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# Assessment of solid and liquid wastes management and health impacts along the failed sewerage systems in capital cities of African countries: case of Abidjan, Côte d'Ivoire

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The management of domestic wastewater and rainwater is a major concern for the population of Yopougon. The study presents the causes of wastewater discharge from dysfunctional sewers and their health impacts on the population. It also highlights the environmental and health risk associated with poor solid and liquid waste management. This was based on literature search, semi-participatory workshop, physicochemical and bacteriological characterization of wastewater and finally through a household survey. The field survey was conducted on 245 household heads obtained using the Canadian statistical guidelines. The results obtained indicated that all main pollution indicators were; total nitrogen (TN, 525 ± 0.02 to 3077 ± 0.3 mg/l), nitrates ($NO_3$, 146 ± 0.01 to 1347 ± 0.12 mg/l), biochemical oxygen demand (BOD, 278 ± 195.16 to 645 ± 391.74 mg/l), chemical oxygen demand (COD, 940 ± 650.54 to 4050.5 ± 71.42 mg/l) and total dissolved solids (TDS, 151 ± 9.9 to 766 ± 237.59 mg/l) which were above the values recommended by the World Health Organization (WHO) and Cote d'Ivoire national policy guidelines standards for the discharge of effluents into the environment. The analysis of the bacterial flora of the effluents revealed that the concentrations of Total Coliforms and fecal streptococci exceeded the values recommended by the WHO and national policy guidelines standards. This means that the populations of this area are prone to infectious diseases. Diseases such as malaria (84.53%), respiratory infections (61%), diarrhea (48.66%), intestinal diseases (44.5%), and typhoid fever (28.84%) were prevalent in the surveyed households.

KEYWORDS

**wastewater, environmental impact, sanitation, collector, pollution indicators, health risk, households**

# 1. Introduction

In most countries in sub-Saharan Africa, high population growth (more than 5%) per year on average is accompanied by uncontrolled spatial development that is beyond the control of public authorities (Bamba and N'doli, 2018). Thus, the health and wellbeing of the inhabitants are affected by insalubrity due to the absence of appropriate public strategies for solid and liquid waste disposal (Coulibaly et al., 2016). According to WHO reports, more than 1.2 billion people do not have access to safe drinking water and 2.5 billion do not have adequate sanitation (Pseau, 2012). This situation is believed to be the cause of many deaths from diarrhea and other fecal-peril-related diseases that particularly affect adolescents, especially in developing countries (Sy et al., 2017a). Sanitation is achieved through physical, institutional and social means in areas such as wastewater and runoff disposal, solid waste disposal, excreta disposal and treatment (Kouadio et al., 2020). Sanitation refers to the collection, transport and treatment (purification) of wastewater before it is discharged into rivers or into the ground (Daramola et al., 2016; Ross, 2021).

In Côte d'Ivoire, as in the developing world, access to sanitation is a daily struggle for hundreds of thousands of people living mainly in cities (Andrianisa and Brou, 2016). Thus, the lack of consistent urbanization means that the population is faced with enormous environmental problems, including poor waste water management (rainwater, domestic, black water). The Yopougon municipality, with an estimated population of 1,071,543 inhabitants (RGPH, 2014), is the most populated municipality in the district of Abidjan. It gives the impression of a city where anarchy, disorder, and insecurity can be observed. More than 51% of the inhabitants are connected to the collective sewage system (SODECI, 2018). As these networks are mostly dysfunctional and pose serious risk of groundwater contamination, this affects the health of residents living along these sewers (Dongo et al., 2009). Yopougon "Nouveau quartier" is not an exception to this situation. With an estimated population of 203,812 inhabitants in 2014 (INS, 2014) and a density of 41.23 inhabitants/km², this district is one of the most densely populated districts in the municipality of Yopougon. This district has a diversified sewage system composed mainly of underground sewers as well as the 21/22 collector which starts from the Lama Fofana district at the Saint François roundabout and discharges into a rainwater channel. Approximately 28,460 households are directly connected to this collector. However, there is high stagnation of wastewater in the streets, between houses, at the level of dysfunctional secondary manholes, following a discharge due to the progressive failure of the sewers. This wastewater becomes breeding grounds for certain pathogens. In addition, the population is exposed to several diseases, such as malaria, which accounts for 84.53% of reported consultations. According to the WHO, the health status of a population depends closely on the quality of drinking water, sanitation and hygiene services. The aim of this study was to assess the environmental and health impacts of the poor management of solid and liquid waste on either sides of the 21/21 collector in Yopougon Nouveau Quartier. The study will also enable to develop strategies for solid waste and wastewater management. This assessment will allow the stakeholders in charge of sanitation to undertake interventions as soon as possible in order to improve the living conditions of the residents of these different districts located along the collector. It is also a new approach that contributes to the understanding of sanitation management, urban planning, living environment and human security. It shows how poor planning and management of urban sanitation systems can expose people to certain diseases and contribute to environmental degradation. It also aims to understand how the inhabitants of Yopougon Nouveau quartier manage their sewage systems and the diseases to which they are exposed. This research is the starting point for future research focusing on the management of sewage and drainage systems in a world increasingly influenced by urbanization.

# 2. Material and methods

## 2.1. Study area

The present study was carried out in Yopougon Nouveau quartier, a municipality located in the North of Abidjan. It is located between latitude 5°16' and 5°27' North and longitude 3°21' and 3°32' West. Yopougon covers an area of ∼153.06 km$^2$, with a population of 1,071,543 inhabitants (INS, 2014). The study area is characterized by an equatorial climate with four seasons including two rainy seasons and two dry seasons. The long rainy season lasts from April to July where more than two-third of the annual rainfall is recorded (Kouamé et al., 2014; Kablan et al., 2019), and the short rainy season occurs from October to November. From December to March, the long dry season occurs, followed by a short dry season from July to October. The temperature in Yopougon can get to as low as 18°C and as highs as 35°C in September. Annual rainfall varies from 57 mm to 266 mm on average in Yopougon. In the study area, about 51% of households are connected to the collective network (sewage system). Most of the drains are dysfunctional and do not enable proper drainage of waste water, and in some cases discharge a mixture of waste, human excreta and waste water on the surface, exposing the health of residents to numerous cases of malaria, respiratory diseases, diarrhea and typhoid fever. This is the case of sewer 21/22, one of the most used sewers in this municipality.

The 21/22 collector is a 5.65 km long underground sewer network. It runs from the Lama Fofanadistrict to the Sideci Iroko district at the Saint François roundabout (Figure 1). It crosses several neighborhoods which are: Lama Fofana, Denver, Sans Loi, Nouveau Bureau, Camp Militaire and Sideci Iroko. The main sewer has a diameter of 800 mm. The secondary collectors, which are the wastewater inlets, have a diameter of 200 mm. The various secondary sewers are mostly perpendicular to the main sewer. The wastewater flows from Lama Fofana to the Saint François roundabout, where it empties into a large open channel, which then flows into the Ebrié Lagoon. The main sewer comprises of a total of 75 manholes. The maximum distance between two consecutive manholes is 50 m.

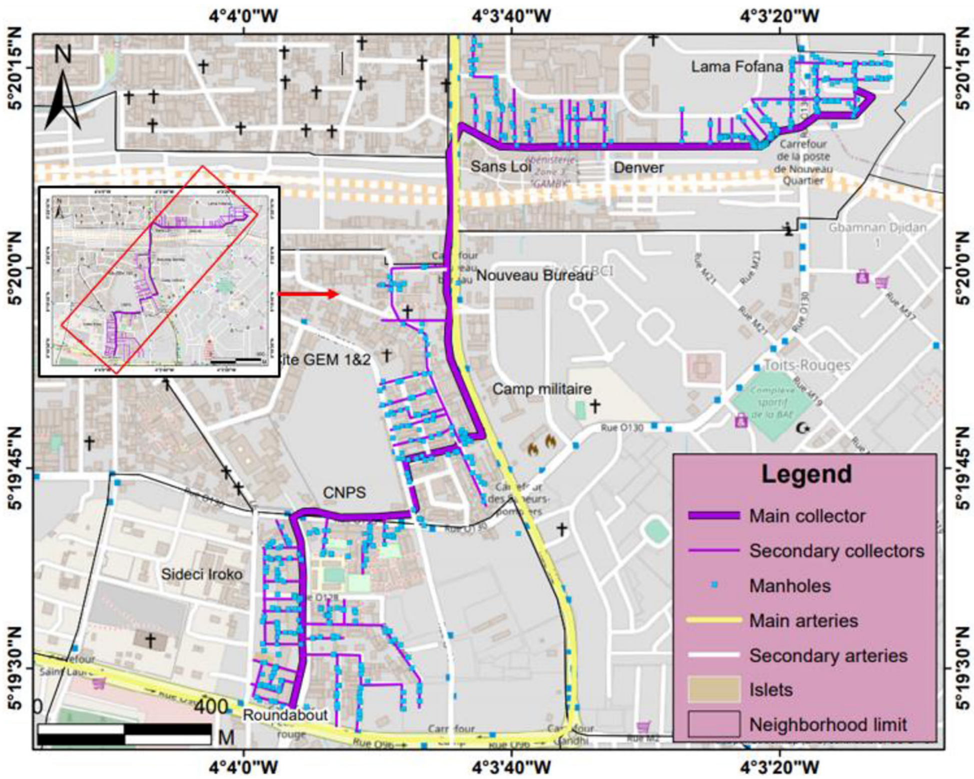


FIGURE 1
Geographical location of the 21/22 collector in Yopougon municipality (Ouattara et al., 2023).

