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I agree. All my data are on the SaniPath tool platform I am sharing with you as soon as possible.
Multi-pathway assessment of fecal contamination in urban areas of Abidjan: the case of Abobo Municipality

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Abstract

The presence of septic tank effluents in the street due to poor fecal sludge management (FSM) in low-income cities represents a source of fecal contamination and potential risk of fecal-oral disease transmission. This study aimed at assessing fecal contamination exposure through six exposure pathways in Abobo, District of Abidjan in Côte d’Ivoire. The public health risk was evaluated in two clusters to identify the dominant exposure pathways and to compare which populations were most exposed.

The SaniPath approach used included behavioral surveys (transect walk, household survey, school survey and community survey) and laboratory analysis. Surveys were conducted among 200 households, 6 schools and 4 community groups. In addition, 120 environmental samples were collected (in 2 clusters of 6 pathways with 10 samples per pathway per cluster). The most-probable-number (MPN or CFU) of *E. coli* was determined in samples using the membrane filtration technique. Bayesian analyses were performed to estimate the distributions of fecal concentration and contact frequency, and exposure to fecal contamination was estimated using the Monte Carlo method with 1000 iterations. The dominant exposure pathways were determined by multiplying the dose and the percentage of the population exposed, which was then log-transformed and denoted by (E). The study found that street food and gullies are the two dominant exposure pathways among the population living in Abobo. 100% of the children and between 73% and 91% of the adults are exposed to these dominant pathways in cluster I, with risks (E) ranging from 8.3 to 9.2 and from 7.4 to 8.6, respectively. In cluster II this concerns
75% to 95% of children and between 26% and 70% of adults with risks of exposure (E) that go from 5.7 to 8.1 and 5.5 to 7.1 respectively.

The study outcomes could help the authorities to structure how to target municipal wide interventions toward improving the sanitation conditions in the different neighborhoods.

**Key words: Exposure pathways, E. coli, FSM, SaniPath, Abidjan**

**Introduction**

The world is currently experiencing high rates of urban population growth. Most of this increase is expected to occur in cities in low- and middle-income countries in Africa and Asia (1). The World Health Organization (WHO) estimates that by 2100 AD, Africa will have 39% of the world's population, almost as much as Asia (1). This rapid and uncontrolled urbanization has led to several challenges, including degradation of the urban environment, global climate change, increasing water stress, infrastructure deficits and rapid expansion of poor settlements (2). In Sub-Saharan Africa, the on-site sanitation system concerns 65% and 100% of the urban population and rural population respectively (3). In Abidjan, the capital city of Côte d'Ivoire, about 60% of the households use on-site sanitation. However, there is poor management of excreta with 90% being discharged in the environment without any treatment (4), and it has been well established that environmental risk factors are an important cause of the burden of disease (5).

The Municipality of Abobo is the most densely populated area in the District of Abidjan. Previous studies in Abobo highlighted a link between solid and liquid waste management and the development of pathologies affecting the population (6) with most septic tanks overflowing into the street, while households illegally connect to open drains (7). In some neighborhoods of Abobo, microbiological contamination has been revealed in the food consumed by the population, particularly the "attiéké" food sold on the street (8). Although several studies have been carried out on sanitation issues in the municipality, the pathways of exposure, their quantification and location seem unexplored to date and need to be investigated. The few studies that have been carried out on fecal contamination have been limited to drinking water as an exposure pathway. Other potential exposure pathways for pathogen transmission have not been well studied (9). However, pathways of fecal exposure are generally interconnected and are a public health concern (9). The lack of accurate information and data may be one of the reasons that municipal authorities are inefficient in improving hygiene and health conditions.
However, the SaniPath tool used in our study allows for evaluating the exposure to fecal contamination, according to several fecal exposure pathways in the public and private domains and can assist the communal authorities in their improvement efforts (10). The tool was applied to the two clusters to assess exposure to fecal contamination, notably in gully water. Most households use the gutters in these areas for emptying their household water and sometimes also the water coming from their latrines. The SaniPath approach includes socio-environmental surveys (transect walk, household survey, school survey, and focus group) and laboratory analysis using *E. coli* detection and enumeration. The collected data are used to perform Bayesian analyses to generate the percent of the population exposed and the average fecal exposure dose. The outcomes of using the SaniPath approach can be useful for actors involved in urban sanitation management to better target interventions for specific improvements.

