_3^-$) and ammonium ($NH_4^+$) as well as in dissolved or particulate organic form (protein, amino acids, urea, etc.). Figure 10 presents the nitrate content of the different services.

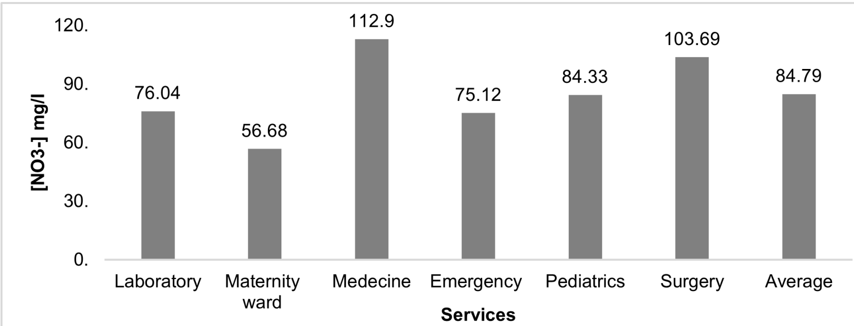


**Figure 10.** Nitrates by service

These different forms of nitrogen are constantly evolving. They pass from one to the other through physicochemical and especially biochemical processes. Nitrates represent only one of the multiple forms of nitrogen present in water, while generally constituting the most abundant form of mineral nitrogen.

### 3.2 Microbiological Analyzes

As part of this study, four classic microbiological indicators of pollution were analyzed, including total coliforms, thermotolerant coliforms, sulphite-reducing anaerobes and fecal streptococci.

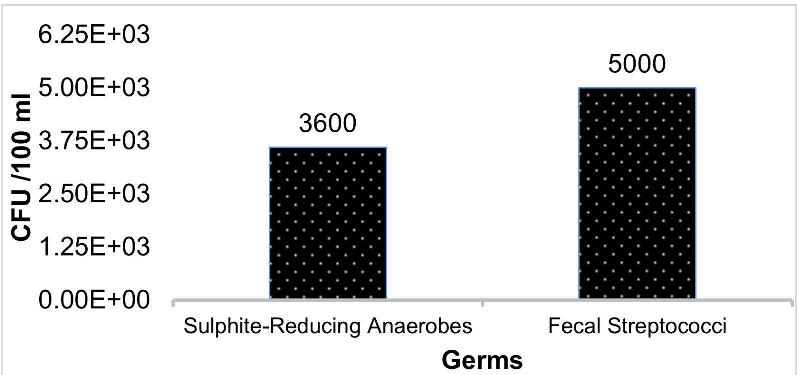


**Figure 11.** Concentrations in sulphite-reducing anaerobes and fecal streptococci

The average concentration of total and thermotolerant coliforms found are respectively of the order of 1.106 and 4.105 CFU/100 mL. These microbial loads are very high in comparison with the concentration of these germs in most hospital effluents reported by various studies in the literature. For instance, Nya [14] and Kapanga et al. [16] found 2.103 fecal coliforms per 100 mL in the effluent of a hospital in a large city in the South-East of France. Figure 11 presents concentrations in sulphite-reducing anaerobes and fecal streptococci.

The concentrations obtained are well above the WHO standards which set the maximum discharge concentration respectively at 5000 CFU/100 mL for total coliforms, 2000 CFU/100 mL for thermotolerant coliforms and 1000 CFU/100 mL for fecal streptococci. Figure 12 presents concentration of coliforms.

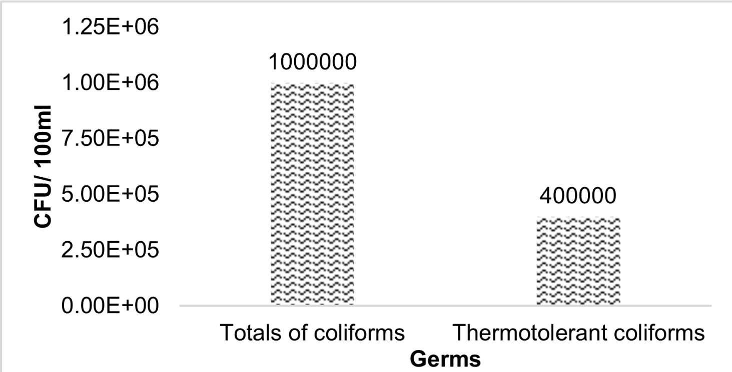


**Figure 12.** Concentration of coliforms

The concentration of fecal coliforms in a hospital effluent could tell us about the ecotoxicity rate of this effluent.

