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SOCIO-ENVIRONMENTAL DETERMINANTS OF MALARIA TRANSMISSION IN URBAN AREAS: A CASE STUDY FROM KISANGANI, DRC

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ABSTRACT

Introduction: Malaria remains hyper-endemic in the city of Kisangani due to environmental factors favorable to mosquito vectors and complex socio-economic conditions. The aim of this study was to identify the socio-economic and environmental factors contributing to high malaria transmission in Kisangani.

Methods: An analytical cross-sectional study was carried out from December 1, 2023 to May 15, 2024 in 402 households in Kisangani. Data were collected using the KoboCollect platform, and blood samples were taken from children (791) and pregnant women (135). The ORb and Pearson chi-square tests were used to investigate associations with potential risk factors.
Results: Environmental conditions favorable to the development of vectors were observed around households (22%), represented essentially by the presence of refuse (80%) and puddles (68%). The low level of education of the head of household and the low level of household income were associated with an environment favorable to malaria transmission ($p<0.05$), and a sanitized environment is a protective factor against malaria ($p<0.001$). The prevalence of malaria was about 5 times higher in pregnant women than in children aged 0-59 months, and the prevalence of Plasmodium falciparum was equal between RDT and EW results, with Plasmodium falciparum being the predominant species.
Conclusion: This study highlighted the importance of socio-economic and environmental determinants in malaria transmission in Kisangani. Targeted interventions are needed to improve living conditions and reinforce prevention practices, particularly among the most vulnerable populations.

KEYWORDS: Malaria, Kisangani, Transmission, Determinants, Public health.

INTRODUCTION

More than a century has passed since the great discoveries by Alphonse LAVERAN (1880) of the causal agent of malaria; then by Ronald ROSS (1897) and Giovanni-Battista GRASSI (1899) of the role of Anopheles as a vector in its transmission. Unfortunately, malaria remains one of the great scourges of humanity today. It is rampant in tropical areas and particularly in sub-Saharan Africa (1).
Malaria remains one of the most widespread and deadly parasitic diseases in the world and is a real public health problem (2).
According to the WHO, this debilitating disease affected 249 million people in 2022 alone and resulted in 608,000 deaths, which could have been prevented if transmission had been stopped and treatments had been accessible to all (3). The African region is the most affected and accounts for nearly 90% of all cases and deaths recorded worldwide, with pregnant women and children under 5 years of age paying a heavy price (2).
It is a preventable and curable disease (4).
It is also known as an environmental disease and is linked to the living conditions of the populations, whose fight against this scourge involves taking into account the sociodemographic and environmental aspects of the populations concerned (5).
In 2021, there were an estimated 247 million cases of malaria worldwide. While the world has been waiting a long time for malaria, one of the oldest and most pernicious human infections, to be eradicated,

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as this disease is responsible for more than 200 million cases and 400,000 deaths per year in 2015 and 619,000 in 2021 (2).

Between 2000 and 2015, exceptional progress was made, raising hopes of eradication for the first time since the end of the Global Malaria Eradication Programme (GMEP) in 1969 (2).

The results of several studies conducted around the world demonstrate the importance of the natural environment, which establishes the risk of malaria transmission incurred by populations in their immediate environment (8, 9, 10).

Environmental factors and the lack of use of malaria prevention measures are the main determinants of malaria transmission among adolescents living in areas of persistent malaria transmission in Senegal (9).

Indeed, malaria is an environmentally-dependent disease. However, in the search for solutions, health measures often take precedence over social and environmental ones. As a result, social and environmental factors are little taken into account in the approach to disease control. In a context of climate variability, taking into account social and environmental factors is all the more important as this phenomenon can increase the risk of malaria vector development (10).

The African Region bears a large and disproportionate share of the global malaria burden. In 2021, 95% of malaria cases and 96% of malaria deaths were recorded in the Region. Children under 5 years of age accounted for 80% of all malaria deaths in the Region (8).

The Democratic Republic of Congo (DRC) and Nigeria alone bear nearly 40% of the global malaria burden. Despite a slightly smaller population in Nigeria, the DRC has a significantly higher annual number of cases (2).