**Materials and methods**

**Study area**

This study was carried out in the District of Abidjan, which is located in the South of Côte d'Ivoire. This district includes 13 municipalities with different socio-demographic conditions (Fig 1). The municipality of Abobo is situated in the North of Abidjan between latitudes 5°21' and 5°32' North and longitudes 3°26' and 3°38' West and covers an area of about 100 km². It borders the Banco National Park to the west, which is the largest underground water reservoir in the District of Abidjan (11). According to the 2021 national population and housing census, Abobo has 1,340,083 inhabitants living in twenty-seven neighborhoods (12). The configuration of these neighborhoods varies according to socio-economic status (13). The average monthly precipitation varies from 19.46 mm in January to 326.34 mm in June (14). In addition, the municipality is affected by undeveloped natural hollows, some of which are used by local residents as spillways for both solid and liquid waste (15).
Data collection

The SaniPath tool uses data from behavioral (household, school, and community) and laboratory surveys to assess fecal contamination. In this study, data collection was done, according to SaniPath protocols, in the four different steps described in the figure below (Fig 2).

Fig 2. Diagram of data collection steps of the Sanipath tool. (10)
Choice of neighborhoods and exposure pathways

A literature review followed by a geographic survey was conducted to learn more about the socio-environmental conditions of the different neighborhoods in the target municipality, and the municipality area was subdivided into two groups: Cluster I and Cluster II. Cluster I is composed of unplanned and informal settlements, mainly with common courtyards. The main part of the population lives in poverty, characterized by a lack of sanitation facilities. However, Cluster II includes well planned settlements, which are made up of single-family homes. There is sanitation infrastructure and the majority of the population lives in medium- to high-income neighborhoods. Cluster I includes the Sagbé, Kennedy and Banco neighborhoods, while Cluster II comprises the Anador, Dokui and Cité Coccinelle neighborhoods.

Analysis of the exposure pathways was done by doing a transect walk through the clusters, walking the streets of the two clusters to observe the behavior of the populations, as well as noting possible sampling sites for each of the sample types. Table 1 shows the six pathways selected after this transect walk. Furthermore, due to the important number of gullies throughout the area, the sampling considered the gullies instead of surface water. In practice, gullies were observed in most of the streets we walked. These are mainly used by the population as informal wastewater drains.

Table 1. List of selected exposure pathways in the municipality of Abobo.

<table>
<thead>
<tr>
<th>Types of exposure pathways</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Open drain</td>
<td>Infrastructure built for sewage or rainwater disposal</td>
</tr>
<tr>
<td>2-Stored drinking water</td>
<td>Water stored in open or closed containers used for drinking and household purposes</td>
</tr>
<tr>
<td>3-Flood water</td>
<td>Water that stagnates for at least one hour after rain</td>
</tr>
<tr>
<td>4-Gullies (surface water)</td>
<td>Drains used mainly for household drainage and sometimes latrine water</td>
</tr>
<tr>
<td>5-Street food</td>
<td>Food sold on the street and commonly consumed by the population</td>
</tr>
<tr>
<td>6-Soil/sand</td>
<td>Portion of land, sand with which residents are most in contact</td>
</tr>
</tbody>
</table>
Behavioral surveys

The behavioral survey involved households, local communities and schools. Concerning the household survey, 100 households were randomly selected per cluster as recommended by the Sanipath tool, corresponding to 200 households. In each cluster, two groups of at least 15 people were identified for the community survey. One group was composed entirely of women and another of men (Figure 2). Regarding the school survey, three primary schools were selected per cluster (Fig 3). In accordance with the protocol of the Sanipath tool, the school selected was based on the following criteria: i) being in a cluster neighborhood, and ii) having a second grade class of less than 30 students of both girls and boys (10). At this level, the pupils can more easily understand the objectives of the study and respond to the questions.

