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SARS-CoV-2 seroprevalence and living conditions in Bamako (Mali): a cross-sectional multistage household survey after the first epidemic wave, 2020

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Abstract

Objectives

In low-income settings with limited access to diagnosis, COVID-19 information are scarce. In September 2020, after the first COVID-19 wave, Mali reported 3,086 confirmed cases and 130 deaths. Most reports originated from Bamako, with 1,532 cases and 81 deaths (2.42 million inhabitants). This observed prevalence of 0.06% appeared very low. Our objective was to estimate SARS-CoV-2 infection among inhabitants of Bamako, after the first epidemic wave. We assessed demographic, social and living conditions, health behaviors and knowledge associated with SARS-CoV-2 seropositivity.

Settings

We conducted a cross-sectional multistage household survey in 3 neighborhoods of the commune VI (Bamako), which reported, September 2020, 30% of the reported cases.

Participants

We recruited 1,526 inhabitants in 3 areas, i.e. 306 households, and 1,327 serological results (≥1 years), 220 household questionnaires and collected answers for 962 participants (≥12 years).

Primary and secondary outcome measures

We measured serological status, detecting SARS-CoV-2 spike protein Antibodies in blood sampled. We documented housing conditions and individual health behaviors through questionnaires among participants. We estimated the number of SARS-CoV-2 infections and deaths in the population of Bamako using the age and sex distributions.

Results

The prevalence of SARS-CoV-2 seropositivity was 16.4% after adjusting on the population structure. This suggested that ~400,000 cases and ~2,000 deaths could have occurred of which only 0.4% of cases and 5% of deaths were officially reported. Questionnaires analyses suggested strong agreement with washing hands but lower acceptability of movement restrictions (lockdown/curfew), and mask wearing.

Conclusions

The first wave of SARS-CoV-2 spread broadly in Bamako. Expected fatalities remained limited largely due to the population age structure and the low prevalence of comorbidities. Improving diagnostic capacities to encourage testing and preventive behaviors, and avoiding the spread of false information remain key pillars, not matter the developed or developing setting.

Registration number

2020-001424-MSAS-SG

Keywords: COVID-19, sero-prevalence, living conditions, knowledge attitude behavior and practice.

Strengths and limitations of this study

- In Mali, this is the first study assessing living condition and SARS-CoV-2 seroprevalence
- A multi-stage cross-sectional survey has been implemented in the main affected neighborhood of Bamako, the capital city, after the first COVID-19 wave
- In addition to the blood samples for SARS-CoV-2 serology, the survey collected household questionnaires on living conditions and individual questionnaires on Knowledges Attitudes Behaviors and Practices
- A logistic generalized additive multilevel model was implemented to estimate factors associated with SARS-CoV-2 seropositivity
- However, a new study needs to be done to complete the seroprevalence estimate after 2 years of COVID-19, including other neighborhoods of Bamako.

Background

COVID-19 disease, due to the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), which emerged at the end of 2019 in Wuhan, China, has spread rapidly around the world and was declared as "pandemic" on 11 March 2020 by the World Health Organization (WHO) [1]. Despite setting up public health policies appropriated to this pandemic situation, such as lockdown, quarantine and curfew, the virus continues to circulate [2, 3] The WHO African Region reported the least number of affected people since the pandemic began. Indeed, in many resource-limited settings, biological confirmation was only available in tertiary medical facilities and has been reserved for symptomatic patients (mostly severe) and/or travelers, the various national policies requiring a negative test for travel. As a result, the number of people exposed to the virus in Sub-Saharan Africa is still largely unknown [1].

After the first reported case on March 25th 2020 (coming from France on March 12th), Mali has recorded, 6 months later (at the time of the survey), 3,086 cases of SARS-CoV-2 diagnosed by RT-PCR, i.e. an incidence rate of 0.015% for the whole country. Spread over 38 health districts (among 75), they led 130 reported deaths, *i.e.* a case fatality rate of 4.2%[4].
Among the recorded cases at M6 (September 2020), ~50% were reported in the district of Bamako *i.e.* 1,532 reported cases, for a population of at least 2.42 million inhabitants. The most affected area was the Commune VI with 466 reported cases and 27 associated deaths. The second largest number of recorded cases was reported in the region of Timbuktu, with 572 confirmed cases at M6 [4].
Given the limited access to diagnosis and care, and in the absence of a reliable syndromic surveillance, the low number of reported cases did not allow to assess accurately the epidemic situation. In this context, serological surveys represent an important tool to assess the extent of the exposure to SARS-CoV-2 in the general population. A single survey provides a snapshot of the extent of the virus spread at a given time point, and informs on vulnerable population groups, on the denominators used to calculate infection fatality rate or hospitalization rates [5]. In Mali, a multi-site study including a peri-urban area of the capital city Bamako demonstrated a sharp increase in seroprevalence between a survey conducted after the first wave of clinical cases (August 2020) and a survey conducted during the decrease of the second wave (January 21), identifying geographical location and age as associated factors [6]. Indeed, Sagara *et al.* reported in the peri-urban area of Sotuba a crude seroprevalence of 13.1 % (n=587) after the first wave. In the capital city of Kinshasa, Nkuba *et al.* reported a similar result with a seroprevalence of 16.6% (n=1233) [7].
Seroprevalence is also essential to assess the level of herd immunity that has been developed, which determines the risk of the following epidemic waves, their potential severity and their potential impact on the healthcare system. Measuring immunity could also help develop response strategies including priority strains for vaccination or targeted awareness campaigns.
In the settings where mortality and hospitalization statistics are not readily available, approximating the number of infections by age groups and by gender was also important to estimate the order of magnitude for expected infection fatality rates and compare it to reported COVID-19 deaths [8].
In addition, better access to information on epidemiological trends, social factors associated, health and protective behaviors, as well as attitudes and beliefs, was needed to design control strategies and strengthen information and awareness campaigns.
The aim of this study was to estimate the seroprevalence of SARS-CoV-2 in the population of the most populated and affected commune of Bamako, after the first epidemic wave. We also assessed demographic, social and living conditions; health behaviors; and knowledge associated with SARS-CoV-2 seropositivity.

Methods

Study design and sample size calculation

In accordance with the WHO guidelines protocol for age-stratified population-based sero-epidemiological surveys for COVID-19 infection, a cross-sectional household survey was conducted [8] in the 3 most affected and populated neighborhoods of Bamako's commune VI: Faladié, Banakabougou, and Yirimadjo (Figure 1), September 2020. At the time of the protocol (July 2020), the number of cases reported was 38, 29, and 40 respectively for these neighborhoods, representing 0.07 cases/ 100 inhabitants, and 54% of the total reported cases in Commune VI.

Figure 1: Map of Bamako showing the location of the 3 investigated neighborhoods within the Commune VI (in red).