In the DRC, malaria remains a major public health problem, where it is the leading cause of morbidity and mortality. In 2020, 12% of malaria cases and 13.2% of malaria deaths occurred in the DRC, and the country accounted for 53.1% of malaria cases in Central Africa in the same year (2).

Malaria endemic is extremely prevalent in the DRC, where 97% of the population lives in areas where transmission is stable for eight to twelve months of the year. The northern and central regions are the most affected (2).

In Kinshasa, a study carried out in 2022 shows that the lack of involvement of the population in the sanitation of the environment, the abundance of shelters in the commune of Ngaba, the natural or anthropogenic environmental conditions, the climate and antimalarial operations, are at the origin of the resurgence of malaria cases (11). The same author in another study, on the characteristics of larval sites leading to the proliferation of malaria, concluded that 82.9% of the sites were temporary, 94.3% of the water came from rain (12).

The city of Kisangani is not spared from this scourge. The rainforest surrounding Kisangani, combined with a hot and humid climate, promotes intense malaria transmission, with an average of at least 1,000 mosquito bites infected per person per year (13).

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Very few studies have addressed a socio-environmental approach to describe the importance of the factors that sustain malaria transmission in Kisangani. Thus, it seemed appropriate to ask ourselves the question about the socio-environmental determinants of malaria transmission in Kisangani.

The objective of this study was to identify the socio-economic and environmental factors that promote the permanent transmission of malaria in the city of Kisangani. This is likely to contribute to the reduction of the overall prevalence of malaria in Kisangani, by proposing strategies to improve prevention.

II. MATERIALS AND METHODS

2.1. Study framework

We conducted our research in the city of Kisangani, the capital of the province of Tshopo, located in the northern part of the Democratic Republic of Congo. She is located at 00°31° north latitude and 25°11° east longitude, at an altitude of 393 meters and its surface area is 1,910 km2. The climate is generally equatorial and the vegetation is dominated by equatorial forest. The temperature of the city ranges from 27.6 to 28.9°C with an average of 28.3°C (14).

The city of Kisangani is divided into 5 Health Zones (Makiso-Kisangani, Tshopo, Lubunga, Kabondo and Mangobo). It has a network of 88 Health Areas and 154 health facilities, as well as numerous community care sites.

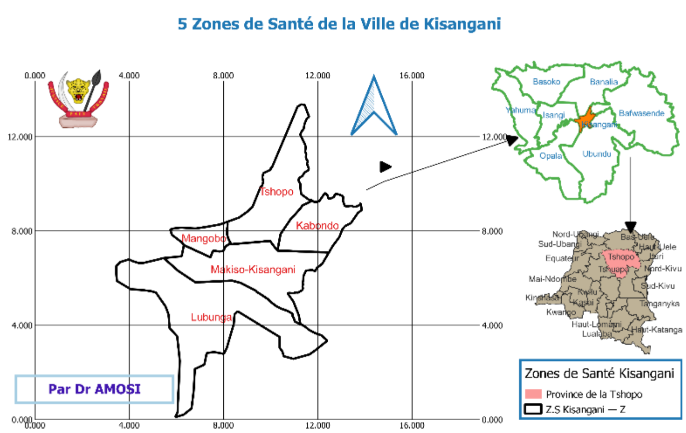

Figure I: Map of 5 Health Zones in the city of Kisangani

2.2. Study site

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This study was conducted in 4 health zones in Kisangani, including Kabondo, Tshopo, Mangobo and Makiso-Kisangani. Due to inter-ethnic conflict and insecurity, the Lubunga Health Zone located on the left bank of the Congo River was not included in the study.

2.3. Type, time period and study population

This was a cross-sectional study with an analytical purpose in the period from December 2023 to May 2024

The study population consisted of households in the city of Kisangani in the health zones of four health zones.

2.4 Sampling

Statistical unit: of the people interviewed in this study were the heads of households or any other adult present at home during our visits, in the randomly selected Health Areas.
Sample size: using the Schwartz formula: $n = ((Z\alpha ^2 \times p \times q))/d^2$ we selected 402 households.