All of the surveys contained questions on the behavior and frequency of contact of the adults and children with the fecal exposure pathways. Questions were asked about the frequency of consumption of street food and stored drinking water, and the frequency of contact with open drains, gullies, and floodwaters.

Five investigators conducted this activity for two weeks during the month of May 2021. The team was composed mainly of students who were previously trained in investigative techniques at the Felix Houphouët Boigny University. The training focused on how to introduce oneself to a household, how to present the goals of the survey, and how to address the various issues with the interviewees. Furthermore, permits from the municipal authorities and the pre-school and primary school inspectors were obtained before carrying out the surveys.

Environmental sample collection

The sampling campaign was carried out during the rainy season in June 2021 as this season provides a "worst case" scenario because many homeowners illegally empty their sanitation storage facilities during heavy rains (16). In each cluster, 10 samples were collected from each

Fig 3. Community survey (a), School survey (b) - Source: Author.
of the exposure pathway as recommended by the SaniPath Protocol. Hence, 120 environmental samples of soil, street food, flood water, drinking water, gully water and open drain water were collected during this sampling campaign (2 clusters of 6 pathways with 10 samples per pathway per cluster) (Fig 4). It should be noted that the sampling campaign was conducted in the same neighborhoods where the behavioral exposure surveys were conducted (household survey, school survey and community survey). This ensures that as much reliable information as possible is gathered from each cluster. All samples collected were stored at 4°C and chemical and microbiological analyses were performed within the six hours following the sampling.

![Image](image1.png)

**Fig 4. Stormwater sampling (a), Open drain water sampling (b), Gully water sampling (c) - Source: Author.**

**Laboratory sample processing**

The microbiological analyses of the samples were carried out, according to the directives of the French association of standardization (17). All samples collected were analyzed for *E. coli*, as an indicator of fecal contamination. The choice of *E. coli* is justified by its being the main indicator of fecal contamination and because it can be detected using simple laboratory methods. Finally, it is the recommended pathogen for the SaniPath tool (18,19).

The membrane filtration technique with Chromocult® Coliform agar was applied only to stored drinking water samples. It consisted of passing 100 ml of drinking water sample through a 0.45-micron membrane filter (Pall Corporation®). The other samples were analyzed using the plating technique, which was made by performing four successive dilutions ($10^{-1}$, $10^{-2}$, $10^{-3}$ and $10^{-4}$) for each sample and then spreading 0.1 ml of the different dilutions on a surface of agar in Petri dishes.

All samples from each technique were placed in an incubator at 37°C for 24 hours and colonies that appeared with a purple coloration (characteristic of *E. coli*) were counted.

Then, the concentration of *E. coli* was calculated by averaging the concentrations of the four dilutions, according to the following equation:
\[ Cs = \frac{N \cdot Vs}{(n_1 \cdot v_1 \cdot F_1) + (n_2 \cdot v_2 \cdot F_2) + (n_3 \cdot v_3 \cdot F_3) + (n_4 \cdot v_4 \cdot F_4)} \]  

(1)

With:

- \( Cs \): number of colony generating units in the reference volume Vs (Vs=1mL) in CFU/mL
- \( N \): Sum of all the colonies counted in the plates from the dilutions F1, F2, F3, F4
- \( n_1 \): number of plates counted for dilutions F1, F2, F3, F4
- \( v_1, v_2, ... v_i \): test volume used for dilutions F1, F2, F3, F4 (v1=0.1mL)
- F1, F2, F3, F4: dilutions used for the test samples
- Vs: reference quantity chosen to express the concentration of micro-organisms in the sample

The collected data was entered into the SaniPath tool, which automatically generates results in several forms for each exposure pathway. Specifically, the tool presents the results in the form of people plots generated from the microbiological and behavioral data. These people plots provide information, such as the percentage of the population (adults or children) exposed to fecal contamination by a specific pathway, the magnitude of the average \( E. coli \) dose ingested per month and the percentage of the population that is not exposed to fecal contamination by that pathway. Afterwards, we determined the risk of exposition \( E \). This was done by multiplying the dose by the percentage of exposure and then transforming the result into a logarithm. However, all pathways with \( E \) greater than 10 (high risk) or within a log 1 interval around the maximum value of \( E \) will be considered dominant (20). Nevertheless, if \( E \) is less than 1 (low risk) for all pathways, there is no dominant pathway.