## 2.2. Framework of the methodology

The study used an adaptation of the Eco-Health approach. Physicochemical factors, inorganic or organic substances, people, and the environment are just a few examples of the many socio-ecological system constituents. The Eco-Health approach is a set of conceptual and methodological processes that enables a better understanding of the complex interactions between these constituents and how they affect human health and wellbeing. Additionally, it searches for ecosystem management strategies that can improve both the population's health and living conditions as well as the sustainability of the ecosystems in which they reside (Forget and Lebel, 2001). The physical surroundings, health status, social, cultural, and economic issues are all taken into account by this method (Nguyen-Viet et al., 2009). A framework centered on six concepts was developed in a study conducted by Charron (2012): (i) systems thinking, (ii) multidisciplinary research, (iii) participation, (iv) sustainability, (v) gender equity, and (vi) knowledge transmission (Charron, 2012). Second, it was discovered that using the Eco-Health approach enabled for both the development of response plans as well as the rapid and comprehensive evaluation of health and environmental risk exposure routes. The study used an Eco-Health approach that focused solely on environmental, health, and opinion assessment.

Multiple assessments of wastewater, soil, and food quality, as well as risk factors, were carried out. The Eco-Health approach was then used to assess environmental and health risks. As shown in Figure 2, the Eco-Health approach examined the following components: (i) the problem description; (iii) the diagnosis of causes and potential effects; (ii) the map of health and environmental risk factors in the various neighborhoods of Yopougon Nouveau quartier; and (iv) the development of a customized intervention plan with stakeholders. This facilitated the ability to describe the distribution and mitigation of the risk patterns in the study area with greater accuracy. The objective of this study is to use social dimensions to show how better liquid and solid waste management and access to sanitation facilities benefit the environment and people's health in Yopougon Nouveau quartier. Equal access to sanitary facilities is referred to as "social equity," and safe neighborhoods are necessary for the social determinants of health to function. Key stakeholders such as, the Water Distribution Company (Sodeci), National Office of Sanitation and Drainage (ONAD), sanitation department of the Ministry of Construction and Urban Planning (MCU), Ministry of Hydraulic, Directorate of Urban Waste and Drainage (DAUD), The technical services of the District of Abidjan and the office of the deputy mayor of Yopougon municipality, National Office of Technical Studies and Development (BNETD) and some Pit emptier association participated in a workshop to share their perspectives on the ecology and health of the study area. Following the development of the action plans based on the results of the stakeholder engagement, some of them were selected for the implementation phase.

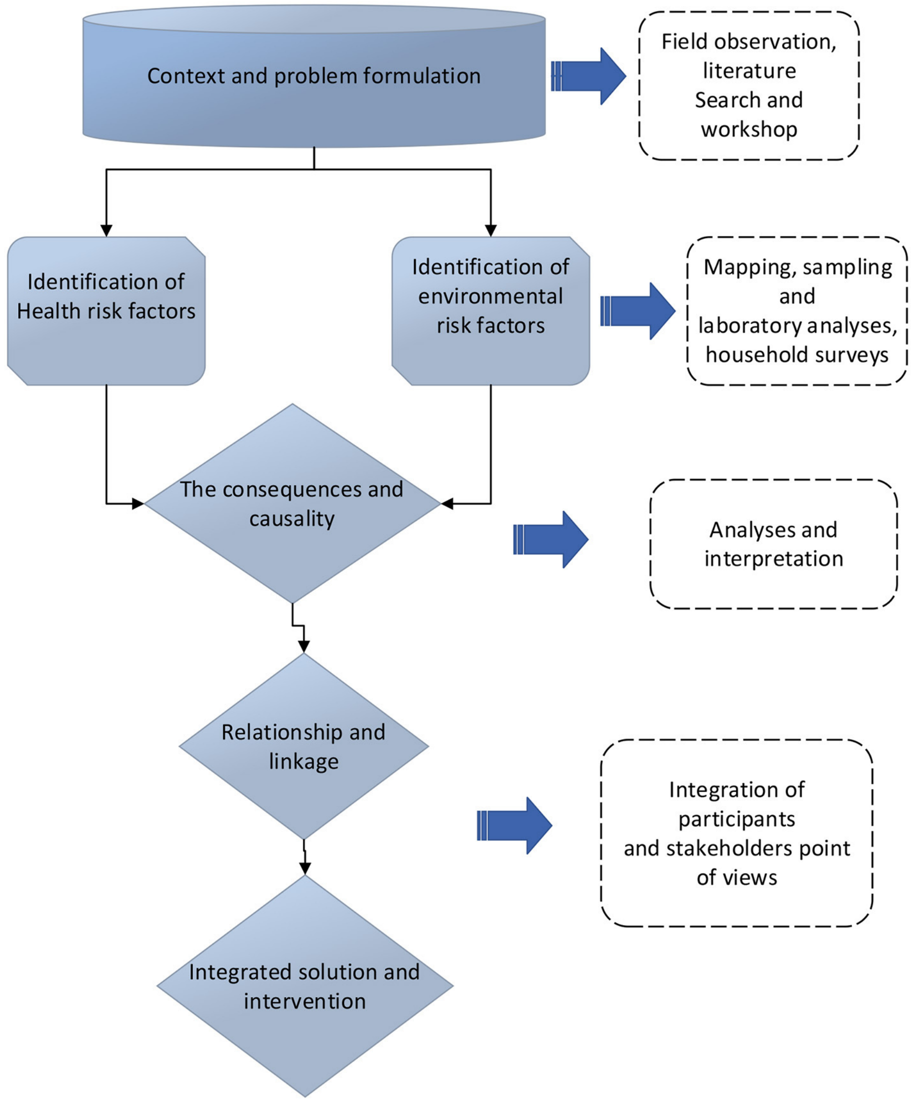


FIGURE 2
Integrated framework for environmental and health risk analysis.

## 2.3. Semi-participatory workshop

In June 2021, a three-day workshop was organized. The key participants were chosen based on the research objectives and the implications for collective sewage system management in the study area. A total of eight (8) stakeholders (which involved 210 participants), including non-governmental organizations, the general public, and representatives from the municipal, health, urban planning, and sewage management sectors of Yopougon, participated. Understanding the requirements and limitations of providing sanitation and health services in the research area was the workshop's key objective. The program followed a set process that consisted of five key steps: (i) identifying key participants; (ii) presenting the study's purpose to participants; and (iii) conducting focus group discussions; (iv) a summary of the key groups' findings; (v) a public discussion in which each group's delegate reported the primary findings. The facilitator produced a final list of action suggestions during this last phase.

## 2.4. Mapping approach for the investigation of environmental and health risk factors

Solid waste discharges on sewer manholes, uncontrolled and defective connections in various neighborhoods, are mapped to show their spatial distribution and exposure routes. Geographical surveys using a Garmin GPS etrex 10 were used to geo-reference the study's main critical mapping points in May and June 2021. UTM (Universal Transverse Mercator) coordinates were used to locate the points. The survey focused on the identification of solid waste on manholes and collectors, the identification of uncontrolled

TABLE 1 Identification and location of the different sampling points on the sewer network.

| Identification | Location | Number of samples | | |
|---|---|---|---|---|
| | | Wastewater samples | Food samples | Soil samples |
| **Upstream** | At the top of the main network collector (Lama Fofana, Denver and Sans Loi districts) | 11 | 5 | 3 |
| **Middle stream** | On the main network (Nouveau Bureau, Camps Militaire districts) | 11 | 5 | 3 |
| **Downstream** | The wastewater and rain water outfall at the Saint Francois roundabout (Sideci Iroko district) | 11 | 5 | 3 |
| **Total** | Across the entire network | **33** | **15** | **9** |

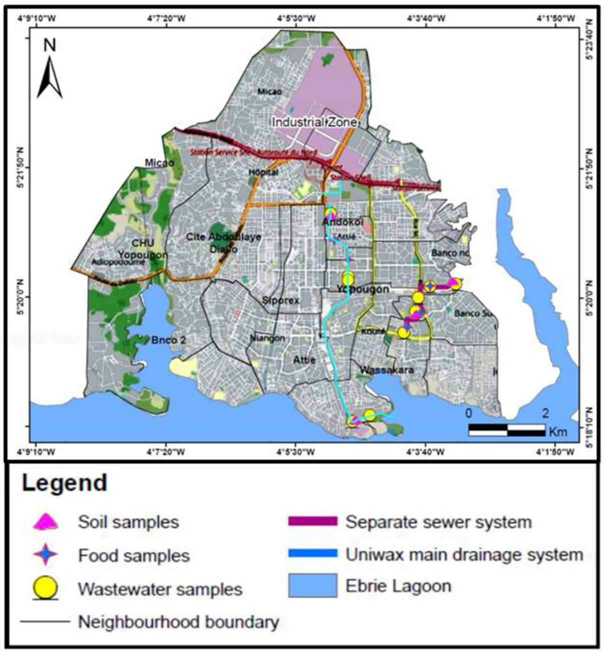


FIGURE 3
Sampling area for wastewater, soil and food.

wastewater connections to collectors, and the availability of sanitary facilities (sewers).