The sample size was calculated assuming an expected prevalence of COVID-19 infection of 0.07 cases/ 100 inhabitants, within the population. Based on this assumption, a sample size of 1300 persons was estimated, with a precision of 2% and a confidence interval of 95%. Considering 15% loss, 1500 people was expected to be included. A multi-stage cluster sampling method covering all age ≥1 groups of the population was performed [9]. In the first stage, the sample size to be recruited per district was proportional to the district population sizes. In the second stage, each district was divided into different sectors (4 or more) of relatively equal sub-population size. The household survey therefore concerned each sector of each district. The first household in each sector was selected by choosing a random direction from the center of the community sector, counting the houses along that road and selecting one at random. Subsequent households were selected by visiting the closest house to the previous one. All household members in the age range willing to participate were recruited. The study was conducted among the general population aged ≥1-year-old for the seroprevalence study, and ≥12-year-old for the questionnaire survey. A housing unit was defined as a private one, such as apartment or villa or collective house (living quarter called "compound") with its own separate entry. Common residence rules (*de jure* rules) defined household unit as group of first-degree relatives usually living in the same housing unit. This approach allowed considering Malian family structure and local housing habits to define household units.

Individual sample and data collection

After informed consent obtained from the participants or their parents, 2mL of blood were collected from all voluntary participants by venipuncture (September 2020), to perform serological tests. Following the blood sampling, a face-to-face questionnaire was administered to collect the following demographic and sociologic factors: gender, age, history of recent travel within and outside Bamako, socio-economic level, contact with COVID-19 cases, occupation, education level, recent clinical symptoms, recent treatment, and attendance at places of worship. The questionnaire also included items relative to the knowledge about the disease, protective measures and consequences on the population health.

Housing conditions and household data collection

The head of household was asked to answer a specific questionnaire documenting their individual characteristics (age, gender, education, profession), household structure (number and age of members) and housing conditions including housing equipment, goods, and incomes of family (auto, TV, moto, cell phone, external funding…).

Biological analyses

The level of exposure of the population to SARS-CoV-2 was estimated by serology. Sera were separated from whole blood and stored at -80^{o}C in cryotubes. SARS-CoV-2 specific IgM and IgG antibodies were assayed in sera by VIDAS® anti-SARS-CoV-2 IgM and anti-SARS-CoV-2 IgG kits (BioMerieux, Lyon, France) [10]. The VIDAS® anti-SARS-CoV-2 IgM and anti-SARS-CoV-2 IgG tests relied on the SARS-CoV-

2 Spike protein immunoassay technique to measure the presence of antibodies in infected participants. Compared to PCR, the sensitivity of the VIDAS® tests for IgM and IgG is 90.4% and 88.6%, 8-15 days after SARS-CoV-2 infection, 100 and 96.6%, 16 days after infection, respectively. The specificity for IgM and IgG is 99.4% and 99.6%, respectively. In this context, the specificity of the tests was particularly important to ensure that the test of an un-infected participant was indeed systematically negative. Serology analyses were performed at the Charles Mérieux Infectiology Centre in Bamako, Mali.

Participants were defined as SARS-CoV-2 seropositive if they presented either a positive IgG or IgM result. Individuals were defined as SARS-CoV-2 seronegative if they presented a negative IgG and IgM result, or a negative IgG and a missing IgM result. Individuals with missing IgG results were excluded from the seroprevalence analysis.

The seroprevalence was estimated as the number of SARS-CoV-2 seropositive by the number of participants. The number of infections for the district of Bamako was estimated using the population of Bamako by sex and age categories. The number of deaths was estimated by using the age- and sex-specific mortality data reported early in the pandemic (February-March in China, prior to the optimization of clinical management) [11].

KABP outcomes measures

The current at-risk practices have been measured using a four bipolar Likert Items on practices during the seven past days assessing: wearing mask when not at home, washing hands with soap, going to crowned areas during the day or the night. Concerning behavior questions, six bipolar Likert Items (from systematically/very often to never) on behavior changes since the start of the epidemic focusing on: washing hands, visiting friends and relatives, going to crowned areas, touching each other, sneezing into elbow, reducing travel. Concerning knowledge questions, a scale-score based on 13 items (True/False/Don't know) on prevention, treatment, symptoms, and transmission of SARS-CoV-2 has been build up. At least, concerning cultural beliefs, four bipolar Likert Items (from very agreed to very disagreed) assessed opinion about the disease focusing on infection origin: a divine punishment, a spell casting, a white people illness, a way to get money for rich people.

Data analysis

First, descriptive analyses estimated mean, prevalence and frequencies, associated with 95% confidence intervals (95%CI).

Household profiles were determined by using 2 step descriptive approach [12]: first a multiple component analysis (MCA), second a Hierarchical Ascendant Classification (HAC). Based on household level variables, this approach led to determine classes according to the different household profiles. Each individual was assigned to its household profile.

Second, in order to estimate factors associated with SARS-CoV-2 seropositivity, we used logistic generalized additive multilevel models (GAMM) [13]. We analyzed the effects of age and sex at individual level, as well as household profile. Intra-household contamination was assessed as a binary variable (more than 1 positive case or not). The GAMM approach allowed also verifying the non-linear effect of continuous covariates by using spline smoothing [14]. The model included random effects for household, compound and district sector to reflect sampling structure and potential correlations between participants sharing the same living space (household nested in compound sampled in the same sector). Main statistical tests were performed using an α-probability threshold of 5%, but with Bonferroni correction for sub-group analysis.

Data analyses were performed using the SPSS software (IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp) for the questionnaire data management and

descriptive analyses, and the R software (version 4.0.0, R Core Team 2020. R Foundation for Statistical Computing, Vienna, Austria.) with the following specific packages: {FactoMineR}, {lme4}, {gamm4}.

Ethics and regulations

The authorization to conduct the study was obtained on August 28th, 2020, from the Ministry of Health and Social Affairs of Mali (decision letter number 2020-001424-MSAS-SG). Clearance from the ethics committee of the Faculties of Medicine and Odonto-Stomatology and Pharmacy, University of Sciences, Technics and Technologies of Bamako (Mali) was obtained on August 10th, 2020 (clearance letter number 2020/162/CA/FMOS/FAPH). First, a community agreement was first obtained from district leaders, local religious leaders, community associations and municipal authorities after explanation and discussion about the study protocol. Second, consents and/or assents of participants or their parent/guardian were obtained. The study team administered consent in local languages, and, if the participant or parent/guardian was not literate, in the presence of a witness. Individuals from each family consented separately.

Patients and Public involvement

The national federation of community health associations is part of the COVID-19 national committee, contacted during study design. For recruitment, the local Community Health Association appointed community health workers as part as the field investigation team. The mayor of the commune, after receiving information on the study, issued a radio announcement to inform the population of the survey and to solicit their participation. A community representative, selected by the neighborhood head and independent from the research team, participated to the field study as a witness, ensuring that participants understand the study and that they have given their informed consent.