Sampling technique: In order to select our sample, we proceeded with a three-step survey.

- ✓ The first step consisted of a simple random selection of 5 health areas per urban health zone in Kisangani, for a total of 20 health areas.
- ✓ In the second step, we randomly selected 2 avenues per health area, for a total of 40 avenues.
- ✓ Finally, within each avenue, we proceeded by systematic sampling to select 420 households. The sampling step was calculated by dividing the total number of households on Avenue (N) by 22 (k=N/22), and the first household was randomly selected (between 1 and k).

This method was chosen to ensure geographical representativeness of the population while allowing for efficient household selection.

2.5. Inclusion criteria

To be included in the study, participants had to meet the following criteria: have lived in Kisangani or within a 30-kilometer radius of the city for at least 6 months, to ensure familiarity with the local context; be 18 years of age or older to be able to give informed consent; have at least one child aged 0-5 years and/or a pregnant woman living in the household and give verbal consent after being clearly and fully informed about the study objectives and procedures. For children old enough to understand, their consent was also sought.

2.6. Sample collection

In order to assess malaria parasitaemia, we took blood samples from all children under 5 years of age and pregnant women in the selected households. To limit the workload and reduce potential stress for participants, we limited the number of samples to 5 children under 5 years of age and 2 pregnant women per household. A total of 791 blood samples were taken from children and 135 from pregnant women. All samples were taken under strict hygienic conditions by trained staff, and samples were transported and stored according to the protocols in place.

2.7. Data collection techniques

To collect the data, we used KoboCollect, a mobile data collection platform. This application created a structured questionnaire, covering various areas such as malaria parasitaemia, household socioeconomic characteristics, environmental practices and malaria prevention behaviours.

Our field team was made up of complementary profiles (Laboratory Technician, Community Relay and Investigator), each bringing specific expertise.

2.8 Operational definition

To assess the level of household income, we had scored the ownership of certain properties whose rating is listed below: **Rating access to drinking water** : Tap in the plot (3 points), tap at neighbors' homes, public fountain and improved spring/well (2) and unimproved springs (river/river) (1 point); **Toilet type rating**: flush toilet and improved ventilated latrine (3 points); ordinary pit (2 points) and no latrine (1 point); **Rating Main energy source** : Electricity and generator (3 points), solar panel (2 points) other source (wood, coal, etc.) (1 point); **Rating Possession of certain goods**: Car (3 points); Motorcycle or Computer (2 points), Bicycle, Television or Mobile Phone: (1 point).

Calculation of the score: the standard of living score for each household is calculated by adding up the points obtained for each criterion and the categorization of the level of household income is as follows:

- ✓ 12 points or more: High standard of living
- ✓ 9 to 11 points: Average standard of living
- ✓ Less than 9 points: Low standard of living

A 'Good' level of knowledge about malaria was assigned to respondents who were able to cite mosquito bites as a mode of transmission, as well as three preventive measures and three complications related to this disease.

2.9. Variables of interest

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Dependent variable: Presence or absence of malaria (detected by RDT and/or GE) in children under 5 years of age and pregnant women.

Independent variables: Socioeconomic characteristics (level of education, level of income, etc.), behavioural characteristics (knowledge of malaria, use of LLINs, etc.) and environmental characteristics (sanitation, presence of breeding sites, etc.).

2.10. Data analysis techniques

The raw data, collected via the KoboCollect platform, was cleaned and structured in an Excel file before being statistically analysed using the specialised software STATA version 13.

Descriptive statistics: we described the characteristics of households using descriptive statistics adapted to the nature of the variables (quantitative: mean and standard deviation or median and interquartile range; qualitative: proportions). Associations between these characteristics and the presence of malaria were explored using Pearson's Chi2 assay, with a 95% confidence level.

Analytical statistics: A bivariate analysis based on the chi-square test was performed to explore the crude associations between malaria serostatus and various sociodemographic, environmental, and behavioral variables. Crude odds ratios and their 95% confidence intervals were calculated and presented to assess the magnitude of these associations. These results are presented in the tables.