## 2.5. Sampling and laboratory analyses

33 wastewater samples were taken from the entire network in the three different sectors that constitute the study area (Table 1). Also, 9 soil samples and 15 food samples (5 attieké samples, 5 rice samples and 5 sauce samples) were collected along the collector.

Sampling was carried out from 25 to 27 April 2021. As the network was represented by the manholes, the samples were taken directly from the main sewer at the dysfunctional manholes. The sampling, transport and conservation of the samples were following with the protocol defined by (AFNOR, 2001) and Rodier (2009). Figure 3 shows the sampling points along the 21/22 collector.

## 2.6. Physico-chemical and bacteriological characterization of wastewater

### 2.6.1. Physico-chemical analysis

The physicochemical analysis of the samples was carried out following with the guidelines of the Association Française de Normalization (AFNOR, 2001). According to the standard sampling guidelines (Rodier, 2009), and "Water Quality in Environmental Monitoring," the samples were stored in plastic bottles and placed in a physiochemical filled cooler (Reference: FD T90-523-1 2008, T90-523-1). Nitrates ($NO_3$) were measured directly in the laboratory using molecular absorption spectrophotometry. Nitrates produced a yellow-colored sodium paranitro-salicylate in the presence of sodium salicylate (Rodier, 2009). The pollution parameters, specifically Biological Oxygen Demand (BDO), Chemical Oxygen Demand (COD), and Total Nitrogen (TN), were analyzed using an adapted protocol to determine the level of degradation of the wastewater that necessitates intervention measures. Temperature (°C), conductivity (S/cm), pH, and dissolved oxygen (mg/l) were measured *in situ* with a HANNA HI 98130 Multi-parameter. All analyses were performed on raw samples. The HACH version 26197-94 was used in the laboratory to measure BOD (mg/l). The Potassium Dichromate Titrimetry method was used to calculate COD (mg/l) (Reference: NF T 90-101-2001). After mineralization with Selenium, we used the ISO 5663-1984 standard for TN (mg/l). The salicylate method, program 385N, HACH DR/2400, was used to determine the nitrate concentration in the water, $NO_3$ (mg/l).

The analysis of these parameters allowed us to assess the level of chemical contamination associated with the study area's urban liquid waste management system. The choice of chemical parameters was made to assess the environmental and health risks in the study area. The laboratory results obtained for nitrogen concentrations also contributed to the modeling of nitrogen flows in the environmental sewage system in Yopougon Nouveau quartier.

### 2.6.2. Bacteriological analysis

#### 2.6.2.1. Stock sample preparation

One gram of cooked rice samples was grounded with 9 ml of sterile distilled water. Whereas, 1 g soil sample was mixed with 9 ml sterile distilled water and vortexed to mix well to form a 1:10

w/v (w/v = weight per volume) stock of cooked rice and soil. Wastewater was used directly for stock.

#### 2.6.2.2. Microbiological analysis

Microbiological evaluation included enumeration of total coliform and E. coli count. Serial dilutions up to $10^5$ were prepared for the determination of Total Viable Count (TVC) using the pour plate method for the isolation of microorganisms. 0.5 ml of serially diluted sample was pipetted in each Petri plate with 25 ml of MacConkey agar medium. The Petri plates for Total Coliform Count (TCC) and E. coli count (ECC) were incubated at 37°C for 24 h and 44.5°C for 24 hrs respectively. The microbial load of the cooked rice and soil samples were calculated per gram of sample whereas per 100 ml for wastewater. The analyses were accomplished in triplicate trials per sampling site.

## 2.7. Household survey

To assess the health impacts and the perceptions of local residents about the potential diseases, individual interviews were conducted on households. These interviews also assisted in understanding the common wastewater and household waste management practices in the study area. The different interviews were conducted in the dry season (the month of March 2021) and in the rainy season (the month of July 2021). This was to monitor, in real-time, the level of propagation and stagnation of wastewater on both sides of the houses during these two periods. Respondents were randomly selected from households located on both sides of the collector in areas where more malfunctioning manholes discharging wastewater on the surface were observed. Households whose head of house or representative agreed to answer the questionnaire were selected. The overall questionnaire covered the residents' perception of diseases related to stagnant wastewater, their experiences during floods, socio-economic characteristics, waste, and sewage management. The method that was used was the on-site questionnaire at the respondent's residence where the interviewer helped the respondent to fill the questionnaire. As the survey involved all social classes, this provision was made to take into account the equity in the choice of households impacted by the surface overflow of wastewater by the 21/22 collector.

In addition, respondents were free to choose to complete the questionnaires according to their interest in the study. The variables pursued included household characteristics, the effect of dysfunctional manholes on family structure, the health impact of sewage and solid waste discharge, etc.

As the study focused on populations exposed to sewage in dwellings in Yopougon Nouveau quartier, the questionnaire was administered to 245 households, randomly selected on either side of the collector by trained interviewers. Households in the three zones were selected using random sampling (stratified simple random sampling method with proportional distribution) (Statistic Canada, 2010), with the selection criterion being exposure and vulnerability as determined by Kablan (2017). Indeed, most of the households interviewed had been affected by several diseases. Each interview was conducted for an average of 25 min.

The sample size was determined using stratified simple random sampling with proportional allocation, as outlined by (Statistic Canada, 2010):

$$n = \frac{z^2 P\,(1 - P)}{\left(\frac{z^2 P(1-P)}{N} + e^2\right)} \tag{1}$$

In this formula, **n** represents the minimum sample size to be interviewed, $\mathbf{Z^2}$ is the desired confidence level (e.g., 1.96 for a 95% confidence level), **P** is the proportion of households expected to have the desired characteristics (between 0.0 and 1.0). If the proportion of households with the desired characteristics is unknown, it is assumed to be 50% (0.5). $\mathbf{e^2}$ is the margin of error allowed (at a statistical risk of 5%), and **N** is the total population size.

The population size (N) for this study was based on the National Institute of Statistics INS (2014) census, which reported a total population of 1,071,543 inhabitants in Yopougon. To apply the sample size formula, it was assumed that $P = 0.5$, $Z = 1.96$ for a 95% confidence level, and $\mathbf{e} = 0.05$ for the margin of error. This resulted in a calculated sample size of 226 households, which was deemed representative of the Yopougon Nouveau quartier. However, due to potential refusals from respondents during the survey, the sample size was readjusted to account for an estimated response rate of 80%. Using the formula, the adjusted sample size was determined to be:

$$n' = \frac{n}{r} \tag{2}$$

Where:

**r**: the expected percentage of respondents; **n'**: represents the size of the population to be interviewed; **n**: the minimum size of the population to be interviewed.

The initial population size to be surveyed was 236 households, but an additional 09 households were included in the sample to enhance its representativeness. Thus, the final sample size was 245 households, which were distributed proportionally across all neighborhoods using Equation 3.

$$nf = \frac{Xi}{s} n' \tag{3}$$

In this formula; **nf** represents the number of inhabitants to be interviewed per neighborhood; **xi** refers to the surface area of each neighborhood; **S**, the total surface area of the area likely to apply collective sanitation; and **n'**, which is the total number of people to be interviewed. Additionally, Table 2 provide information about the distribution of the number of respondents per household in the two study areas.