The field study team provided a report to the local authorities and to the community health association. All participants who wanted to have personal results (or any question about the study) had 2 medical contacts (telephone numbers). Public feedback meetings were held with the local community health association and the local authorities.

Results

Inclusions

A sample of 174 housing units (separate living quarter) were investigated including 2,015 inhabitants grouped in 306 identified household units.

Of 2,015 inhabitants, 1,526 (75.7%) participants aged ≥1 year provided a blood sample for the seroprevalence survey and 962 participants aged ≥12 years answered the KABP survey (Table 1).

Table 1: Study participants' demographic characteristics and detailed serological results (Bamako, n=1,526, September 2020).

		n	%
Site			
	Banankabougou	588	38.5
	Faladie	300	19.7
	Yirimadio	638	41.8
Gender			
	Male	599	39.3
	Female	927	60.7
Age			

	[1-10y]	416	27.3
	[10-20y]	491	32.2
	[20-30y]	299	19.6
	[30-40y]	144	9.4
	[40-60y]	118	7.7
	[60-100]	51	3.3
	NA	7	0.5
SARS-CoV-2 status			
	Negative	1100	72.1
	Positive	227	14.9
	NA	199	13.0
Detailed positives			
	IgG pos only	170	
	IgM pos only	17	
	IgG+IgM	35	
	IgG pos, IgM missing	5	

Data on housing conditions were collected for 220 of the 306 household units included, *i.e.* 78.9% of the household members tested (n=1,204) (Figure 2).

Figure 2: flowchart of the seroprevalence survey

SARS-CoV-2 seroprevalence

Out of 1,526 participants, 2 did not provide samples, 170 had no interpretable test results for both IgG and IgM, and 27 inconclusive results due to a missing IgG and negative IgM results or inversely. Overall, interpretable serological results were available for 1,327 participants, corresponding to 227 SARS-CoV-2 seropositive (by either IgG, IgM or both) and 1,100 seronegative individuals. The crude seroprevalence rate was estimated at 17.1% (95% Confidence interval (95%CI) [15.1-19.1], ranging from less than 10% to upper than 30% across genders and age groups (Figure 3).

Figure 3: Seroprevalence by age and sex (Bamako, n=1327, September 2020).

Applying estimated prevalence, by age and sex, to the population of the district of Bamako (2.42 million inhabitants), we estimated around 400,000 the number of infections in the city between the onset of the epidemic and the time of the survey (September 2020), compared to 1,532 recorded cases for the district of Bamako. This corresponded to an adjusted prevalence of 16.4% (adjusted on the population age and sex distribution) vs an observed prevalence of 0.06%. Using the age- and sex-specific mortality data reported early in the pandemic, we roughly estimated 1,725 COVID-19 deaths occurred between the onset of the pandemic and the date of the survey, *i.e.* more than twenty times the 81 official

reported deaths (Table 2). According to these estimates, the detection rates were low, with only 0.4% of cases and 5% of deaths reported.

Table 2: SARS-CoV-2 seroprevalence in the study sample, and estimated vs reported cases and deaths at Bamako city level after accounting for age population structure (Bamako, n=1,526, September 2020).

SARS-CoV-2 serological status		
	negative	1,100
	positive	227
		17.1% [15.1-19.2]
Population		
	inhabitants in 2020	2,420,000
Prevalence		
	Reported COVID cases (%)	1,532 (0.07%)
	Estimated infections (%)	397,321 (16.4)
COVID-19 associated Deaths		
	Reported deaths	81 (0.3)
	Estimated deaths	1,725 (7.1)

Household profile as social proxy

Among the 220 households documented, 64.6% (n=142) lived in a private house, 19.1% (n=42) shared their house with another family and 12.3% (n=27) with two others. Only 0.9% (n=2) shared their house with more than two other families (three or four).

Assessing social characteristics and housing conditions, three specific profiles have been determined related to three social dimensions (Table 3): i) Location and family structure; ii) Goods and incomes; iii) Housing conditions. The first profile selected was labelled "Poor Small Family" unit (PSF, n=62), and the second "Poor Large Family" unit (PLF, n=117). These two profiles, mainly located at Yirimadio and Banankabougou, were associated with a low level of incomes or goods, and deleterious housing conditions. The main difference between these two profiles came from the household size: 8.1% of large family (>10 members) vs 27.4% (p=0.002). The PSF profile showed also slightly (but significant) less livestock than the PLF profile (8.1% vs 12.8%, p<0.001), slightly more private toilets (24.2% vs 19.7%, p<0.001), and less rooms (14.5% vs 33.3%, p<0.001). Both profiles showed a low level of education (resp. 35.5% and 46.2% of no education), and around 50% of private house.

The third and last profile, mainly located at Faladie (68%), showed significant high level of incomes (75.6% with a private car, 41.5% having an external financial help, 43.9% having livestock) and best housing conditions (95.4% having a private house, 51.2% having private toilets, 80.5% having more than 4 rooms), and, consequently, was labelled "Rich Family" unit (RF, n=41).

Table 3: Household units' main characteristics (Bamako, n=220, September 2020)

					p value	
	PSF* (ref-%)	PLF* (%)	RF* (%)	Global	PLF vs PSF	PLF vs RF
Dimension 1: Location and family structure						
Location				<0.001§	0.052	<0.001§

BANAKABOUGOU	30.6%	22.2%	22.0%			
YIRIMADIO	58.1%	51.3%	9.8%			
FALADIE	11.3%	26.5%	68.3%			
Large family (>10members vs less)	8.1%	27.4%	46.3%	<0.001§	0.002§	<0.001§
Family chief with low level of education (no school vs education)	35.5%	46.2%	7.3%	<0.001§	0.169	<0.001§
Family chief with high level of education (post-graduate vs no)	14.5%	16.2%	78.8%	<0.001§	0.763	<0.001§
Dimension 2: Incomes and goods of Household unit						
Help from outside (members living outside Mali vs no)	4.8%	3.4%	41.5%	<0.001§	0.641	<0.001§
Goods: private car (yes vs no)	9.7%	9.5%	75.6%	<0.001§	0.952	<0.001§
Goods: livestock (yes vs no)	8.1%	12.8%	43.9%	<0.001§	<0.001§	<0.001§
Dimension 3: Housing conditions						
Private house (yes vs no)	45.2%	49.6%	85.4%	<0.001§	0.574	<0.001§
House with private toilets (yes vs no)	24.2%	19.7%	51.2%	<0.001§	<0.001§	<0.001§
Size of the housing unit (>4 vs 4<= rooms)	14.5%	33.3%	80.5%	<0.001§	<0.001§	<0.001§

**Household profiles defined by hierarchical clustering on components after MCA ('PSF' for Poor Small Family unit, 'PLF' for Poor large Family unit, RF for Rich Family)*

§*significant after Bonferroni correction*

Factors associated with SARS-CoV-2 seropositivity

Factors associated with SARS-CoV-2 seropositivity were identified with a multilevel logistic regression approach (table 4) (individual, household and neighborhood levels). There were no significant differences between the three neighborhoods. Women and older age were significantly associated with increased odds of seropositivity, showing respectively adjusted Odd Ratios (aOR [CI95%]) of 1.75 [1.27;2.43] and 1.06 [1.01;1.11]. Having a positive household member was associated with an increased odd of seropositivity (aOR=1.54 [1.08;2.19]). Household corresponding to the highest socio-demographic status appeared to have increased (but not significant, p=0.06) odds of seropositivity compared to households of poor status living in (aOR=1.74 [0.99;3.07]).