2.11. Ethical considerations

The necessary ethical and administrative authorizations to carry out this study have been obtained from the provincial Ministry of Health and the University of Kisangani.
Verbal consent was obtained from all heads of households, and verbal consent was obtained from parents for the participation of their children. Interviews were conducted in the participants' native language and all data were anonymized before being analyzed.

III. RESULTS

3.1. Environmental characteristics

The characteristics of domestic environments are presented in Table I.

Table I. Characteristics of the household environment

Variables	Terms	Frequency	Percentage
Healthy Household Environment N=402	Yes	312	78
	No	90	22
Observed unsanitary problems N=90	Presence of garbage	72	80
	Presence of brush around the household	36	40
	Presence of puddles/standing water	61	68
	Presence of cans	26	29
	Presence of abandoned containers	19	21
	Presence of abandoned tires	8	9
	Other	2	2
Origin of stagnant water N=61	Household wastewater	23	38
	Rainwater	17	28
	Eau de toilette	16	26
	Gutter water	12	20
Wastewater system assessment N=402	Good	294	73,1
	Bad	74	18,4
	Very bad	34	8,5
Garbage disposal system assessment N=402	Good	294	73,1
	Very bad	85	21,1
	Bad	23	5,7
Soil characteristics N=402	Sandy soil	237	58,9
	Dry soil	98	24,4
	Moist soil	34	8,5
	Marshy ground	32	7,9
	Other	1	0,3
Presence of larval breeding sites in the vicinity of households	Yes	90	22
	Not	312	78

Analysis of the table on the sanitation of the living environment (n=402)

Although a majority of households benefit from a sanitized environment, the presence of garbage, sewage and puddles of water has been identified as favourable conditions for the proliferation of vectors, especially in areas where larval breeding sites have been detected.

3.2. Factors associated with unhealthy environment and malaria

3.2.1. Factors associated with the unhealthy environment

The table below shows the correlations between selected variables and the environmental characteristics of households.

Table II. Analysis of factors associated with the enabling environment for malaria transmission.

Variables	Healthy environment		ORb / Chi2	IC95%	P value
	Yes (N=317)	Not (N=85)			
Level of education			9,07*		0,028*
None	10 (3)	9 (10)			
Primary	15 (5)	4 (5)			
Secondary	207 (65)	55 (65)			
Higher education and university	85 (27)	17 (20)			
Income level			8,7*		0,015*
High	16 (5)	0 (0)			
Medium	154 (49)	31 (36)			
Low	147 (46)	54 (64)			
Overall level of knowledge			0,6**	0,34 – 1,06	0,055**
Good	248 (78)	58 (68)			
Weak	69 (22)	27 (32)			
Blanket 1 LLIN/2 people			1,6**		0,08**
Yes	110 (35)	21 (25)			
Not	207 (65)	64 (75)			

*Chi square of Pearson **GOLD

Low education of the head of household and low household income were associated with an environment conducive to malaria transmission (p<0.05).

3.2.2. Factors associated with malaria

The associations between different factors and the risk of malaria within households are presented in the following table.

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Table III. Analysis of factors associated with malaria in households.

Variables	Malaria children 0-59 months Present (n=53)	Absent (N=349)	ORb	IC95%	P value
Average income level					
High	2 (4)	14 (4)			0,98*
Medium	23 (43)	155 (44)			
Low	28 (53)	180 (52)			
Overall level of knowledge			0,92	0,42 – 1,89	0,82*
Good	12 (23)	84 (24)			
Weak	41 (77)	265 (76)			
Healthy environment			0,26	0,13 – 0,49	0,001**
Yes	28 (53)	284 (81)			
Not	25 (47)	65 (19)			

*Chi square of Pearson **GOLD

The table shows that the healthy environment is a protective factor for malaria ($p<0.001$), but the level of household income and the overall level of knowledge about malaria prevention did not show any association.

3.3. Malaria prevalence and identified plasmodial species

Table IV details the prevalence of malaria among children under 5 years of age and pregnant women, showing the distribution of the different Plasmodium species detected by GE examination.