## 2.8. Statistical analyses

The data collected for the physicochemical and bacteriological characterization were processed using Statistica 7.1 software. This software made it possible to obtain the arithmetic means and the related standard deviations. In addition, two non-parametric tests (Kruskal–Wallis and Mann–Whitney tests) at a significance level of $\alpha = 5\%$ ($p < 0.05$) were applied to the data. SPHINX software (Ver.5.1) was used to analyze the household survey data using descriptive and inferential analytical methods at a statistical

TABLE 2 Distribution of the number of respondents along the 21/22 collector.

| Total number of respondents | Total surface area (km$^2$) | Zones | Surface area by zone (km$^2$) | Number of respondents by zone | Percentages (%) |
|---|---|---|---|---|---|
| | | Upstream | 12.6 | 102 | 41.63 |
| 245 | 27.63 | Midstream | 8.2 | 81 | 33.06 |
| | | Downstream | 6.83 | 62 | 25.31 |

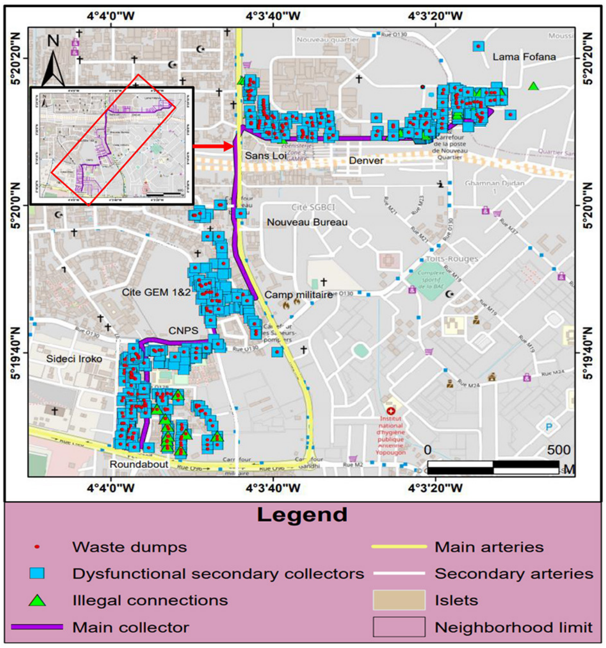


FIGURE 4
Spatial distribution of disease transmission pathways along the collector (Ouattara et al., 2023).

significance of 5% error (0.05), i.e., at a 95% confidence level. Descriptive statistics was used to examine the socioeconomic profile, residents' perceptions of potential diseases, and their liquid and solid waste management practices. Cronbach's alpha reliability ($\alpha = 0.69$) was used to assess the internal validity of the Likert scale results. This implies that the data collection instrument was 69% reliable and will yield similar results if the study was repeated. To understand the behavior of the parameters studied, univariate analysis was used to calculate percentages, frequencies, and means.

# 3. Results

## 3.1. Public perception of environmental and health threats and spatial distribution of risk factors

According to the findings of the participatory workshop, the majority of participants are concerned about the deteriorating environmental and health conditions in the study area. Furthermore, they emphasized the negative effects of poor wastewater management due to progressive sewer dysfunction, solid waste, groundwater contamination, and disease load dynamics such as cholera, dysentery, diarrhea, and typhoid fever. However, the health risks associated with uncontrolled connections and waste disposal in drains are not well understood in Yopougon Nouveau quartier. During the workshop, participants suggested the reconstruction of the pipes in the damaged areas, as well as a complete cleaning of the network from upstream to downstream to facilitate the proper drainage of wastewater. It was proposed that the municipality of Yopougon should implement a plan to collect solid waste in the study area on a regular basis. Furthermore, mapping solid waste dumping sites and points of dysfunctional manholes discharging a mixed wastewater-waste combination on the surface allowed for the identification of the most vulnerable areas along the collector and facilitated subsequent intervention. Furthermore, the findings of the field observations, in conjunction with the geographical surveys, revealed a variety of exposed pathways in the study area. Sewage and solid waste were found openly dumped near homes, markets, and restaurants. The residential districts, where many sewage discharge sites from blocked manholes were identified, were gradually deteriorating and had unequal access to sanitation facilities. The distribution of the various risk variables in the research area is depicted in Figure 4.

## 3.2. Environmental pollution and health risk

### 3.2.1. Variation of physico-chemical parameters of wastewater along the 21/22 collector

The Kruskal-Wallis test was used initially to determine the variability of the physicochemical parameters of the different environments. If this test showed a significant difference at a risk of $\alpha = 5\%$ ($p < 0.05$), the differences between the groups were located by the Mann–Whitney test at a risk of $\alpha = 5\%$. The results of these tests are presented in Table 3. This table describes the spatial variations of the physicochemical parameters of the sewage network effluents according to the sites. From the results of the Kruskal Wallis test, there is a significant difference in the variation of parameters such as nitrates, COD, and total nitrogen. Furthermore, there were significant differences at the 5% level in pH, temperature, dissolved oxygen, conductivity, total dissolved solids (TDS), and BOD.

#### 3.2.1.1. Physical parameters

The considered physical parameters include temperature, pH, conductivity, TDS and dissolved oxygen. The temperature of the effluent showed higher variations in the midstream and downstream sectors than upstream and remained closed to the

TABLE 3 The level of physicochemical parameters in wastewater.

| Parameters | Sampling Sites | | | Average | WHO standard |
|---|---|---|---|---|---|
| | Upstream | Midstream | Downstream | | |
| DO (mg/l) | 8.76 ± 0.06 | 8.935 ± 3.2 | 7.27 ± 0.85 | 8.3217 ± 1.69 | ≥5 |
| BOD (mg/l) | 278 ± 195.16 | 513 ± 52.33 | 645 ± 391.74 | 478.667 ± 257.88 | 100-150 |
| COD (mg/l) | 940 ± 650.54 | 2350 ± 1626.34 | 4050.5 ± 71.42 | 2446.83 ± 1598.54 | 250-500 |
| $NO_3$ (mg/l) | 146 ± 0.01 | 1347 ± 0.12 | 959 ± 0.09 | 817 ± 0.09 | ≤50 |
| TN (mg/l) | 525 ± 0.02 | 3036 ± 0.3 | 3077 ± 0.3 | 2212 ± 0.23 | 1 |
| Temperature (○C) | 27.095 ± 0.18 | 27.715 ± 0.4 | 27.44 ± 0.28 | 27.4167 ± 0.36 | 20-28 |
| Conductivity (μS/cm) | 304 ± 25.46 | 259 ± 117.38 | 1531.5 ± 474.47 | 698.167 ± 681.9 | ≤400 |
| pH | 7.105 ± 0.19 | 7.16 ± 0.95 | 7.315 ± 0.05 | 7.1933 ± 0.44 | 6.5-9 |
| TDS (mg/l) | 151 ± 9.9 | 433 ± 387.49 | 766 ± 237.59 | 450 ± 342.28 | 50-150 |

Data is presented as mean ± standard deviation. DO, Dissolved Oxygen; BOD, Biological Oxygen Demand; COD, Chemical Oxygen Demand; $NO_3$, Nitrate; TN, Total Nitrogen; TDS, Total Dissolved Solids.

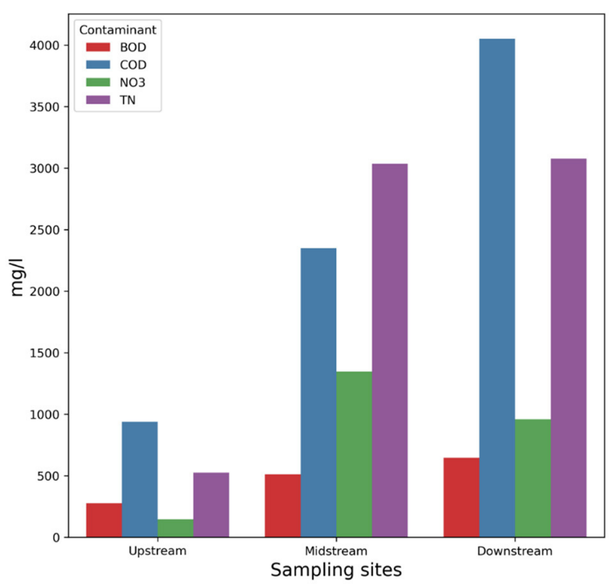


FIGURE 5
Variation of chemical parameters in different sampling site along the collector.

average annual temperature of the region, i.e., 27°C. Also, the pH variations were higher in the Midstream and downstream wastewater compared to the upstream section. Also, the average TDS values for all sampling points were above the WHO tolerance limits for wastewater. The electrical conductivity ranged from 259 ± 117.38 μS/cm to 1531.5 ± 474.47/cm, and was higher upstream and downstream than in the midstream wastewaters. The average electrical conductivity of the wastewater from the 21/22 collector was more than the WHO recommended value (≤400 μS/cm). The amount of dissolved oxygen in all the sampling points greatly exceeded the WHO standards, whose threshold value is 5 mg/l.