Table 4: Factors associated with SARS-CoV-2 seropositivity

		SARS-CoV-2 serology n(%)/median (IQR)		Univariate*		Multivariate*	
		neg	**pos**	**OR [CI95%]**	**p**	**aOR [CI95%]**	**p**
Sex	**Male**	456 (87.2)	67 (12.8)	1		1	
	Female	644 (80.1)	160 (19.9)	1.78 [1.28;2.49]	<0.001§	1.75 [1.27;2.43]	<0.001§
Age*	**(+1 years)**	16 (9-25)	18 (11-30)	1.07 [1.02;1.12]	0.008§	1.06 [1.01;1.11]	0.017§
Household profile	**Poor Small Family units**	304 (84.9)	54 (15.1)	1		1	
	Poor Large Family units	456 (83.1)	93 (16.9)	1.08 [0.67;1.74]	0.75	1.14 [0.74;1.74]	0.56
	Rich Family units	119 (75.3)	39 (24.7)	1.66 [0.88;3.12]	0.12	1.74 [0.99;3.07]	0.06
	Unclassified	221 (84.4)	41 (15.6)	0.91 [0.52;1.58]	0.74	1.03 [0.62;1.72]	0.91
Already 1 case in the household	**No**	412 (86.9)	62 (13.1)	1		1	
	Yes	688 (80.7)	165 (19.3)	1.37 [0.96;1.95]	0.085	1.54 [1.08;2.19]	0.018§

Neighborhood	**Banankabougou**	454 (82.5)	96 (17.5)	1	0.98	Not included	
	Faladie	229 (82.4)	49 (17.6)	0.98 [0.57;1.70]			
	Yirimadio	417 (83.6)	82 (16.4)	1.03 [0.67;1.59]			

§significant test result

* n=1327

** n=1323 (4 participants showing negative serology with missing ages)

Knowledge, attitudes, behaviors, practices (KABP)

The KABP score, using the 13 items (false/true/don't know questions) described in table 5, showed no mean differences according to gender, with respectively mean=7.9 vs 7.6, p=0.065.

Attitudes, behaviors and practices measured by age and gender (table 6a and 6b) showed, at first, a high level of denial on COVID-19 disease: a large part believed that COVID-19 was a punishment from God (43.7%), a belief mainly shared by older people (mean=25.1 years) compared to others (mean=21.7 years). Many participants believed that COVID-19 was introduced in Mali by white people (45.3%). Other opinion was less held among participants: almost one-third (30.3%) thought that COVID-19 was a way used by Malian politicians to take money from developed countries. This last opinion was more shared among men than women (33.6% vs 26.2%, p=0.01). A small proportion of participants believed that COVID-19 was due to a spell (14.8%).

Concerning changes in daily preventive behaviors from the start of the COVID-19 pandemic, hand washing was reported as the most used by people: only 4.9% of the participants declared rarely, very rarely or never washing hands in their daily life, compared to 29.9% who declared washing hands systematically. Conversely, few participants reported adopting systematically other preventive behaviors in their daily life, such as blowing into the elbow (12.9%), stop touching other people (15.0%), traveling less frequently (11.1%), avoid populated places (9.3%), and avoiding seeing friends (6.6%). Regarding results displayed by age and sex (tables 6a and 6b), the youngest participants were more reluctant to change their daily behaviors whatever their gender.

Finally, most of the participants declared having at-risk practices during the 7 last days, such as never wearing mask when outside (32.7%), visiting very often or daily highly populated public places (31.0%), going out very often or every night (26.1%), not washing hands most of the time (43.2%), staying in closed spaces more than two hours daily or very often (22.4%), or participating to social or family events daily or very often (40,3%). Young participants declared wearing mask less systematically or very often: mean age=22 years vs mean age=25 years). Young women also declared more visiting populated public places than men (40.2% vs 24.2%, 20–39-year-old)

Table 5: Knowledge on COVID-19 (Bamako, n=962, September 2020).

	Questions (true/false/ don't know)	Success (%)
1.	The main clinical symptoms of the disease are dry cough, fever, tiredness and muscle pain (true)	65.0%
2.	Unlike the common cold, blocked nose, runny nose and sneezing are not symptoms that are systematically associated with COVID-19. (true)	42.7%
3.	At present there is no treatment for COVID-19 but early treatment of symptoms can help patients recover (true)	67.0%
4.	Not all infected people will develop severe forms of the disease (true)	60.0%

5. Older people, those with chronic illnesses and the obese are at greater risk of developing a severe form (true)	65.2%
6. Eating or touching wild animals can lead to infection (false)	16.7%
7. People with the virus, if they do not have a fever, are not contagious and therefore cannot transmit COVID-19 to others (false)	30.6%
8. COVID-19 is primarily transmitted by respiratory droplets from infected persons.(true)	70.5%
9. Residents of epidemic areas can wear masks to prevent infection by the COVID-19 virus (true)	73.4%
10. COVID-19 prevention measures do not apply to children and young adults. (false)	37.2%
11. To prevent COVID-19 infection, people should avoid going to populated places (mosques, markets, railway stations) (true)	72.7%
12. Isolating infected people helps to reduce transmission of the virus (true)	77.9%
13. Any person in contact with an infected person should be isolated in a suitable place for an observation period of 14 days (true)	80.2%

Mean score (SD) one point by correct answer from 0 to 13 (13 items scale)
measure of internal consistency: Cronbach's alpha (0.73).
measure of validity (factor analysis): Kaiser-Meyer-Olkin (0.882); Barlett test (p<0.001)

Table 6a: Knowledge, attitudes, behaviors and practices toward COVID-19 among Bamako inhabitants (Bamako, n=962, September 2020)