**Data analysis**

The data analysis was performed, according to the Sanipath methodology, behavioral and microbiological data were used to estimate exposure at each pathway. The exposure assessment is based on the distribution parameters of behavior frequencies and concentrations of \( E. coli \) for each pathway. Distribution parameters are estimated using Bayesian methods using JAGS (21). Also, Monte Carlo simulations estimate exposure to fecal contamination through each pathway in Abobo municipality (adults and children) based on estimated distribution parameters for fecal contamination levels and frequency of behaviors.

The statistical model used by the Sanipath tool assumes that the concentration of \( E. coli \) in the different samples follows a lognormal distribution, while the frequency of exposure behaviors is assumed to follow a negative binomial distribution (20). The parameters of these distributions were estimated using the Bayesian framework by JAGS (21). Then, 1000 iterations of Monte
Carlo simulation were performed using the distribution parameters related to the \textit{E. coli} concentrations in the samples, the frequencies of the behaviors, as well as the intake volumes. This allowed for the generation of exposure estimates of fecal contamination for each exposure pathway in each cluster for both adults and children.

\textbf{Ethics Statement}

The implementation of this project has received several ethical approvals. The first one was from the Université Félix Houphouet Boigny Ethics and Deontology Committee (2020/CED/UFHB-N°47), the second one was the authorisation provided by the municipal authorities (N°399/MAB/SG) and the third one is the authorisation of the inspection of the primary and preschool education (N°278/2021/IEP/Ab-H). Indeed, the ethical clearance for this study was obtained from the Université Félix Houphouet Boigny Ethics and Deontology Committee (CED-UFHB) which has allowed the implementation of the study. However, in addition to the CED-UFHB approval, an authorization was also provided by the authority of the city where the study was specifically taking place. During the data collection, informed consent was obtained from each participant before they were interviewed. Oral consent was preferred than written informed consent, because of the high level of illiteracy in our study area. Indeed, the ethical clearance for this study was obtained from the Université Félix Houphouet Boigny Ethics and Deontology Committee (CED-UFHB) which has allowed the implementation of the study. However, in addition to the CED-UFHB approval, an authorization was also provided by the authority of the city where the study was specifically taking place. During the data collection, informed consent was obtained from each participant before they were interviewed. Oral consent was preferred than written informed consent, because of the high level of illiteracy in our study area. Regarding the participation of the children, as well as the permission of the Inspection, we had the oral consent of the teachers and the pupils before the interview. However, the participation to the study was voluntary and participants could withdraw at any time without obligation.

\textbf{Results}

\textbf{Fecal contamination in the studied cluster in Abobo}

The \textit{E. coli} enumeration reveals the presence of \textit{E. coli} in 90\% (n=108) in the samples. The highest concentrations are observed in the samples of soil, gullies and open drains (Table 2). The maximum values of the concentrations are $6.46 \times 10^5$ CFU/ml for soil; $1.14 \times 10^6$ CFU/ml for gullies and $1.43 \times 10^6$ CFU/ml for open drains samples. Significant \textit{E. coli} concentrations of 2.4 CFU/100ml and 1.74 CFU/100ml were also observed in the drinking water samples in the two target clusters.
Table 2. *E. coli* concentration in the various pathways per cluster.