#### 3.2.1.2. Chemical parameters

For the chemical parameters, the concentration of COD in the effluent was higher in the midstream (2350 ± 1626.34 mg/l) and downstream (4050.5 ± 71.42 mg/l) than upstream (940 ± 650.54 mg/l). In addition, the COD values in the three sectors were above the WHO threshold value, which is between 250 and 500 mg/l. As for the BOD, the concentrations, ranging from 278 ± 195.16 to 645 ± 391.74 mg/l for all the sampling points, were also above the WHO tolerance limits of 100 to 150 mg/l. The $NO_3$ and TN ion concentrations and threshold values in the wastewater of the three sectors are shown in Table 3. These parameters are indicators of pollution which can potentially endanger the health of the population. The values of these parameters in the analyzed wastewater were variable; varying between 146 ± 0.01 mg/L and 1347 ± 0.12 mg/l for nitrates and 525 ± 0.02 to 3077 ± 0.3 for total nitrogen. The nitrate and total nitrogen contents of the wastewater in all sampling points were above the WHO threshold value (≤50 mg/l for $NO_3$ and 1 mg/l for TN). Therefore, the analyzed wastewater samples were subject to the risk of nitrate and nitrogen pollution. Figure 5 shows the variation of these parameters in the different zones.

### 3.2.2. Variation of bacteriological parameters of wastewater along the 21/22 collector

The microbiological analyses showed the presence of total coliform bacteria (TCC) and E. coli (ECC) (see Table 4). In general, the TCC and ECC values were higher at the upstream and midstream of the collector compared to downstream for the soil samples (TCC Upstream: $6.5 \times 10^3$ cfu/g; TCC Midstream: $8.0 \times 10^2$ cfu/g; TCC downstream: $2.4 \times 10^1$ cfu/g) (ECC Upstream: $3.4 \times 10^2$ cfu/g; ECC Midstream: $2.2 \times 10^1$ cfu/g; ECC downstream: $1.2 \times 10^1$ cfu/g).

For the food samples, the concentration of TCC and ECC were also higher upstream and midstream of the collector compared to downstream (TCC Upstream: $4.7 \times 10^1$ cfu/g; TCC Middle: $3.4 \times 10^2$ cfu/g; TCC downstream: $1.1 \times 10^1$ cfu/g) (ECC Upstream: $2.0 \times 10^0$ cfu/g; ECC Middle: $3.2 \times 10^1$ cfu/g; ECC downstream: $1.0 \times 10^2$ cfu/g).

The microbial count in the wastewater sample for TCC (Upstream: $8.3 \times 10^2$ cfu/100 ml; Midstream: $7.2 \times 10^2$ cfu/100 ml; Downstream: $2.2 \times 10^4$ cfu/100 ml) and ECC (Upstream: 11.9

TABLE 4 Microbial load in food, soil and waste water across sampling sites.

| Parameters | Sampling sites | | | Average | WHO standard |
|---|---|---|---|---|---|
| | Upstream | Middle stream | Downstream | | |
| **Soil sample** | | | | | |
| Total coliform count (cfu/g) | $6.5 \times 10^3$ | $8.0 \times 10^2$ | $2.4 \times 10^1$ | $2.4 \times 10^3$ | |
| *E. coli* count (cfu/g) | $3.4 \times 10^2$ | $2.2 \times 10^1$ | $1.2 \times 10^1$ | $1.2 \times 10^2$ | |
| **Food sample** | | | | | |
| Total Coliform count (cfu/g) | $4.7 \times 10^1$ | $3.4 \times 10^2$ | $1.1 \times 10^1$ | $1.3 \times 10^2$ | |
| *E. coli* count (cfu/g) | $2.0 \times 10^0$ | $3.2 \times 10^1$ | $1.0 \times 10^2$ | $4.5 \times 10^1$ | |
| **Wastewater sample** | | | | | |
| Total coliform count (cfu/100 mL) | $8.3 \times 10^2$ | $7.2 \times 10^2$ | $2.2 \times 10^4$ | $7.9 \times 10^3$ | $\leq 1.0 \times 10^3$ |
| *E. coli* count (cfu/100 mL) | $11.9 \times 10^1$ | $9.9 \times 10^1$ | $2.7 \times 10^3$ | $9.7 \times 10^2$ | $\leq 1.3 \times 10^2$ |

Data is presented as TCC, Total Coliform count; ECC, E. coli count.

$\times$ $10^1$ cfu/100 ml; Midstream: $9.9 \times 10^1$ cfu/100 ml; Downstream: $2.7 \times 10^3$ cfu/100 ml) were highest upstream followed by the Midstream: with the lowest count downstream. Compared to the WHO wastewater standard, all wastewater sampled along the collector had TCC and ECC above the WHO threshold of $\leq 1.0 \times 10^3$ cfu/100 mL for TCC and $1.3 \times 10^2$ cfu/100 mL for ECC.

## 3.3. Socio-economic characteristics of households and description of the housing in the study area

This section presents the results of the household survey conducted on the inhabitants along the 21/22 collector. A total of 245 households were interviewed. A total of 74.1% ($n = 182$) were men and 25.9% ($n = 63$) were women aged between 18 and 55 years. The responsibility of the head of the household was assigned to men in 77% of the cases, compared to 23% for women. Each head of household had an average of 6 dependents. Figures 6A, B show the level of education of the respondents and their monthly household income.

With regards to the level of education, the analysis in Figure 6 shows that more than half of the respondents (59.6%, $n = 146$) had attended a formal school and 7.2% ($n = 18$) reported having studied in a Koranic school. On the other hand, 33.2% ($n = 81$) of the respondents had not received any formal education. In addition, the majority of households (88.4%) lived in common yards. Indeed, regarding the average monthly income of the heads of households, 24% of the working population had a monthly income between USD 97.80 and USD 163.00; 11% of the working population earned between USD 244.50 and USD 326.00 per month; 9% of the working population had a monthly income of about USD 489.00 and 56% were unemployed.

The level of the built environment was quite diverse in the study area and was marked by four main groups classified according to the decreasing structural standards (Figure 7). The structures were grouped into residential houses which are high-standard houses; "economic" houses which are modern dwellings; "evolving" houses, which are characteristic of a group of houses usually overlooking a common courtyard; and "slum" houses which are characterized by disordered settlements. Most of the houses along the drains were dominated by basic and evolving dwellings generating a large amount of solid waste that was eventually emptied into the urban sewerage system.

## 3.4. A defective sewage system

In Yopougon Nouveau quartier, the wastewater discharged into the courtyards and the street are emptied through the main sewer and the secondary sewers, which were mostly blocked (see Supplementary Figure S1).

This neighborhood has a collective sewage, rainwater and black water system. The infrastructure observed was the sewage system and the gutters. The existing open-air rain water drains were located on the edge of the asphalt road. They have been transformed into dumping sites for waste and are clogged with sand (see Supplementary Figure S2). Inadequate maintenance has made it difficult to drain rainwater, especially during the rainy season. The sewage system was completely blocked and almost non-existent in some areas, and the lack of sanitation is pushing households to dump wastewater in the streets, alleys and open areas. The wastewater stagnates in the streets and within the neighborhood.

## 3.5. Poor management and disposal of household waste and sewage in the different neighborhoods along the collector

Among the residents living along the 21/22 collector, 62.24% of the household's own garbage bags. Thus, 58.6% deposit their

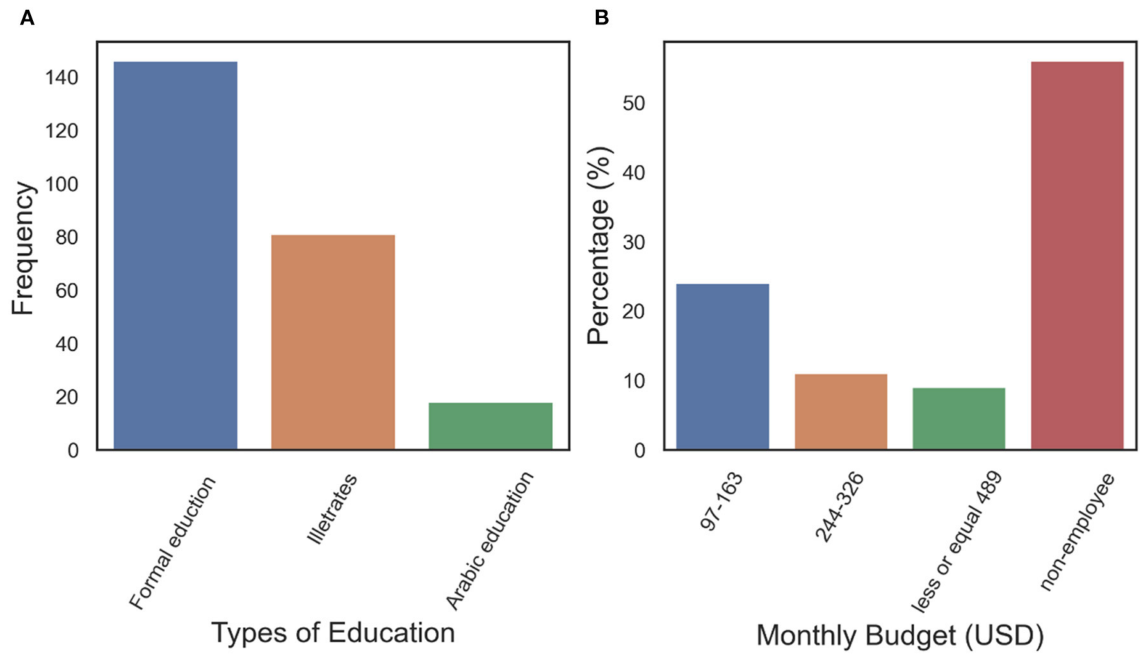


FIGURE 6
Distribution of monthly household budget and education level of the respondents. **(A)** Distribution of monthly household budget. **(B)** Respondents' level of education.

garbage bags on the dysfunctional manholes which end up in the network. Of the remaining 37.6% without garbage bags, 29.43% deposit their waste directly into the sewer especially in areas such as Lama Fofana, Denver, Sans Loi, Nouveau Bureau and Camp Militaire. However, 11.65% use pre-collectors for waste collection (see Supplementary Figure S3). These pre-collection services were used exclusively in midstream and downstream.