	12-19 years old			20-39 years old		
	Men	Women	p value	Men	Women	p value
Attitudes/denials towards COVID-19 measured by agreement (agreed, very agreed) with following opinions:						
• Is a god Punishment	40.1%	41.7%	0.702	41.2%	44.6%	0.591
• Has been introduced in Mali by the white people	46.4%	43.6%	0.487	48.5%	46.4%	0.749
• Is due to a spell	14.9%	15.6%	0.822	11.5%	14.3%	0.509
• Help politicians' strategy to take money from developed countries	33.8%	27.8%	0.112	**37.4%**	**24.1%**	**0.026**
Systematic daily changes in behaviors reported from the start of COVID-19 pandemic:						
• Washing hands	27.5%	24.6%	0.420	35.9%	35.7%	0.979
• Blowing into the elbow	12.6%	8.4%	0.099	14.4%	14.4%	0.996
• Stop touching other people (systematically)	12.6%	15.2%	0353	14.4%	16.1%	0.716
• Traveling less frequently	8.7%	9.8%	0.616	14.4%	13.4%	0.822
• Avoiding populated places	7.2%	9.1%	0.389	13.0%	11.6%	0.746
• Avoiding seeing friends	3.9%	5.7%	0.299	8.4%	11.6%	0.403
At-risk practices during the seven past days declared:						
• Wearing mask outside systematically or very often	27.5%	24.2%	0.361	32.8%	33.0%	0.972
• Visiting populated public places every day or very often	31.4%	27.8%	0.329	**24.2%**	**40.2%**	**0.008**[§]
• Going out every night or very often	21.3%	17.5%	0.250	13.0%	17.9%	0.291
• Washing hands when necessary	59.1%	57.4%	0.677	51.1%	56.3%	0.426
• Staying every day, or very often, more than two hours in a small closed space	22.8%	22.4%	0.926	20.5%	20.7%	0.959
• Had participated to social events every day or very often	21.3%	21.6%	0.921	18.9%	24.1%	0.326

[§]significant, after Bonferroni correction

Table 6b: Attitudes, behaviors and practices toward COVID-19 among Bamako inhabitants (Bamako, n=962, 2020)

	39-64 years old			>64 years old		
	Men	Women	p value	Men	Women	p value
Attitudes/denials towards COVID-19 measured by agreement (agreed, very agreed) with following opinions:						
• Is a god Punishment	41.2%	44.6%	0.591	55.1%	60.4%	0.596
• Has been introduced in Mali by the white people	48.5%	46.4%	0.749	38.8%	39.6%	0.935
• Is due to a spell	11.5%	14.3%	0.509	12.2%	12.8%	0.938
• Help politicians' strategy to take money from developed countries	**37.4%**	**24.1%**	**0.026**	24.5%	22.9%	0.855
Systematic daily changes in behaviors reported from the start of COVID-19 pandemic:						
• Washing hands	30.6%	41.7%	0.257	33.3%	33.3%	1.000
• Blowing into the elbow	24.5%	12.5%	0.129	**46.7%**	**0.0%**	**0.015**
• Stop touching other people (systematically)	16.3%	22.9%	0.414	33.3%	11.1%	0.224
• Traveling less frequently	8.0%	20.8%	0.070	26.7%	0.0%	0.090
• Avoiding populated places	8.0%	14.6%	0.302	6.7%	11.1%	0.703
• Avoiding seeing friends	8.0%	12.5%	0.462	13.3%	0.0	0.253
At-risk practices during the seven past days declared:						
• Wearing mask outside systematically or very often	32.7%	37.5%	0.617	46.7%	44.4%	0.916
• Visiting populated public places every day or very often	40.8%	41.7%	0.932	**0.0%**	**30.0%**	**0.024**
• Going out every night or very often	28.6%	20.8%	0.377	**0.0%**	**30.0%**	**0.024**
• Washing hands when necessary	40.8%	47.9%	0.482	33.3%	40.0%	0.734
• Staying every day, or very often, more than two hours in a small closed space	28.5%	25.0%	0.691	6.7%	30.0%	0.119
• Had participated to social events every day or very often	32.7%	27.1%	0.549	6.7%	22.2%	0.265

[§]significant, after Bonferroni correction

Discussion

SARS-CoV-2 population adjusted seroprevalence in the urban commune VI of the Bamako district was 16.4%. This prevalence was much higher than the cumulative incidence reported by epidemiological surveillance since the beginning of the pandemic on the investigation site, which was 0.07% at the time of this survey (September 2020). It can be assumed that there was still active circulation of the virus in the capital city at the time of the surveys, suggested by the presence of IgM positive individuals. The corrected survey data suggest that a high number of SARS-CoV-2 infections occurred in the study site. Projected on the total population of Bamako, this prevalence would correspond to a total of 397,321 cases in September 2020. Mortality projections are crude but suggest that deaths caused by COVID-19 were also under-reported, with 81 reported for an estimated 1,720 expected deaths in Bamako in September 2020. The presence of IgM positive individuals suggests the persistence of active viral circulation at the time of the survey.

Seroprevalence was significantly lower in the Kenyan study, reporting 5.6% in a sample of 3,098 blood donors during the same period [15]. This study found a higher prevalence in urban cities and more widespread circulation of SARS-CoV-2 than reported by case-based surveillance. A similar study conducted in Kinshasa, Democratic Republic of Congo, in October-November 2020 after the first wave found a prevalence of 16.6%, a value close to that estimated here [7]. The differences between the different districts of the Congolese capital were not significant, as in the commune VI of Bamako. In Mali, Sagara *et al.* reported in the peri-urban area of Sotuba a crude seroprevalence of 13.1 % (n=587) across samples collected over a 2-month period after the first wave. But the subsequent study conducted in January 2021 in this peri-urban area showed an adjusted seroprevalence rate of 73.4%, after the second COVID-19 wave [6]. This sharp increase in the prevalence rate can be explained by a wave of intense transmission of COVID-19 related to alpha variant in Mali between November 2020 and January 2021 together with the increase of the screening capacity of the health services [4]. . Indeed, 3,258 new cases were officially reported at the Bamako district (and 172 new deaths) between November 1rst 2020 and January 24 2021.

In our study, seropositivity was higher among women, with a predominance in the 20-40 age group. Conversely, in Senegal, a survey of the acceptability of the measures to fight the COVID-19 found a predominance of the 25-59 years age and male group [16]. Similarly, a literature review on seroprevalence among health workers worldwide found a seroprevalence of 8.2% in Africa with a male predominance [17]. This difference may be explained by the methodology of our study, which recruited only in households and during the day, *i.e.* working time: men aged 20 to 60 may be under-represented in our sample. We did not find any difference in symptomatology between COVID-19 positive and negative individuals during the last four months of the survey. This confirms the pauci-symptomatic clinical situation of the disease.

The main demographic characteristics (age and gender) and proximity as a high potential contact rate (a household member already infected) remained significantly associated with seropositivity after adjusting for the contextual elements available. Although the household condition profile was not a significant determinant of seropositivity, the impact of infection among rich family units should be discussed (aOR 1.74 [0.99;3.07]). Indeed, poor families are more likely to live outdoors, to have lower ages, to have fewer co-morbidities (obesity, diabetes) in this population.