<table>
<thead>
<tr>
<th>Clusters</th>
<th>SDW (CFU/100ml)</th>
<th>FW (CFU/ml)</th>
<th>GL (CFU/ml)</th>
<th>OD (CFU/ml)</th>
<th>Soil (CFU/ml)</th>
<th>SF (CFU/ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>2.4</td>
<td>5.18E+05</td>
<td>3.85E+05</td>
<td>1.12E+06</td>
<td>1.98E+05</td>
<td>1.00E+04</td>
</tr>
<tr>
<td>Min</td>
<td>0</td>
<td>4.00E+04</td>
<td>1.08E+05</td>
<td>5.36E+04</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
</tr>
<tr>
<td>Mean</td>
<td>0.288</td>
<td>2.31E+05</td>
<td>2.56E+05</td>
<td>3.55E+05</td>
<td>4.81E+04</td>
<td>2.44E+03</td>
</tr>
<tr>
<td>Max</td>
<td>1.74E+00</td>
<td>9.45E+04</td>
<td>1.14E+06</td>
<td>1.43E+06</td>
<td>6.46E+05</td>
<td>1.40E+03</td>
</tr>
<tr>
<td>Min</td>
<td>0.00E+00</td>
<td>9.09E+02</td>
<td>1.64E+04</td>
<td>1.82E+03</td>
<td>0.00E+00</td>
<td>0.00E+00</td>
</tr>
<tr>
<td>Mean</td>
<td>1.80E-01</td>
<td>3.50E+04</td>
<td>4.12E+05</td>
<td>5.06E+05</td>
<td>6.91E+04</td>
<td>2.70E+02</td>
</tr>
</tbody>
</table>

SDW: stored drinking water; FW: floodwater; SW: surface water (gullies); OD: open drains; SF: street food

Risk profiles and people plots

Table 3 summarizes the global risk of exposure to fecal contamination in the two sampled clusters. However, soil sample results were not generated because the SaniPath tool does not include a behavioral question on this subject (22). The highest risk (E) of fecal contamination was recorded in the street food samples of cluster I with values of 8.6 for adults and 9.2 for children. The lowest risks (E) were recorded in cluster II drinking water samples, with values of 1.4 for children and 1.5 for adults (Table 3). The dominant pathways in cluster I are considered to be those with a risk value (E) ranging from 8.2 to 9.2 (Table 3). This concerns street food and gully for the children and adults in cluster I. Street food is a dominant pathway of exposure for children and adults with respective risks (E) values of 8.7 and 9.2. Gully water was identified as the dominant exposure pathway with a risk level (E) of 8.3 in children and 7.4 in adults. At the cluster II level, the maximum risk value (E) is 8.1 (E=8.1), with the greatest risk of exposure to fecal contamination ranging from 7.1 to 8.1. Table 3 presents gullies as the only dominant exposure pathway in this cluster with risk values of 7.1 and 8.1 for children and adults, respectively.
Table 3. Global risk of exposure (E) among adults and children in the municipality of Abobo in both sampling clusters.

<table>
<thead>
<tr>
<th>Exposure pathways</th>
<th>Cluster I</th>
<th></th>
<th></th>
<th>Cluster II</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exposition (%)</td>
<td>Dose (Log10 CFU/month)</td>
<td>Risk (E)</td>
<td>Exposition (%)</td>
<td>Dose (Log10 CFU/month)</td>
<td>Risk (E)</td>
</tr>
<tr>
<td></td>
<td>Children</td>
<td>Adults</td>
<td>Children</td>
<td>Adults</td>
<td>Children</td>
<td>Adults</td>
</tr>
<tr>
<td>Open drains</td>
<td>45.9</td>
<td>44.2</td>
<td>6</td>
<td>5.1</td>
<td>5.6</td>
<td>4.7</td>
</tr>
<tr>
<td>Stored drinking water</td>
<td>94.3</td>
<td>98.6</td>
<td>5.4</td>
<td>5.8</td>
<td>5.3</td>
<td>5.7</td>
</tr>
<tr>
<td>Flood water</td>
<td>100</td>
<td>93.1</td>
<td>7</td>
<td>5.8</td>
<td>7</td>
<td>5.7</td>
</tr>
<tr>
<td>Surface water (gully)* / **</td>
<td>100</td>
<td>73.1</td>
<td>8.3</td>
<td>7.6</td>
<td>8.3*</td>
<td>7.4*</td>
</tr>
<tr>
<td>Street food *</td>
<td>100</td>
<td>91.2</td>
<td>9.2</td>
<td>8.7</td>
<td>9.2*</td>
<td>8.6*</td>
</tr>
<tr>
<td>Soil</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