Table IV. Malaria prevalence and identified plasmodial species

Targets	Reviews Completed	TDR positif n(%) IC95%	GE positive n(%) IC95%
Children 0 to 59 months	791	47 (5,9) [1,6-7,5]	53 (6,7) [1,7-8,4]
Pregnant women	135	41 (30,4) [7,9-41,9]	44 (32,6) [7,9-40,5]
Plasmodial species N=91 (GE+)	**Frequency**	**Percentage**	
P falciparum	86	97,8	
P vivax			
P oval			

P malariae	11	12,1	

The analysis in Table IV reveals a prevalence of malaria about 5 times higher in pregnant women compared to children aged 0 to 59 months and the equality of prevalence between RDT and GE results. *Plasmodium falciparum* was the predominant species in both groups, but the presence of *Plasmodium malariae* is also noteworthy.

IV. DISCUSSION

4.1. Environmental characteristics

This study revealed that the majority of households had a healthy environment.

Environmental conditions favourable to the development of vectors were observed around households (22%), mainly represented by the presence of garbage (80%) and puddles (68%). This is similar to the results of other studies in Africa, which have also identified garbage as a major unsanitary problem. A study conducted in Senegal found that environmental factors are the main determinants of malaria transmission among adolescents living in areas of persistent malaria transmission in Senegal (9). In Cameroon, a study conducted in Yaoundé III highlights that areas where increased insalubrity exposes populations every day to the bites of mosquitoes, vectors of malaria (15).

Other unsanitary problems frequently observed in our study were household wastewater, stagnant rainwater, and toilet water. A study conducted in Abidjan, Côte d'Ivoire, argues that the failing wastewater system contributes significantly to environmental degradation and has a negative impact on the health of the population. In Kennedy Clouétcha, Abidjan, Côte d'Ivoire, wastewater discharged either in the courtyard of concessions, in the streets, or in sanitation facilities (gutters, sewers, etc.), promotes the unsanitary living environment and the proliferation of pathogens (16).

However, the presence of larval sites in the vicinity of households was rare. This is a positive result, indicating that efforts to control breeding sites are underway.

The analysis of our results reveals that the sanitation of the living environment is generally satisfactory in the population studied. However, unsanitary problems persist in some households, which could promote malaria transmission. Targeted interventions to improve wastewater and rainwater management, raise awareness of good hygiene practices and promote environmental sanitation could help reduce the risk of malaria.

4.2. Factors associated with unhealthy environment and malaria

4.2.1. Factors associated with the unhealthy environment

Among the associated factors, in our study, we found that low education of the head of household and low household income were associated with an environment conducive to malaria transmission ($p<0.05$). This is comparable to the results of other studies in Africa that have found an association between higher education levels and a lower risk of malaria. The case of a study conducted in Bobo-Dioulasso, Burkina Faso, highlights a link between the socio-economic level of households and the risk of malaria (17) and a study in Kenya that also found that people with higher levels of education were half as likely to be infected with malaria as those without education (18).

In Benin, although the study was conducted in rural areas, it also highlights the importance of environmental factors in malaria transmission (19).

The results of our study, as well as those of the other studies cited, suggest that interventions to reduce malaria transmission in urban settings need to take into account socioeconomic determinants. Effective malaria control programmes should combine vector control measures with interventions to improve the living conditions of the most vulnerable populations, particularly in terms of access to safe drinking water, sanitation and health care.

4.2.2. Factors associated with malaria

With regard to the factors associated with malaria, our study showed that the low level of education of the head of household and the low level of household income were associated with an environment conducive to malaria transmission ($p<0.05$) and the healthy environment is a protective factor for malaria ($p<0.001$) but the level of household income and the overall level of knowledge on malaria prevention were not shown no association.

A study conducted in the neighborhoods of the city of Bouake in Côte d'Ivoire highlights that the high risk of exposure to malaria in precarious housing neighborhoods results from a cumulative effect of precarious environmental and socio-economic conditions. Environmental conditions influence vectors by providing them with biotopes that are favourable to their development. It also interferes with the development cycle of vectors (20).