Also, several commercial activities were observed in the area generating about 32% of the waste found in the sewer. As regards wastewater, poor management was observed throughout the area. Several uncontrolled connections were observed on the networks for the evacuation of liquid waste, generating large quantities of water in the systems. Most of the wastewater discharged by local residents and wood companies were loaded with chemical effluents and solid objects that jeopardize the functioning of the collector. This wastewater was discharged at varying frequencies depending on the household, industrial and commercial activities in the area. Also, as the collector was partly blocked by solid waste, several families have created septic tanks for the evacuation of their wastewater.

## 3.6. A strong link between poor sanitation and the risk of disease

Yopougon Nouveau quartier is a neighborhood characterized by a total lack of maintenance of the sewage system, which favors the proliferation of wastewater throughout the neighborhood. The runoff and domestic wastewater (bath, laundry, dishes and black water) that stagnate in the street were due to the malfunctioning of the sewage infrastructure such as gutters and sewage networks. Wastewater was a risk factor for disease because it was a breeding ground for disease vectors. Indeed, the risk of disease was higher among populations living near liquid waste (exposed subjects) than those living far from wastewater and rainwater stagnation points (unexposed subjects) in Yopougon; the relative risk (RR) was 6.33, which shows the increased risk of disease (households cohabiting with wastewater had a 6.33 times higher probability of registering cases of disease than households located far from wastewater points). A percentage of 38.6 of the illnesses suffered by the population of Nouveau quartier were attributed to the proliferation of uncontrolled waste disposal sites and 61.4% were attributed to the proliferation of sewage points and the stagnation of rainwater, which are breeding grounds for disease vectors.

## 3.7. Socio-economic and environmental consequences

The field surveys identified several environmental and socio-economic problems related to the malfunctioning of the urban sewage systems in the study area. The problems affecting the urban technical networks were poorly drained wastewater, the obstruction of wastewater and rainwater drainage systems, and the rupture of pipes leading to the backflow of wastewater to the road. The consequences include the destruction of urban infrastructure, the reduction of the life span of urban networks, particularly the roadway which had become impassable, and the slowing down of economic activities. Also, the pollution of the urban environment generates insalubrity and foul odors. The environmental problems

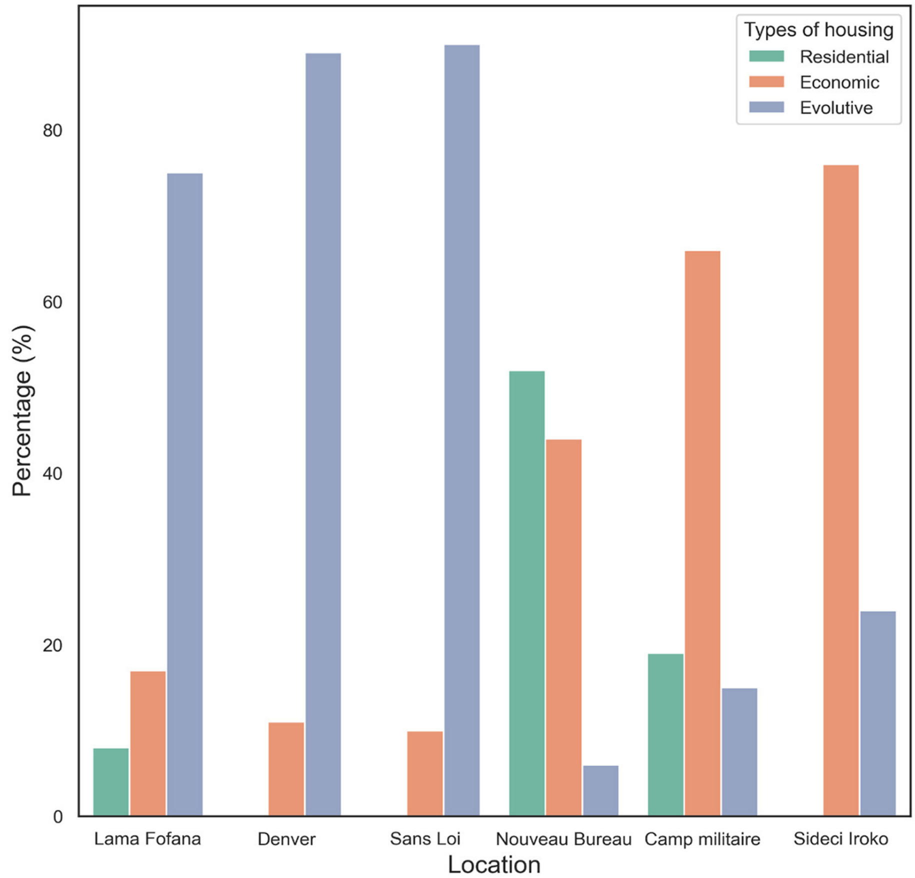


FIGURE 7
Distribution of housing in the study area.

caused by highly charged wastewater were a concern in the study area. These include the pollution and degradation of the quality of the lagoon where all the wastewater is discharged, leading to the loss of aquatic species, the contamination, erosion, and gullying of the soil. There is progressive deterioration of the living environment in Lama Fofana, Denver and Sans Loi such as the damage of urban heritage, the rising insalubrity in the neighborhood, the risk of diseases, the reduction in socio-economic activities and the increasing risk of accidents. Also, there is atmospheric pollution with the release of nauseating odors, exposing the inhabitants to intestinal diseases. In addition, sanitary problems caused by the non-treatment of wastewater and its stagnation in gutters have been identified in the area. This is a major cause of the proliferation of disease vectors (mosquitoes, flies, cockroaches and rodents) and foul odors. The presence of pathogenic microbes in wastewater was a source of contamination of drinking water following infiltration (the case of Lama Fofana, Denver and Sans Loi boreholes), soil and food, thus exposing local residents to waterborne diseases.

## 3.8. Perception and health profile of residents in Yopougon Nouveau quartier

The poor management of solid waste along the collector exposes residents to certain diseases. According to the households surveyed, this situation is the cause of several diseases such as: (i) malaria, (ii) respiratory infections, (iii) diarrhea, (iv) typhoid fever, (v) cholera and (vi) intestinal diseases. The many dysfunctional manholes along the length of the collector, discharge a mixture of waste and wastewater. Stagnant in some places, this wastewater was perceived differently by the residents. Thus, contrary to the 5% of respondents who think that this wastewater has no impact on their health, 95% of respondents stated that this wastewater was the main source of diseases affecting them. Several families declared that they had been victims of one of these diseases. Indeed, the participatory epidemiological survey revealed that over the last 3 years before the study, residents had been victims of diseases such as malaria, which was frequently reported in the area and whose rate varied between the different neighborhoods (ranging from 81 to 90%), and respiratory diseases, with a higher proportion in the Upstream (79%). In addition, several households reported incidents of diarrhea, the frequency of which varied from 36 to 61% per zone. Also, residents were victims of diseases such as typhoid fever and intestinal diseases with prevalence rates ranging from 26 to 32% and 33 to 59% respectively as shown in Figure 8.