*Dominant pathways in cluster I/ **Dominant pathways in cluster II
This section presents the results of the dominant pathways as a people plot with the different percentages of exposure and relative intake doses per month. Figure 5 shows the two dominant pathways (street food and gullies) of exposure to fecal contamination in the clusters (Fig 5). In cluster I, children (100%) are slightly more exposed to fecal contamination than adults (92%) for the street food pathway. In cluster II, regarding the gully water pathway, adults' exposure percentage (27%) is low compared with children (78%). In terms of the number of dominant exposure pathways, the population living in cluster I are more exposed to fecal contamination than those in cluster II, with a maximum dose of 9.2 Log10 CFU/month and 8.3 Log10 CFU/month, respectively.

**Fig 5. Risk profiles of dominant pathways to fecal contamination in Abobo municipality**

### Discussion

The high concentrations of *E. coli* detected in the samples from the different pathways indicate poor fecal management in Abobo, especially in on-site sanitation areas. In both clusters, gullies (surface water) represent the dominant pathway for adults (CI/ E=7.4; CII/ E=7.1) and for children (CI/ E=8.3; CII/ E=8.1) considering *E. coli* contamination. During the transect walk, several gullies were observed throughout the clusters. Also, we could see that some households dump their wastewater in the streets that end up in the gullies. It is the same for toilet water and septic tank effluents.
This behavior is the explanation for the high average concentrations of *E. coli* recorded from gully samples in cluster I (2.56E+05 CFU/ml) and cluster II (4.12E+05 CFU/ml), as well as the significant values of percentage of exposure (children cluster I: 100%) and of high doses (children in cluster I: 8.3 Log10 CFU/month) in the cluster. Similar concentrations were found in wastewater from gullies in Yopougon, a neighborhood municipality with a significant presence of bacteria indicator of fecal contamination, in particular *E. coli*, in gully samples (3.0E+06 CFU/ml) (14) indicating the importance of fecal contamination in the District of Abidjan. The situation was pointed out by another study which revealed that the reuse of urban wastewater and lagoon water caused an average annual risk of infection ranging from 90.07 to 99.9% for *E. coli* and from 9.42 to 34.78% for *G. lamblia*. Moreover, *E. coli* concentrations varied from 2.60 E+05 to 3.01 E+04 CFU/100 mL in the canal and between 1.28 E+03 and 1.76 E+04 CFU/100 mL in the lagoon (23). The author explains the presence of these pathogens by open defecation, as well as the dumping of household waste and wastewater in these areas.

Our study found street food is also a dominant exposure pathway, with high level of risk of exposure in cluster I, especially among children (E= 9.2). The high risk among children could be explained by the sampling period, which took place during the school period when the children were away from home and ate food sold in the street (around the schools) where hygiene rules are not often respected. Most children are enrolled in schools, according to the policy of universal schooling, instituted by the government for all children from 6 to 16 years. According to World Health Organization, ingesting contaminated food is one of the most critical fecal-oral transmission pathways (24,25).

Furthermore, the street food exposure pathway is more important for children in cluster I with a risk (E) of 9.2. This situation could be explained by this study being carried out during the school period. During this period, most of the children eat from sellers located in the surroundings and/or in the school yard. However, these sellers do not really respect the hygienic conditions. Many studies have characterized street food sites as breeding grounds for rodents, insects, and flies that could promote the growth of microorganisms and increase the risk of food contamination and disease transmission (26). Also, the Centers for Disease Control and Prevention (CDC) estimated that more than 30% of gastroenteritis cases in low- and middle-income countries are related to foodborne transmission (27). Exposure studies in Bangladesh have also found high levels of microbial contamination, including coliform bacteria, in street foods, ranging from 1x10^5 log10 cfu/g in the beef burger to 2.35x10^6 log10 cfu/g in the sandwich (28). According to the government report, nearly 58% of the food sellers in Bangladesh did not cover their food and many did not wash their hands with soap during food preparation.