This is how we could link the high content of fecal coliforms in the effluents of the Kara University Hospital to a low presence of antibiotics and/or disinfectants.

At Kara University Hospital, all expired pharmaceutical products are disposed of outside the sanitation network.

The quantity of bleach used at Kara University Hospital during the first 6 months of 2016 is estimated at approximately 12,103 L.

In addition, hospitals are generally large consumers of water and this leads to a dilution of effluent. Consequently, there is a reduction in the concentration of various bacterial species studied below.

### 3.3 Comparative Synthesis of Results with Other Studies on Hospital Effluents

The results of this study were compared with those of other research on hospital effluents in order to situate them in a broader scientific context. This comparison highlighted the similarities and divergences regarding the chemical, microbiological and physico-chemical composition of the effluents, as well as the associated environmental and health risks. Table 6 presents a synthesis of these comparisons, facilitating the critical analysis and contextualization of the results obtained at the University Hospital Centre de Kara compared to other national and international studies.

**Table 6.** Comparative studies on the analysis of hospital effluents

| **Study/Site** | **Temperature (°C)** | **pH** | **Conductivity ($\mu$S/cm)** | **Total Suspended Solids (mg/L)** | **$NO_3^-$ (mg/L)** | **Total Coliforms (CFU/100 mL)** | **Fecal Streptococci (CFU/100 mL)** | **Comments** |
|---|---|---|---|---|---|---|---|---|
| CHU Kara (Togo) | 27.9 | 7.2 | 166.5 | 58.1 | 84.8 | $1 \times 10^6$ | $5 \times 10^3$ | Rainy season, strong dilution |
| CHU HKM Cotonou–rainy season (Benin) | 29.3 | 7.0 | 891 | 66.0 | — | — | — | Diluted hospital effluents |
| CHU HKM Cotonou–dry season (Benin) | — | — | — | 116.0 | — | — | — | Dry season, higher concentration |
| Rabat-Salé-Zemmour-Zaer (Morocco) | — | — | 1500 | — | — | — | — | Maternity ward, high ionic load |
| CHU Lyon (France) | — | 7.4 | — | — | — | — | — | European reference value |
| Ouargla (Algeria) | — | — | — | 917 | — | — | — | Domestic wastewater (comparative) |
| WHO–discharge limit | $<30$ | 5.5–8.5 | — | $<30$ | $\leq 50$ | $\leq 5 \times 10^3$ | $\leq 1 \times 10^3$ | WHO guideline values (2001) |

3.3.1 Temperature and hydrogen potential (pH): Apparent compliance, but mesophilic context

In Kara, the temperatures (27.4–28.3 °C; for an average of 27.87 °C) remain below the WHO benchmark (<30 °C) and fall within the favorable range for mesophilic microorganisms (20–40 °C); the pH is slightly alkaline (7.1–7.4), consistent with comparisons (Cotonou = 7.0; Lyon 7.4) and conforms to the WHO benchmark 5.5–8.5. This means that the physico-chemical environment does not hinder microbial survival, hence the importance of downstream treatments.

3.3.2 Conductivity: High regional variability, role of dilution

Kara has a low average conductivity (166 $\mu$S/cm) compared to Cotonou (790–891 $\mu$S/cm) and the maternity hospital of Rabat-Salé-Zemmour-Zaer (1,500 $\mu$S/cm). The discrepancy is largely explained by the rainy season in Kara, with dilution of solutes (and MES/microbes), which artificially dilutes concentrations compared to the low flow.

3.3.3 Suspended solids (SS): Frequent exceedances vs WHO

In Kara, the total suspended solids (avg. = 58 mg/L) exceed the WHO guide value (<30 mg/L), despite seasonal dilution. The Cotonou data confirm the marked seasonality: 66 mg/L in the rainy season compared to 116 mg/L in the dry season. In contrast, the domestic waters of Ouargla reach 917 mg/L, illustrating that a hospital discharge can remain well below certain concentrated urban effluents, but remains non-compliant with the WHO benchmark.