The age-related results were consistent with the epidemiological trends observed during the first wave of the epidemic worldwide: young people were less exposed than older one despite the higher level of risk practices, revealed by the KABP survey, and, as a result, were more reluctant to change their health behavior. According to psychological models of preventive behavior, self-perceived exposure is a key component of individual acceptability of preventive behavior change [18]. Nevertheless, hand

washing was a common practice, perhaps associated with former epidemic (e.g. Ebola in 2014), but not mask wearing, a little-know health practice in the Malian culture.

Conversely, gender differences in outcomes remain problematic. Given the complexity of the relationship between sex, gender, and infectious disease [19], the updated medical literature reports greater vulnerability of men to COVID-19 than women due to gender-related social activities or comorbidities, but also due to significant sexual variations in the immune system [20, 21]. The vulnerability of women highlighted by our survey refers to a broader conception of the impact of SARS-CoV-2, including the carriage of the infection. However, with respect to the KABP survey results, with the exception of a tendency for women to score lower on knowledge of COVID-19, no significant statistical evidence emerged on an association between gender and health behaviors and risk practices. A possible selection bias in the serological survey could partly explain these results, but other hypotheses concerning the specific lifestyle and social position of West African women in light of exposure to infectious diseases need to be further explored. Furthermore, the results of multivariate analyses showing the role played by proximity in person-to-person transmission confirm that the spread of infectious diseases within the community involves a significant amount of within family transmissions due to asymptomatic transmission [22], particularly via children[23].

A study on factors associated with the acceptability of government measures against COVID-19 in Senegal showed a correlation between education level and the proposed measures (inter-regional travel ban, curfew, closure of places of worship and closure of markets). But those with primary education and those with no education were likely to accept of curfews and less likely to accept inter-regional travel bans and the closure of places of worship [16].

Finally, the trend of increasing positivity of the social indicator summarized in household profiles leads us to consider that understanding epidemic dynamics in populated cities involves taking into account the spatial structure of the population [24]. Additional evidence from geographic and socio-economic components [25, 26]), highlight the question of inequalities and individual vulnerability at each stage of the epidemic's spread: from dissemination including various factors such as household size [27], transmission of infection within the community to the associated societal consequences [28].

Conclusion

In March 2022, 2 years after the pandemic onset and 4 epidemic waves, 30,398 confirmed cases (725 associated deaths) were officially reported in Mali, 20,115 for the district of Bamako, and 60 health districts (among 75) reported cases. The Commune VI remains the most affected (or the most reporting cases) area with 5,712 reported cases. However, these reported numbers under-estimate the number of infected persons. The following waves involved variants, which were more aggressive and may also have led to a heavier death toll, and the consequences could be evaluated using revised prevalence and variant-adjusted infection fatality ratios. Conducted after the first wave, this study highlights the need for sufficient screening data to design efficient epidemic control strategies. Improving diagnostic capacities as well as awareness of populations, to encourage testing and preventive behaviors, as well as avoiding the spread of false information on the epidemic remain key pillars, not matter the developed or developing setting.

List of abbreviations

IRD: Institut de Recherche pour le Développement France
RF: Rich Family units
PLF: Poor Large Family units
PSF: Poor Small Family units
SARS-CoV-2: Severe Acute Respiratory Syndrome Coronavirus 2

***WHO**:* World Health Organization
GAMM: generalized additive multilevel models
KABP: Knowledge, Attitudes, Behaviors and Practices

Declarations

Ethics approval and consent to participate

The study was approved by the ethics committee of the Faculty of Medicine and Odontostomatology of Mali **N°2020/162/CE/FMOS/FAPH** and the Ministry of Health and Social Action **N° 001424 MASA-SG**.
A community agreement was first obtained from district leaders, local religious leaders, community associations and municipal authorities after explanation and discussion about the study protocol. Second, consents and/or assents of participants or their parent/guardian were obtained. The study team administered consent in local languages, and, if the participant or parent/guardian was not literate, in the presence of a witness. Individuals from each family consented separately.

Consent for publication

NA (no personal details/images/video in the manuscript)

Availability of supporting data

The data that support the findings of this study are available on reasonable request from the corresponding author, JG. The data are not publicly available due to confidentiality and ethical restrictions.

Competing interests

None declared

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Author contributions

JG and HB conceived and designed the study protocol, helped by JL, IS, MC, BK, IB, AG, OD, AD and MKBD. All the authors validated the study protocol.
MKBD wrote the household and KABP questionnaires, with the help of JL, MC, JG and IS.
MC, AKS and IS organized and supervised the samples and data collections, performed by AK, SS, ZD, CD, IT, ST, HM.
ST and IT were in charge of the information system under the supervision of IS.
JL, MKBD, MC and JG conceived and designed the data analysis. JL, MKBD and MC performed the data management and analysis.
BK and AKS designed and supervised the serological analysis, performed by HM, ES, KC.
JL, MKBD, MC and JG wrote the paper, corrected by all authors.
All authors participated to the manuscript and approved its last version.

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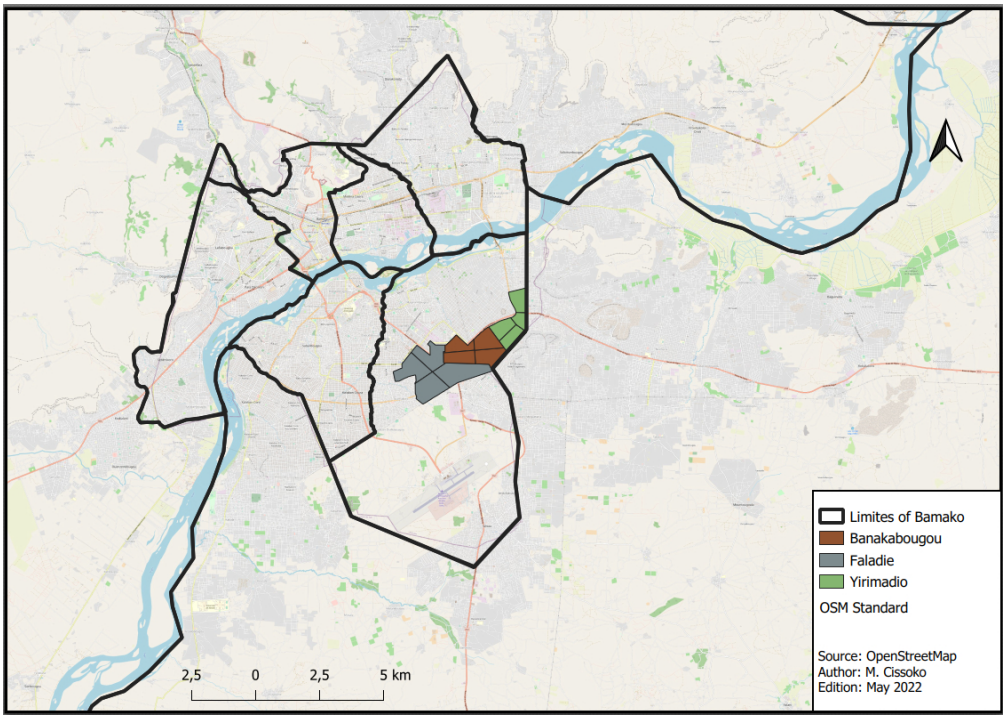