# 4. Discussion

The application of transdisciplinary research could help developing countries to improve both the wellbeing of people and

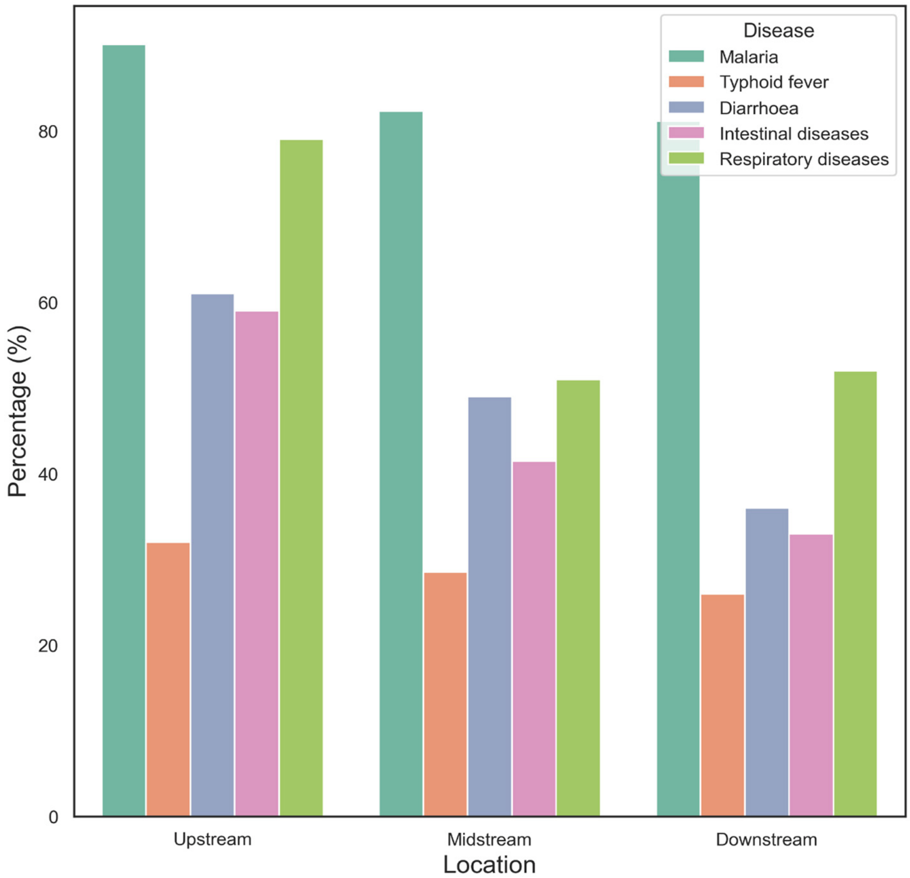


FIGURE 8
Percentage of households in the communities along the 21/22 collector that have reported disease incidences in the 3 years.

the environment (Kablan et al., 2019). Poor solid and liquid waste and sewage management practices are associated with economic development in these countries, contributing to the progressive deterioration of urban sanitation systems (Zia et al., 2013). In this study, a framework for assessing factors related to human and environmental health was evaluated, including urban waste management systems (liquid and solid waste) and human practices. It was found that the clogging of sewers by household waste promotes a progressive dysfunction of the network in Abidjan, Côte d'Ivoire, which harms environmental quality, human health and wellbeing, particularly in the Yopougon Nouveau district (Dongo et al., 2010).

Consequently, it is therefore essential to take immediate action to reduce the health problems associated with urban waste in these areas. The workshop adopted solutions such as the reconstruction of damaged collectors, gradual cleaning of the collectors, construction of additional sanitation infrastructures, legal connections made only by Sodeci to the base collector, and the implementation of an effective solid waste collection system with a participatory framework including residents, pre-collectors, the Yopougon municipality, and neighborhood leaders.

This project enabled the population to have a clearer orientation on the good methods of connections to the collector and to better understand the impacts of poor solid waste management on their environment. A study by Fofana on the diagnosis of the functioning of the domestic sewage systems in the Andokoi district, discussed the lack of sanitation in Yopougon and focused on blockages and the progressive dysfunction of the sewers linked to poor waste management (Fofana, 2017). Annual reports from health authorities in the study area mentioned several cases of malaria, diarrhea, typhoid fever, intestinal diseases and respiratory infections. Surveys carried out in the health centers of Nouveau quartier showed that there have been 3,200 malaria victims, 2,712 diarrhea victims, 1,320 patients of intestinal diseases, 1,800 patients of respiratory diseases and 960 victims of typhoid fever in the last 2 years. It should be noted that several diseases coexist in the study area as a result of progressive malfunctioning of the collector and it is therefore difficult to clearly differentiate between them without thorough clinical or microbiological examinations (Clasen and Haller, 2008). The present research investigated the potential health effects and environmental impacts of discharges of a mixture of solid waste, untreated surface sewage and human excreta discharged directly into the environment from the network.

The participatory workshop revealed that the local population was concerned about the environmental threats and health problems that could be caused by the poor quality of wastewater discharged to the surface from the 21/22 collector. The main contributing factors to poor management of urban waste and environmental deterioration were evaluated. The lack of solid waste removal, the difficulty in getting sanitation services, and the inequity in sanitation services in some locations were shown by mapping solid waste disposal sites on dysfunctional manholes and defective housing connections. The spatial distribution of critical areas, such as waste disposal sites and defective house connections to the sewer system, were highlighted by mapping these factors. These practices are much more concentrated in the upstream part at the level of the main collector and especially the secondary collectors (Lama Fofana, Denver and Sans Loi) and downstream (Sideci Iroko), precisely at the level of the secondary collectors.

The wastewater was evacuated by a sewer network that was dysfunctional and was characterized by overflows and surface discharges of a wastewater/garbage mixture with very strong nauseating odors. Thus, the characterization of the wastewater consisted of the determination of physicochemical and microbiological properties in order to evaluate the environmental and sanitary impact. According to the results of the analyses, the quality of the effluents along the entire length of the collector was variable, with increasing concentrations of the contents measured from upstream to downstream of the drainage network and did not meet the standards required by the WHO (Table 3). Organic chemical pollution was determined by analyzing COD and BOD. The average concentrations obtained were 478.667 $\pm$ 257.88 mg/l and 2446.83 $\pm$ 1598.54 mg/l and remained above the wastewater discharge standards recommended by the WHO. In addition, the biodegradability indices (COD/BOD) were very high, varying from 3.38 upstream, 4.58 midstream and 6.27 downstream, and indicated strong and increasing pollution of the effluents downstream. Indeed, this high ratio prompted the presence of a large proportion of non-biodegradable matter in the wastewater in the sewer system. The presence of these inorganic materials in the effluent was generally due to the direct discharge of solid waste into the sewer system and would probably be the cause of the clogging and overflow of the sewer system. A study by Leite et al. (2019) on the physicochemical characterization of wastewater in the provinces of São Carlos and São Paulo State, Brazil, highlighted that the high concentration of chemical pollutants such as BOD and COD were the result of the discharge of numerous non-biodegradable wastes into these waters, causing numerous environmental and health problems. With regard to dissolve oxygen (DO), the measured levels were generally low but slightly higher upstream and midstream than downstream (8.76 $\pm$ 0.06 mg/l, 8.935 $\pm$ 3.2 mg/l and 7.27 $\pm$ 0.85mg/l). As this wastewater lacks oxygen, it provides a suitable environment for the growth of anaerobic bacteria, especially downstream. This biological decomposition is accompanied by foul-smelling gaseous emissions, leading to odor nuisance, the development of vectors of infectious diseases, the deterioration of the urban environment and unhealthy conditions in the surrounding area. As regards nutrient concentrations (NT), the levels obtained were progressive from upstream to downstream (525 $\pm$ 0.02; 3036 $\pm$ 0.3; 3077 $\pm$ 0.3 mg/l) and largely exceeded the WHO standard. This indicates increased pollution for the residents in the midstream and downstream of the collector. The average values of the biodegradation coefficients between organic matter and nutrients (BOD/NT and COD/NT) were low (0.216–1.10) and demonstrate the strong eutrophication of the wastewater. In other terms, this high concentration of nutrients in wastewater was a source of pollution of natural resources (surface and/or groundwater) and may have consequences on human health. Gnagne et al. (2015) noted the same trend in the city of Abidjan. According to their study, the high concentration of chemical pollutants in the wastewater in Abidjan's main sewer was a major source of environmental pollution and negatively impacts the health of the population, including the residents located along the Abobo to Koumassi sewer. Elsewhere, Vidyarthi et al. (2020) noted that high concentrations of phosphorus, nitrates, ammonium, nitrites, BOD and COD were responsible for environmental damage and have affected the health of thousands of residents in India, precisely in the districts of Ghaziabad, Gorakhpur, Jaunpur, Kanpur, Mirzapur, Unnao, Bhadohi, Farrukhabad, Chandauli and Hapur as a result of contamination of drinking water by these nutrients. Consumption of water heavily contaminated with nitrates can lead to various health problems, including methemoglobinemia, stomach cancer, goiter, birth defects and high blood pressure. In addition, the high concentration of physicochemical parameters (BOD, COD and nutrients) in the midstream and downstream of the channel is explained by the fact that the network receives wastewater of various origins (industrial wastewater) from the wood industry via other collectors that flow into the 21/22 collector.