3.3.4 Nitrates: Structural excesses

Kara records average NO 84.8 mg/L (56.7–112.9), above the WHO benchmark (50 mg/L). This signal translates either a nitrogen input (urea/transformed organic nitrogen) or oxidation conditions favoring the accumulation of nitrates in the absence of suitable treatment (e.g., denitrification).

3.3.5 Microbiology: Order(s) of magnitude exceedances

In Kara, total (10 CFU/100 mL) and thermotolerant (4 10 CFU/100 mL) coliforms, as well as fecal streptococci (5 103 CFU/100 mL) and sulphite-reducing anaerobes (3.6 103 CFU/100 mL), largely exceed the WHO benchmarks (total coliforms 5 103; thermotolerant coliforms 2 103; faecal streptococci 10 3). Even if some European studies report orders of magnitude lower, the local reality (pluvial dilution but high microbial load) calls for reduction measures at source and appropriate treatment.

Moreover, the physical characteristics of the environment (soil permeability, runoff dynamics, groundwater depth, density of water sources) can influence the mobility, dilution and bioaccumulation of pollutants from hospital effluents. Infiltration into the soil or discharge into surface waters can lead to secondary contamination of aquatic ecosystems and groundwater resources, particularly in areas where these waters are used for human consumption, livestock watering or irrigation. Studies conducted in Burkina Faso, Morocco, Benin and Cameroon have shown that untreated hospital effluents can significantly alter the microbiological and chemical quality of nearby rivers, wells and groundwater, thereby increasing health risks for downstream populations [1, 6, 21–23].

Therefore, although the data from this study indicate significant exceedances of the WHO recommended limit values, the ecological and health implications of these results should be interpreted with caution. Future research should include an analysis of environmental transfer pathways linking discharge points to receiving environments and anthropogenic uses in order to strengthen the external validity and operational relevance of risk assessments related to hospital effluents in the context of sub-Saharan Africa [8, 9, 24, 25].

## 4 Discussion

Biomedical wastes pose health risks for patients, accompanying people, the staff and risks for environment pollution. The correlation between public health, environmental and waste water is proved by the characterization results physicochemical and microbiological parameters as well as by the management practices. Within the framework of this study, with regard to the results and norms of WHO waste water, it emerges that the waste water of the Kara University Hospital Centre carries some risks of human health and the environment pollution. These results go together with those studies [21, 22], which asserted that the management of biomedical solid and liquid wastes is insufficient in Togo University Hospitals and represent a potential risk for human health and for the environment.

### 4.1 Risk on Human Health

The microbiological characterization has revealed the presence of indicator germs of fecal pollution and which are the signs of the presence of pathogenic germs. Those pathogenic agents present in waste water split up into several microorganism groups [9]. These mainly includes bacteria, viruses, protozoa and helminths. Those pathogenic agents can cause serious diseases especially to vulnerable groups particularly (the children, the aged people, people whom the immune system is weakened) [9, 23]. The hospital population of Kara University Hospital Centre is exposed to those different risks in three (03) levels especially at the level of production, sanitation network due to malfunctioning examined at the level of some pits and pipes that are permeable and finally during the final drainage (emptying and soil enriching) which takes place without genuine protection measures toward workers.

Table 7 presents the summary of exposed population categories and types of expositions linked to water waste management of Kara University Hospital.

**Table 7.** Summary of exposed population categories and types of exposition

| Category of Population | Exposition Types | | | |
|---|---|---|---|---|
| | Cutaneous (Contact) | Oral (Inhalation) | Intramuscular (Prick) | Respiratory Way |
| Nursing staff | ▲ | ▲ | ▲ | ▲ |
| Patients and accompanying people | ▲ | ▲ | • | ▲ |
| Workers involved in the emptying | ▲ | ▲ | • | ▲ |
| Surrounding populations of the hospital | • | ■ | • | • |
| Farmers working on fields enriched by hospital effluents | ▲ | ▲ | • | ▲ |
| Surrounding populations in the area of rubbish | • | ▲ | • | ▲ |

Note: ▲: High exposure; ■: Minor exposure; •: Very low exposure.