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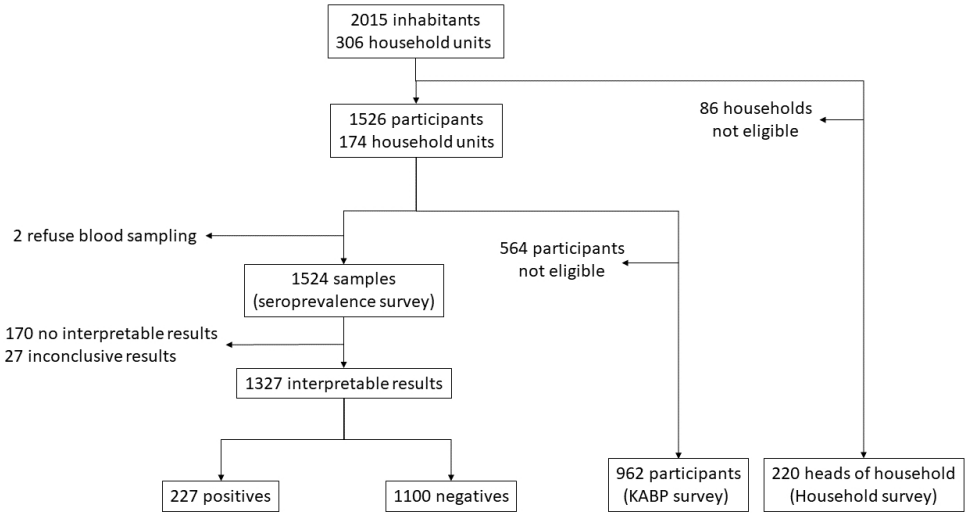

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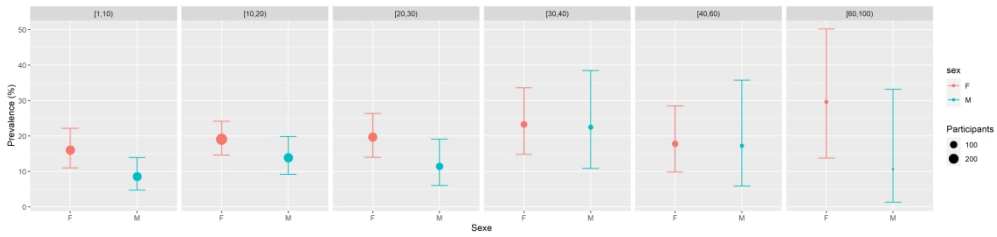

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SARS-CoV-2 seroprevalence and living conditions in Bamako (Mali): a cross-sectional multistage household survey after the first epidemic wave, 2020

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SARS-CoV-2 seroprevalence and living conditions in Bamako (Mali): a cross-sectional multistage household survey after the first epidemic wave, 2020

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Abstract

Objectives

In low-income settings with limited access to diagnosis, COVID-19 information is scarce. In September 2020, after the first COVID-19 wave, Mali reported 3,086 confirmed cases and 130 deaths. Most reports originated from Bamako, with 1,532 cases and 81 deaths (2.42 million inhabitants). This observed prevalence of 0.06% appeared very low. Our objective was to estimate SARS-CoV-2 infection among inhabitants of Bamako, after the first epidemic wave. We assessed demographic, social and living conditions, health behaviors and knowledges associated with SARS-CoV-2 seropositivity.

Settings

We conducted a cross-sectional multistage household survey during September 2020, in three neighborhoods of the commune VI (Bamako), where 30% of the cases were reported.

Participants

We recruited 1,526 inhabitants in 3 areas, *i.e.* 306 households, and 1,327 serological results (≥1 years), 220 household questionnaires and collected answers for 962 participants (≥12 years).

Primary and secondary outcome measures

We measured serological status, detecting SARS-CoV-2 spike protein antibodies in blood sampled. We documented housing conditions and individual health behaviors through questionnaires among participants. We estimated the number of SARS-CoV-2 infections and deaths in the population of Bamako using the age and sex distributions.

Results

The prevalence of SARS-CoV-2 seropositivity was 16.4% CI95%(15.1; 19.1) after adjusting on the population structure. This suggested that ~400,000 cases and ~2,000 deaths could have occurred of which only 0.4% of cases and 5% of deaths were officially reported. Questionnaires analyses suggested strong agreement with washing hands but lower acceptability of movement restrictions (lockdown/curfew), and mask wearing.

Conclusions

The first wave of SARS-CoV-2 spread broadly in Bamako. Expected fatalities remained limited largely due to the population age structure and the low prevalence of comorbidities. Improving diagnostic capacities to encourage testing and preventive behaviors, and avoiding the spread of false information remain key pillars, regardless of the developed or developing setting.

Registration number

This study was registered in the registry of the ethics committee of the Faculty of Medicine and Odonto-Stomatology and the Faculty of Pharmacy, Bamako, Mali, under the number: 2020/162/CA/FMOS/FAPH.

Keywords: COVID-19, sero-prevalence, living conditions, knowledge attitude behavior and practice.

Strengths and limitations of this study

- A multi-stage cross-sectional survey was set up within the most affected health district of Bamako, the capital city, Mali, after the first wave of COVID-19
- In addition to the blood sampling for SARS-CoV-2 serology, the survey collected information on household living conditions and participants' knowledges, attitudes, behaviors and practices
- A multilevel generalized additive logistic model was performed to estimate the factors associated to SARS-CoV-2 seropositivity
- Seroprevalence monitoring over time was not possible, and it was not possible to include all the districts of Bamako in the study.

Background

COVID-19 disease, due to the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), which emerged at the end of 2019 in Wuhan, China, has spread rapidly around the world and was declared as "pandemic" on 11 March 2020 by the World Health Organization (WHO) [1]. Despite setting up public health policies appropriated to this pandemic situation, such as lockdown, quarantine and curfew, the virus continues to circulate [2, 3]. The WHO African Region reported the least number of affected people since the pandemic began. Indeed, in many resource-limited settings, biological confirmation was only available in tertiary medical facilities and has been reserved for symptomatic patients (mostly severe) and/or travelers, the various national policies requiring a negative test for travel. As a result, the number of people exposed to the virus in Sub-Saharan Africa is still largely unknown [1].