Regarding microbiological characterization, the analyses carried out concerning total coliforms (TC) and Escherichia coli (EC) and the average pollution were higher than the WHO requirements (TC $\leq$ 1.0 $\times$ 103 cfu/100 mL and EC $\leq$ 1.3 $\times$ 102 cfu/100 mL). When comparing the three sampling areas, the wastewater collected downstream of the main sewer was found to be more polluted with TC and EC than the middle and upstream wastewater. These results could be due to an accumulation of wastewater downstream of the main sewer because once the wastewater is discharged by the polluters, the sewerage system transfers the wastewater gravitationally from upstream to downstream where the water tends to stagnate. The contamination of soil and water could be explained by the direct infiltration of effluents into the soil due to overflows, contrary to that of foodstuffs, where the phenomenon takes place through the transfer of bacteria contained in wastewater to foodstuffs in the vicinity of the network by transport agents such as flies, mice and cockroaches. Summarily, the presence of these bacteria in the environment represents a danger to the surrounding population as this exposes them to various diseases (Government of Rwanda, 2016). The data from the analyses showed an uneven distribution of disease prevalence across the sampling sites. At the mid and end of the channel where the concentration of pollutants were very high, the probability of recording disease cases was higher. These results of the analysis are therefore in agreement with the observations of the households surveyed (Tables 3, 4 and Figure 8) where they attested that there was indeed a relationship between inadequate sanitation and the health of the population.

The results of the household surveys assessed the socioeconomic characteristics of the households, their level of education, their waste disposal methods their perceptions and the severity of the diseases caused by the release of hazards such as micro-organisms, contaminants from municipal waste and sewage.

Approximately 73% of the residents dump their waste in collectors. This practice could be influenced by the inhabitants' level of education where there is lack of awareness of the impacts of waste disposal in the network (Andrianisa and Brou, 2016). Monthly household income could also be a factor to this probelm. It should be noted that most of the neighborhoods along the collector do not have any rolling stock for waste collection. Thus, low-income families are forced to use the network as a dumping ground because they cannot afford the services of the pre-collectors. Households in the immediate vicinity of the sewage were more prone to diarrhea, malaria, respiratory infections, intestinal diseases and typhoid fever than those located far from the collector. Statistics test revealed that the type of residence and income level had an impact on the disease risk. A high risk of disease was observed among people living in neighborhoods with economic and progressive housing. The results of disease occurrence obtained from the surveyed households were verified at the health centers in the study area to see the veracity of the information. These results were derived from clinical analyses that were acquired from the medical facilities following diagnosis. Planning procedures to eliminate health risks from waste management should take into account information on the relationship between waste disposal, disease, and income. According to this study, high rates of malaria and typhoid were associated with poor sewage collection and waste management practices, which was indicative of the absence of modern sanitation infrastructure in the study area. Therefore, the primary factor affecting the populations' wellbeing is the interaction between social (lack of infrastructure), environmental (poor urban waste management), and health status aspects. In Faro, Portugal, a study showed that the implementation of decentralized hygiene equipment helped to reduce the frequency of diarrheal diseases by up to 40% (Lourenço and Nunes, 2020). The findings of the statistical evaluation revealed that malaria, diarrheal diseases, intestinal and respiratory diseases were most influenced by poorly managed sanitation conditions. Households in poor neighborhoods (Lama Fofana, Denver, and Sans Loi) which had illegal connections that discharged human excreta and wastewater with strong foul odors had high rate of diseases. In this research, diarrhea was attributed to a lack of hygiene, poor sewage quality, unintentional contact with waste and wastewater, and other factors. It is interesting to note that 42% of residents obtain drinking water from boreholes while 58% get their drinking water from the tap in Yopougon Nouveau quartier. Previous studies revealed that the source of household well water supply had an effect on the occurrence of diarrhea in Yopougon (Coulibaly and Zoumana, 2018). Sewage discharged from malfunctioning sewers influences the quality of well water through groundwater contamination by infiltration in most peri-urban cities and numerous studies have demonstrated that drinking of well water contributes to diarrheal infections (Omona et al., 2020). Micro-organisms, such as E. coli, is connected in the transmission of diarrhea due to the run-off and use of sewage-contaminated well water, as well as the accidental discharge of effluent into the surface network from dysfunctional and poorly managed sanitation facilities (Sy et al., 2017b).

The preferred method of examining solid and liquid waste management practices in communities was the household survey (Ouattara et al., 2021). This enabled the attitudes and risk practices of the households to be identified in relation to the management of household waste and wastewater. Here, the level of education of the inhabitants and the length of stay in the surveyed areas were relevant criteria that underline the reliability of the results. Although some residents handed their waste to the pre-collectors (11.65%), the majority of residents living along the drains (88.03%) used the drains as a public dumping ground, especially in neighborhoods with low levels of education. This situation highlights the reasons for the clogging of the drains due to the misuse of the drains by the residents. Examination of the solid waste disposal method helped to clarify on the extent of the situation. Indeed, even if some people used the pre-collectors, many residents prefer to dispose of their waste in the drains, as observed in Lama Fofana, Denver and Sans Loi. If the lack of civic-mindedness and the low level of education of the population can be considered as the main reason, the galloping demography, the accelerated urbanization and the inefficiency of the public authorities cannot be ignored.

Indeed, the rapid demographic growth of the municipalities has rendered the previously conceived urban plans and other master plans non-operational. At the same time, it has accelerated the uncontrolled development of the various districts. This increase in needs of all kinds, out of all proportion to local availability, has led to a break in the capacity of existing infrastructures, particularly in terms of rainwater and domestic drainage as well as other networks. Studies and surveys conducted in the field have revealed a greater share of several irregular settlements on both sides of the drains in the Yopougon municipality. Faced with the difficulties experienced by the municipal authorities in satisfying the demands expressed, the populations settled without the legal rightto, most often in areas unsuitable for habitation, thus creating a proliferation of precarious and unhealthy neighborhoods. This situation was at the root of the increase in all kinds of waste, which was one of the major causes of unhealthy neighborhoods, the main receptors of which were the rain water and wastewater drainage channels and the urban road network (Foorginezhad et al., 2021). Bangoura (2018), in a study on the management of solid household waste in the city of Conakry, showed that 76.6% of household waste was generated by precarious neighborhoods whose destination was the street and urban sewage systems.

In the specific area of solid waste, management remains poor in the Yopougon municipality, despite the efforts of the municipal technical services. Collection was irregular and unsystematic, and the material means of collection were insufficient and most often unsuitable and inappropriate. In the recent past, the rate of household waste collection varied from 32% (2001) to 98% (1998) over the period from 1994 to 2007 (Aké, 2008). This was found (NGambi, 2016) in five African capitals (Dakar, Bujumbura, Yaoundé, Cotonou and Nairobi). Their study showed that the rate of waste collection in all the cities taken into account does not exceed 50% and the average was 36.7%. This waste thus, ends up in the drains, causing them to malfunction.

As for wastewater management, the waste water drainage network did not sufficiently cover all the districts, even though the area seemed to be developed. For the most part, standalone sanitation was the norm in some neighborhoods: toilets with a connection to a septic tank. In areas where the groundwater table was sub-surface, it was possible that groundwater was contaminated by latrines and leaking septic tanks. Household wastewater (washing and cooking water) was mostly discharged through uncontrolled connections to the rain water network and to the public highway, as 60% of the 21/22 collector was blocked, contributing enormously to the deterioration of the environment and the pavement.

## 5. Conclusion

The deficient wastewater system contributes considerably to the degradation of the environment and has a negative impact on the health of the population. In Yopougon Nouveau quartier, the wastewater discharged into the environment through the 21/22 sewer system contributes to the unhealthy living environment and the proliferation of pathogens. In addition, poor solid waste management was also observed in the area, with a considerable impact on the environment. About 30% of households dump their waste directly into the sewer system and 58.6% deposit their waste in dysfunctional manholes that end up in the network. Regarding the state of health of the population, malaria had a high prevalence with about 84.53%, the second pathology from which the population suffers was acute respiratory infections with a proportion of about 61%, then diarrheal diseases (48.66%), followed by intestinal diseases (44.5%) and finally typhoid fever with about 28.84%. For a healthy environment without negative impact on the population, effective strategies for connecting all households to the sewage system must be undertaken. This requires a synergy of actions from stakeholders. Firstly, raising awareness and educating communities is crucial to promote responsible waste management and encourage community participation. Secondly, it is important to establish adequate infrastructure for the collection, treatment, and disposal of solid waste and wastewater. Selective sorting and recycling systems can also be implemented to reduce the amount of waste produced in the area. Additionally, the use of alternative wastewater treatment technologies such as natural treatment systems can be considered. Finally, integrated solid waste and wastewater management can be improved by promoting cooperation between different stakeholders involved in the management chain, such as local authorities, businesses, and citizens.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Author contributions

Conceptualization, methodology, writing original draft, preparation, visualization, project administration, and formal analysis: ZO. Software: ZO and ES. Validation and supervision: AK-B, KD, KA, FA, and GG. Writing review and editing: ZO, AK-B, KD, KA, FA, CI, and GG. All authors have read and agreed to the published version of the manuscript.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frwa.2023.1071686/full#supplementary-material

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