### 4.2 Environmental Pollution

The environmental pollution by the hospital waste water of Kara University Hospital Centre occurs at two (02) levels especially at the level of hospital through the sanitation network and at the level of throwing out sites through shed muds. At the level of the hospital, hospital effluents pollute the soil, the surface and underground waters by seepage through sumps and malfunctioning (permeable pits and pipes) examined on the sanitation network. The atmosphere is polluted by dusts which come from infected soil. Taking into account of dilution factors of waste water by the rainwater and the filtering role of the soil, the pollution of the soil and surface waters will be more important than the one of underground water and atmosphere. At the level of tip sites, the hospital effluents loaded being poured without any treatment, they pollute the soil, the surface and underground waters by drainage of pluvial water and seepage. As in the first scenario, the atmosphere is polluted from dusts that result from the soil. The level of pollution is weaker at the level of underground waters and the atmosphere than at the level of soil and surface waters. The environmental pollution by waste water can be responsible for many impacts among other things, the degradation of surface waters quality, the degradation of river waters quality, the pollution of underground water.

Thus, the discharge of untreated hospital effluents has implications that extend beyond the hospital boundaries. In the Kara region, the drainage network and temporary discharge zones are often connected to nearby surface waters and shallow groundwater that supply local populations with domestic and agricultural water. Infiltration through permeable soils and runoff during rainfall events can therefore transport contaminants toward downstream ecosystems and communities. The absence of a dedicated wastewater treatment plant means that hospital effluents can directly contribute to the microbiological and chemical degradation of surrounding aquatic environments, intensifying exposure risks for populations living near rivers, wells, or agricultural areas using these waters.

### 4.3 Degradation of the Surface Water Quality

At the level of the hospital, considering the weak rate admittance of patients and accompanying people to the sanitation infrastructures (2.99% for the showers and 2.84% for the Water Closets) a quantity of liquid wastes is not collected by the sanitation network of Kara University Hospital, it is then poured out of sanitation network and pollute surface water.

The degradation of surface water is greater at the level of throwing out areas with regard to large poured quantities. The hospital throwing outs considerably affect and pollute the microbiological and chemical quality of water meant for the production of drinking water and contribute to the eutrophication of streams in Democratic Republic of Congo, had found the existence of toxic substances in effluents of concerned hospitals establishments and these could have a harmful impact on the environment [8, 24]. The test/analysis of the river waters in which those effluents were poured had allowed to confirm those reports [26, 27].

It is obvious that the polluting microbiological load is relatively decreasing due to the dilution factors and the microorganism also has relatively a short-life in the environment but those infected surface waters are able to cause diseases linked to germs, viruses, protozoa, etc. The excessive input of nutriment, mainly nitrogen and phosphorus in waste waters can provoke a contamination of surface waters and lead to their eutrophication (enrichment in nutriments). The eutrophication can create environmental conditions allowing the growth of cyanobacteria and algae which produce toxins.

### 4.4 Pollution of the Underground Waters

The level of underground waters pollution by waste water depends on the nature of the soil, subjacent rocks and the depth of the ground water. The sheets relatively shallow are the most exposed to the pollution. The deep sheets can eventually be contaminated if there is a communication (a drilling for example) with the surface of soil. As the wastewater of Kara University Hospital Centre do not undergo any treatment before the throwing, their contribution to the pollution of the underground waters seems obvious. Taking into account certain number of parameters especially by the dilution, soil filtering and relative short-life of microorganisms in the environment, the quantity of microorganism that will reach the underground waters will be very weak [3, 28, 29]. However, even if it is a small quantity of microorganisms, if the conditions are favorable, they can grow in number and cause a serious health problems seeing that the underground waters are much in demand for supplying with drinking water by the means of drillings.

In this way, studies [3, 30] conducted in Lomé, Togo, reported some contaminated wells of fecal origin with a thermotolerant coliforms/faecal streptococci ratio greater than 4. Since hospital effluents in Lomé are managed in the same manner as those at the Kara University Hospital Centre, it can be assumed that these effluents contribute to the fecal contamination. The underground waters are then from hospital wastewater and can have enormous risks for the health on the microbiological as on the chemical plan.

### 4.5 Characterization and Estimation of the Level of Exposure Risk

Exposure characterization consists of determining the probabilities of contact between the causal factor (stressor) and the "targets" (receptors). It therefore generally involves the analysis of sources, transfers from these sources and the distribution of contaminants in the environment. Figure 13 presents the matrix for identifying and estimating the risk level of each category of person exposed following the stages of liquid effluent management in the context of the Kara University Hospital scenario.