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preparation (28). A similar situation was observed in Accra (Ghana), where the risk of exposure was dominant among children under five years of age, independent of the standard of living. Indeed, in most markets in Accra, food is placed on dirty surfaces and collects dust contaminated with fecal matter. Also, the cultural context of Ghana means that the majority of food is traditionally consumed with the hands (29). However, Wang et al. found evidence of fecal contamination in hand washing samples, with *E. coli* concentrations that ranked from $2.25 \times 10^5$ to $1.55 \times 10^5$ CFU/pair of hands (30). Regarding drinking water, the majority of households living in the neighborhoods of the two clusters consumed stored drinking water. This water was not identified as a dominant exposure pathway of because the drinking water samples had low concentrations of *E. coli*. However, some *E. coli* was in drinking water samples from the clusters, probably a result of the practice of storing water in unsafe and/or uncovered containers (31). Indeed, many households reported storing water for consumption during the behavioral survey. Despite the program “Water for All” initiated by the Ivorian government since 2020, some populations living in informal settlements are still not connected to the drinking water network. These people buy their water from water sellers and store it in containers without respecting the hygiene requirements. Also, the practice of storing water could be explained by the recurrent blackouts that the city of Abidjan experienced during the period from March to June 2021, mainly in the municipalities of Yopougon, Abobo and Cocody. This situation is not specific to Abobo or Sub-Saharan African urban areas. A study conducted in the city of Dhaka (Bangladesh), revealed relatively high levels of *E. coli* ($3.20 \log_{10}$ MPN/100 mL) in municipal drinking water. The author justifies these results by frequent pipe breaks, illegal connections, and low water pressure due to intermittent service (32,33). In contrast to these findings, studies by Ronoh and al. in Uganda showed that drinking water was free of *E. coli* throughout the year. In fact, 70% of the population uses water supplied by the National Water and Sewerage Corporation (NWSC). However, these households treat the water before drinking by either boiling or chlorinating it (22). This practice is not common in the municipality of Abobo, where most people do not treat the water supplied by National Water Company (SODECI) before drinking it. Moreover, Wright *et al.* found that contamination of drinking water stored in households is related to the cleanliness of the containers (34). Previous studies at national level have shown *E. coli* to be the most prevalent pathogen in the environment. Indeed, according to the work of Becker and al., this pathogen is responsible for 32% of the confirmed cases of patients with persistent diarrhea (35).
Conclusion

Poor management of fecal sludge is a common practice in the low-income neighborhoods of Abobo Municipality. The SaniPath tool was used in this study to identify the different exposure pathways of fecal contamination, which residents of the informal settlements in Abobo face. This study reveals the presence of the pathogen *E. coli* in 90% of the samples collected in the different neighborhoods of the municipality. Street food and storm water/greywater are the dominant exposure pathways for children and adults in cluster I (low-income neighborhoods). However, in cluster II (medium and high-income neighborhoods), storm water drains are the only dominant exposure pathway. Despite the existing Municipal Order from 03.08.2018 on police regulations for on-site sanitation, the risk of exposure to fecal contamination remains high in cluster I. Systematic control of sludge storage facilities and supervision of street food vendors should be explored by the municipal authorities as strategies to prevent fecal contamination. Also, implementation of an inclusive sanitation system approach at the municipal level could considerably reduce these sources of contamination. Future equitable intervention strategies must consider the socio-economic inequalities across the different neighborhoods and provide targeted interventions for exposure hotspots. Therefore, policymakers, NGOs, and the private sector should provide access to reliable sanitation to all households, regardless of their socioeconomic status, to prevent epidemic risks in urban areas.

Supporting information

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Author Contributions

Zoumana Zié Phaniwa Coulibaly: Conceptualisation, methodology, investigation, writing – original draft
Kouassi Dongo – Methodology, curation, review and editing
Christoph Lüthi – Review and editing

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Fig 1. Map of Abobo showing the six sample locations.

Fig 2. Diagram of data collection steps of the Sanipath tool.
Fig 3. Community survey (a)

Fig 3. School survey (b)
Fig 4. Stormwater sampling (a)

Fig 4. Open drain water sampling (b)
Fig 4. Gully water sampling (c)

Fig 5. Risk profiles of dominant pathways to fecal contamination in Abobo municipality
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