Our study confirms the importance of the healthy environment in the prevention of malaria in urban areas. The results obtained in Kisangani make a valuable contribution to the understanding of malaria transmission in our region. However, further research is needed.

4.3. Malaria prevalence and identified plasmodial species

The study found that the prevalence of malaria was about 5 times higher in pregnant women compared to children aged 0 to 59 months and the same prevalence between RDT and GE and Plasmodium falciparum results was the predominant species. This observation raises important questions about the socio-environmental factors that influence malaria transmission in these vulnerable population groups.

Several studies conducted in different countries in Africa have explored the prevalence of malaria in pregnant women and children under five years of age. The results of these studies show considerable variations in terms of RDT positivity rates, reflecting the diversity of socio-environmental and epidemiological contexts of malaria on the African continent.

- ✓ Uganda: A study in Uganda found a RDT positivity rate of 27.4% in pregnant women and 11.2% in children aged 0-59 months (21).
- ✓ Ghana: In Ghana, a study reported a RDT positivity rate of 35.2% in pregnant women and 13.0% in children aged 0 to 59 months (22).
- ✓ Tanzania: In Tanzania, a study found a RDT positivity rate of 17.1% in pregnant women and 6.7% in children aged 0 to 59 months (23).

As this comparison shows, the RDT positivity rates among pregnant women in our study are comparable to or slightly higher than those found in other African studies (27.4% to 35.2%). In contrast, RDT positivity rates in children 0-59 months of age in our study are generally lower than those reported in other settings (6.7% to 13.0%).

The differences observed in RDT positivity rates between pregnant women and children aged 0 to 59 months may be explained by several socio-environmental factors. Pregnant women are physiologically more vulnerable to malaria due to the immunological and physiological changes associated with pregnancy.

In contrast, children aged 0 to 59 months have some protection against malaria due to maternal immunity acquired during pregnancy and increased use of mosquito nets and other prevention measures (24). However, this protection decreases over time and young children remain vulnerable to malaria, especially in areas of high malaria transmission.

Our study provides valuable insights into the disparities in malaria prevalence between pregnant women and children aged 0-59 months in Kisangani. Comparing our results with those of other studies highlights the influence of socio-environmental factors on malaria transmission in these vulnerable population groups. The results of this study suggest that pregnant women are a particularly vulnerable group for malaria in this population. Further efforts are needed to target malaria control interventions to this group and to identify the socio-environmental factors that contribute to their increased risk of disease.

Numerous studies conducted in sub-Saharan African contexts confirm the high prevalence of malaria among pregnant women. A meta-analysis of 49 studies found an average prevalence of parasitological malaria among pregnant women of 30.5% (95% CI: 27.1-34.0%) (25).

In accordance with the data presented in the table, Plasmodium falciparum is the dominant plasmodial species responsible for malaria in pregnant women and children in sub-Saharan Africa. A study conducted in Burkina Faso found that P. falciparum accounted for 99.5% of malaria infections in pregnant women (26). This dominance underscores the importance of maintaining efforts to control this deadly species, including through the promotion of the use of insecticide-treated nets and adequate access to effective antimalarial treatment.

Although less common than P. falciparum, the presence of Plasmodium malariae, as observed in the table, is corroborated by other studies. A study conducted in Uganda found that P. malariae accounted for 4.1% of malaria cases (27). The presence of P. malariae recalls the importance of accurate parasitological diagnosis and adequate management for all forms of malaria, as this species can also cause serious complications, especially in pregnant women and children.

V. CONCLUSION

The study showed that, although a majority of households have a relatively clean environment, the presence of garbage, stagnant water and larval breeding sites poses a significant risk for malaria transmission. Socioeconomic factors, such as education level and income, have also been associated with an unhealthier environment and an increased risk of malaria.

The most vulnerable populations, including pregnant women and young children, are particularly at risk of infection. It is essential to strengthen public health interventions by targeting these specific groups and taking into account local contexts.

In order to reduce the incidence of malaria in Kisangani, interventions to establish a robust surveillance system, increase the distribution and use of long-lasting insecticide-treated nets, promote improved sanitation practices, and increase public awareness are needed.

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