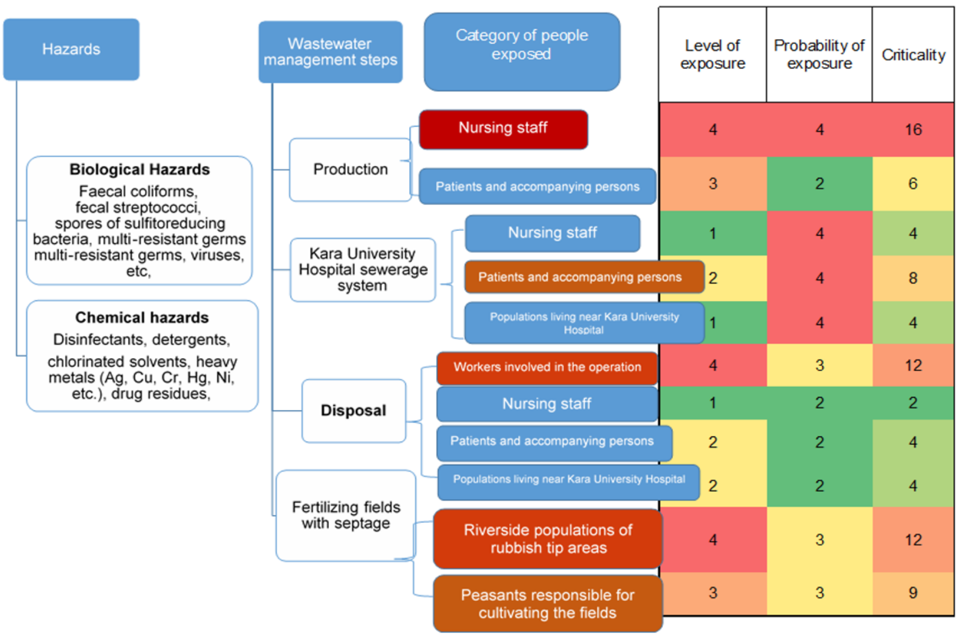


**Figure 13.** Risk level identification and estimation matrix on a scale of 4

The analysis shows that all categories of exposed people run risks both biologically and chemically. However, the estimation of the level of criticality of the risks highlights the most exposed categories and the circumstances in which these people are exposed.

### 4.6 Recommendations

The health risks associated with different biological and/or chemical elements from hospital effluents are an emerging public health problem that is important to address. This threat is essentially twofold:

• The survival of micro-organisms in outdoor environments and any mutations they may undergo;

• Chronic and multiple exposures through water and food, low doses of heavy metals and drug residues.

The data collected made it possible to estimate the level of exposure of the various actors and the situations in which they are exposed in the specific case of University Hospital Centre Kara. The following recommendations are therefore made.

• Quantification and characterization of chemical substances used in each department. Indeed, improving knowledge of the formulations of substances and the quantities used per service would allow a better management of these substances;

• Information, awareness and training of hospital staff, emptying agents and farmers who use hospital effluents to correct the biological and chemical hazards associated with hospital effluents;

• Use of biocides, bio or reduced toxicity when possible;

• Equip workers with appropriate personal protective equipment ;

• Carry out the vaccination follow-up of workers;

• If possible, reduce the frequency of emptying by resizing the maternity and surgery pits if STEP is not immediately implemented;

• Revitalization of the health and safety committee at University Hospital Centre Kara;

• Setting up and monitoring the operation of a hospital wastewater treatment plant.

## 5 Conclusion

This study addresses the issue of characterizing and evaluating the risks associated to the discharge of effluent from the Kara University Hospital. The research primarily focused on identifying the nature of pollutant loads and assessing their impacts on both human health and the environment.

The determination of certain classic physicochemical pollution parameters (pH, temperature, conductivity, SS, nitrates, absorbance 254 nm) and microbiological (total coliforms, thermotolerant coliforms, faecal streptococci, sulphite-reducing anaerobes) allowed the estimation of the exposure levels of the different actors to risks linked to the management of these effluents. Biomedical waste in Togo's university hospitals is a source of environmental impact and risks for human health.

The nursing staff, the sick and those accompanying them, the workers responsible for emptying and those responsible for the exploitation of soil amended by hospital effluent are the most exposed considering all the stages of hospital effluent management in the Kara University Hospital scenario. It should be noted, however, that the study revealed that the populations surrounding Kara University Hospital and those surrounding landfill sites are also exposed.

This research contributes to enhancing the understanding of hospital effluent management at Kara University Hospital and calls for greater attention from both health and municipal authorities, urging the establishment of appropriate treatment systems for hospital effluents.

The project to rehabilitate the Kara University Hospital with the installation of a wastewater treatment station and the project to build a sewage sludge treatment station in Kara offer some hope for improving the management of liquid waste at the Kara University Hospital.

## Author Contributions

Conceptualization, S.N. and E.K.K.; methodology, S.N., E.K.K., I.B., and N.M.K.; software, S.N. and E.K.K.; validation, S.N., E.K.K., and N.M.K.; formal analysis, S.N., E.K.K., and I.B.; investigation, S.N., E.K.K., I.B., and N.M.K.; resources, S.N. and E.K.K.; data curation, S.N.; writing—original draft preparation, S.N.; writing—review and editing, S.N., E.K.K, I.B., and N.M.K.; visualization, S.N.; supervision, E.K.K. and N.M.K.; project administration, E.K.K.; funding acquisition, S.N. All authors have read and agreed to the published version of the manuscript.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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## Conflicts of Interest

The authors declare that they have no conflicts of interest.

**References**


[1] G. A. Ouédraogo, D. J. Djopnang, O. Zongo, F. T. Badé, A. Ouédraogo, B. Kaboré, H. Cissé, Y. Traoré, I. H. N. Bassolé, T. François, and et al., "Toxic potential evaluation of liquid effluents discharged into nature by the university hospital centers (UHC) and mixed wastewater treatment station (WWTS) at Ouagadougou-Burkina Faso," *Environ. Monit. Assess.*, vol. 196, no. 8, p. 718, 2024. https://doi.org/10.1007/s10661-024-12852-3

[2] A. Keleb, C. Daba, A. Endawkie, L. Asmare, F. D. Bayou, E. T. Abeje, A. Ayres, A. Mohammed, N. Kebede, K. M. Abera, and et al., "Rural-urban disparities in basic sanitation access among households: A multivariable decomposition analysis of Ethiopian demographic and health survey 2019," *Front. Public Health*, vol. 12, p. 1420077, 2024. https://doi.org/10.3389/fpubh.2024.1420077

[3] T. Gnaro, A. Ali, A. Adom, E. S. Abiassi, C. Degbey, Y. Douti, D. K. Messan, G. E. Sopoh, and D. K. Ekouevi, "Assessing biomedical solid and liquid waste management in university hospital centers (CHU) in Togo, 2021," *Open J. Epidemiol.*, vol. 12, no. 4, pp. 401–420, 2022. https://doi.org/10.4236/ojepi.2022.124033

[4] Ministry of Health and Social Protection (Togo), "Strategic plan for the management of medical Waste_PNMW_ProjetREDISSE," 2016. https://www.afro.who.int/fr/publications/plan-strategique-de-gestion-des-dechets-medicaux-2016-2020

[5] Ministry of Health and Public Hygiene (Togo), "National quality policy of health services of Togo," 2009. https://www.giz.de/en/downloads/Politique%20Nationale%20de%20Qualit%C3%A9%20des%20Services%20de%20Sant%C3%A9%20du%20Togo.pdf

[6] Z. Garba, I. O. Bonkoungou, N. O. Millogo, H. M. Natama, P. A. P. Vokouma, M. D. A. Bonko, I. Karama, L. A. W. Tiendrebeogo, K. Haukka, H. Tinto, and et al., "Wastewater from healthcare centers in Burkina Faso is a source of ESBL, AmpC-$\beta$-lactamase and carbapenemase-producing Escherichia coli and Klebsiella pneumoniae," *BMC Microbiol.*, vol. 23, no. 1, p. 351, 2023. https://doi.org/10.1186/s12866-023-03108-0

[7] R. Iyer and L. P. Toe, "Effet des aléas climatiques sur les pratiques d'hygiène et d'assainissement en milieu rural au Burkina Faso," 2022. https://pdfs.semanticscholar.org/30f7/62489b6d7298fd2da9ebe39316abc3d8f32d.pdf

[8] N. A. Khan, V. Vambol, S. Vambol, B. Bolibrukh, M. Sillanpää, F. Changani, A. Esrafili, and M. Yousefi, "Hospital effluent guidelines and legislation scenario around the globe: A critical review," *J. Environ. Chem. Eng.*, vol. 9, no. 5, p. 105874, 2021. https://doi.org/10.1016/j.jece.2021.105874

[9] E. Deguenon, V. Dougnon, V. M. C. Houssou, E. Gbotche, R. A. Ahoyo, K. Fabiyi, J. Agbankpe, W. Mousse, K. J. R. Lougbegnon, C., and et al., "Hospital effluents as sources of antibiotics residues, resistant bacteria and heavy metals in Benin," *SN Appl. Sci.*, vol. 4, no. 8, p. 206, 2022. https://doi.org/10.1007/s42452-022-05095-9

[10] C. T. B. Boti, S. Kenfack, T. Gnagne, and G. Soro, "Économie d'eau des toilettes, une approche crédible de réduction du déficit en eau potable de la ville d'Abidjan (Côte d'Ivoire)," *Int. J. Biol. Chem. Sci.*, vol. 13, no. 5, pp. 91–104, 2019. https://doi.org/10.4314/ijbcs.v13i5.7S

[11] B. M. D. Kanouo, M. D. Tsobeng, M. F. Fonteh, J. M. Sagne, B. L. Ndongsong, and M. S. Sobze, "Diagnostic en vue de l'élaboration d'une stratégie municipale concertée pour l'accès à l'eau potable et l'assainissement: Cas de la commune de Kye-Ossi au Sud-Cameroun," *Int. J. Biol. Chem. Sci.*, vol. 15, no. 7, pp. 120–130, 2021. https://doi.org/10.4314/ijbcs.v15i7.12S

[12] F. Traoré, M. A. Konaré, S. Sossou, H. A. Andrianisa, and Y. Samaké, "Contribution a l'amélioration de l'accès a l'eau, l'hygiène et l'assainissement dans la commune rurale de Zan Coulibaly au Mali," *Eur. Sci. J.*, vol. 17, no. 40, pp. 196–214, 2021. https://doi.org/10.19044/esj.2021.v17n40p196

[13] S. A. R. Fossou, S. E. Mèdoatinsa, D. C. P. Agbangnan, T. Azonhe, and V. D. Wotto, "Evaluation of the efficiency of hospital wastewater treatment systems and stations in the Atlantic and Littoral departments of Benin," *Am. J. Environ. Prot.*, vol. 12, no. 4, pp. 48–54, 2024. https://doi.org/10.12691/env-12-4-1

[14] E. L. Nya, "Acces to drinking water and sanitation in Nde division (west region-Cameroon)," Ph.D. dissertation, University of Yaoundé I (Cameroon), 2020. https://theses.hal.science/tel-02937356

[15] C. C. Wang, Y. L. Chen, T. C. Lu, C. Lee, Y. C. Chang, Y. F. Chan, P. Mathew, X. R. Lin, W. R. Hsieh, T. Y. Huang, and et al., "Design and evaluation of oral formulation for apixaban," *Heliyon*, vol. 9, no. 8, p. e18422, 2023. https://doi.org/10.1016/j.heliyon.2023.e18422

[16] P. M. Kapanga, G. W. A. Nyakairu, C. I. Nkanga, S. N. Lusamba, R. M. Tshimanga, and Z. Shehu, "A review of dye effluents polluting African surface water: Sources, impacts, physicochemical properties, and treatment methods," *Discov. Water*, vol. 4, no. 1, p. 85, 2024. https://doi.org/10.1007/s43832-024-00129-2

[17] E. Attiah, M. Z. S. Ndeboah, and A. Abubakar, "Assessment of the quality of water from hand-dug wells in Essikado community," *IJSAT-Int. J. Sci. Technol.*, vol. 16, no. 3, p. 7717, 2025. https://doi.org/10.71097/IJSAT.v16.i3.7717

[18] L. R. S. Owono, R. C. Zinga Koumba, E. Nzengue, A. A. Koumba, B. Normark, L. G. Acapovi-Yao, L. S. Djogbenou, and F. J. Mavoungou, "Abondance et distribution des cochenilles sur les feuilles des plantes-hôtes

dans la parcelle forestière permanente de Rabi, Sud-Ouest du Gabon," *Afr. Sci.*, vol. 14, no. 1, pp. 119–128, 2018. https://doi.org/10.19044/esj.2022.v18n36p117

[19] S. K. H. Yamontché, R. C. Johnson, F. M. Gouissi, G. Boni, C. Degbey, and C. S. Houssou, "Etat des lieux et facteurs associés en matière d'eau, d'hygiène et d'assainissement dans la commune d'abomey-calavi au bénin," *Eur. Sci. J.*, vol. 16, no. 6, p. 524, 2020. https://doi.org/10.19044/esj.2020.v16n6p524

[20] A. Tattan, F. Jaara, and N. Nebghali, "Comparative analysis of hospital laboratory wastewater treatment techniques in Syrian Arab Republic," *East. Mediterr. Health J.*, vol. 30, no. 12, pp. 829–836, 2024. https://doi.org/10.26719/2024.30.12.829

[21] United Nations Children's Fund (UNICEF) and World Health Organization (WHO), "Progress on household water, sanitation and hygiene, 2000-2022," 2023. https://www.unwater.org/sites/default/files/2023-07/jmp-2023-wash-households-launch-version_0.pdf

[22] P. Verlicchi, "Trends, new insights and perspectives in the treatment of hospital effluents," *Curr. Opin. Environ. Sci. Health*, vol. 19, p. 100217, 2021. https://doi.org/10.1016/j.coesh.2020.10.005

[23] M. T. Khan, R. Ahmad, G. Liu, L. Zhang, R. Santagata, M. Lega, and M. Casazza, "Potential environmental impacts of a hospital wastewater treatment plant in a developing country," *Sustainability*, vol. 16, no. 6, p. 2233, 2024. https://doi.org/10.3390/su16062233

[24] J. S. Eheth, M. Djaouda, K. B. P. Tamatcho, E. O. V. Noah, K. P. R. Fotsing, A. A. Tamsa, L. M. Moungang, and M. Nola, "Vulnerability of groundwater to hospital wastewater driving antimicrobial-resistant pseudomonas aeruginosa, in Cameroon Central Africa," *J. Environ. Pollut. Hum. Health*, vol. 12, no. 2, pp. 10–23, 2024. https://doi.org/10.12691/jephh-12-2-1

[25] I. Chirisa, E. Bandauko, A. Matamanda, and G. Mandisvika, "Decentralized domestic wastewater systems in developing countries: The case study of Harare (Zimbabwe)," *Appl. Water Sci.*, vol. 7, no. 3, pp. 1069–1078, 2017. https://doi.org/10.1007/s13201-016-0377-4

[26] L. Berhanu, M. Abebe, A. Gizeyatu, G. Berihun, D. Teshome, and Z. Walle, "Evaluation of the effect of wastewater irrigation on the microbiological quality of vegetables in Northeast Ethiopia: Implication for food-borne infection and intoxications," *Environ. Health Insights*, vol. 16, 2022. https://doi.org/10.1177/11786302221127856

[27] A. Ait Bella, "Environmental impact assessment of effluents from Mohammed VI University Hospital in Marrakech (Morocco) through physicochemical characterization," *Am. J. Environ. Sci. Eng.*, vol. 9, no. 3, pp. 131–137, 2025. https://doi.org/10.11648/j.ajese.20250903.15

[28] Ministry of Environment and Forest Resources, "Première communication relative à l'adaptation aux changements climatiques au Togo," 2023. https://unfccc.int/sites/default/files/ACR/2023-08/togo-ad-comm-fr.pdf?utm_source=chatgpt.com

[29] Agence Japonaise de Coopération Internationale, "L'etude sur l'etablissement d'une base de donnees topographiques au Togo," 2013. https://openjicareport.jica.go.jp/pdf/12126538_01.pdf

[30] UNESCO and UN Water, "Rapport mondial des nations unies sur la mise en valeur des ressources en eau 2020: l'eau et les changements climatiques," 2020. https://unesdoc.unesco.org/ark:/48223/pf0000372941