After the first reported case on March 25th 2020 (coming from France on March 12th), Mali has recorded, 6 months later (at the time of the survey), 3,086 cases of SARS-CoV-2 diagnosed by RT-PCR, *i.e.* an incidence rate of 0.015% for the whole country. Spread over 38 health districts (among 75), they led 130 reported deaths, *i.e.* a case fatality rate of 4.2%[4].
Among the cases recorded in September 2020, ~50% were reported in the district of Bamako *i.e.* 1,532 reported cases, for a population of at least 2.42 million inhabitants. The most affected area was the Commune VI with 466 reported cases and 27 associated deaths. The second largest number of recorded cases was reported in the region of Timbuktu, with 572 confirmed cases at 6 months after the onset of the epidemic [4].

Given the limited access to diagnosis and care, and in the absence of a reliable syndromic surveillance, the low number of reported cases did not allow to assess accurately the epidemic situation. In this context, serological surveys represent an important tool to assess the extent of the exposure to SARS-CoV-2 in the general population. A single survey provides a snapshot of the extent of the virus spread at a given time point, and informs on vulnerable population groups, on the denominators used to calculate infection fatality rate or hospitalization rates [5]. In Mali, a multi-site study including a peri-urban area of the capital city Bamako demonstrated a sharp increase in seroprevalence between a survey conducted after the first wave of clinical cases (August 2020) and a survey conducted during the decrease of the second wave (January 21), identifying geographical location and age as associated factors [6]. Indeed, Sagara *et al.* reported in the peri-urban area of Sotuba a crude seroprevalence of 13.1 % (n=587) after the first wave. In the capital city of Kinshasa, Nkuba *et al.* reported a similar result with a seroprevalence of 16.6% (n=1233) [7].
Seroprevalence is also essential to assess the level of herd immunity that has been developed, which determines the risk of the following epidemic waves, their potential severity and their potential impact on the healthcare system. Measuring immunity could also help develop response strategies including priority strains for vaccination or targeted awareness campaigns.
In the settings where mortality and hospitalization statistics are not readily available, approximating the number of infections by age groups and by gender was also important to estimate the order of magnitude for expected infection fatality rates and compare it to reported COVID-19 deaths [8].
In addition, better access to information on epidemiological trends, social factors associated, health and protective behaviors, as well as attitudes and beliefs, was needed to design control strategies and strengthen information and awareness campaigns.
The aim of this study was to estimate the seroprevalence of SARS-CoV-2 in the population of the most populated and affected commune of Bamako, after the first epidemic wave. We also assessed demographic, social and living conditions associated with SARS-CoV-2 seropositivity, and health behaviors, knowledges according to COVID-19.

Methods

Study design and sample size calculation

In accordance with the WHO guidelines protocol for age-stratified population-based sero-epidemiological surveys for COVID-19 infection, a cross-sectional household survey was conducted [8] in the 3 most affected and populated neighborhoods of Bamako's commune VI: Faladié, Banakabougou, and Yirimadjo (Figure 1), September 2020. At the time of the protocol (July 2020), the number of cases reported was 38, 29, and 40 respectively for these neighborhoods, representing 0.07 cases/ 100 inhabitants, and 54% of the total reported cases in Commune VI.

Figure 1: Map of Bamako showing the location of the 3 investigated neighborhoods within the Commune VI (in red).

The sample size was calculated assuming an expected prevalence of COVID-19 infection of 0.07 cases/ 100 inhabitants, within the population. Based on this assumption, a sample size of 1300 persons was estimated, with a precision of 2% and a confidence interval of 95%. Considering 15% loss, 1500 participants were expected to be included. A multi-stage cluster sampling method covering all age ≥1 groups of the population was performed [9]. In the first stage, the sample size to be recruited per district was proportional to the district population sizes. In the second stage, each district was divided into different sectors (4 or more) of relatively equal sub-population size. The household survey therefore concerned each sector of each district. The first household in each sector was selected by choosing a random direction from the center of the community sector, counting the houses along that road and selecting one at random. Subsequent households were selected by visiting the closest house to the previous one. All household members in the age range willing to participate were recruited. The study was conducted among the general population aged ≥1-year-old for the seroprevalence study, and ≥12-year-old for the questionnaire survey. A housing unit was defined as a private one, such as apartment or villa or collective house (living quarter called "compound") with its own separate entry. Common residence rules (*de jure* rules) defined household unit as group of first-degree relatives usually living in the same housing unit. This approach allowed considering Malian family structure and local housing habits to define household units.

Individual sample and data collection

After informed consent obtained from the participants or their parents, 2ml of blood were collected from all voluntary participants by venipuncture (September 2020), to perform serological tests. Following the blood sampling, a face-to-face questionnaire was administered to collect the following demographic and sociologic factors: gender, age, history of recent travel within and outside Bamako, socio-economic level, contact with COVID-19 cases, occupation, education level, recent treatment, and attendance at places of worship. The questionnaire also included items relative to the knowledge about the disease, protective measures and consequences on the population health.

Housing conditions and household data collection

The head of household was asked to answer a specific questionnaire documenting their individual characteristics (age, gender, education, profession), household structure (number and age of members) and housing conditions including housing equipment, goods, and incomes of family (car, TV, motorbike, cell phone, external funding…). Assessing social characteristics and housing conditions, three specific profiles have been determined. To determine household profile as social proxy the location and family structure, goods and incomes and housing conditions were used.

Biological analyses

The level of exposure of the population to SARS-CoV-2 was estimated by serology. Sera were separated from whole blood and stored at -80°C in cryotubes. SARS-CoV-2 specific IgM and IgG antibodies were assayed in sera by VIDAS® anti-SARS-CoV-2 IgM and anti-SARS-CoV-2 IgG kits (BioMerieux, Lyon, France) [10]. The VIDAS® anti-SARS-CoV-2 IgM and anti-SARS-CoV-2 IgG tests relied on the SARS-CoV-2 Spike protein immunoassay technique to measure the presence of antibodies in infected participants. Compared to PCR, the sensitivity of the VIDAS® tests for IgM and IgG is 90.4% and 88.6%, 8-15 days after SARS-CoV-2 infection, 100 and 96.6%, 16 days after infection, respectively. The specificity for IgM and IgG is 99.4% and 99.6%, respectively. In this context, the specificity of the tests was particularly important to ensure that the test of an un-infected participant was indeed systematically negative. Serology analyses were performed at the Charles Mérieux Infectiology Centre in Bamako, Mali.

Participants were defined as SARS-CoV-2 seropositive if they presented either a positive IgG or IgM result. Individuals were defined as SARS-CoV-2 seronegative if they presented a negative IgG and IgM result, or a negative IgG and a missing IgM result. Individuals with missing IgG results were excluded from the seroprevalence analysis.

The seroprevalence was estimated as the number of SARS-CoV-2 seropositive by the number of participants. The number of infections for the district of Bamako was estimated using the population of Bamako by sex and age categories. The number of deaths was estimated by using the age- and sex-specific mortality data reported early in the pandemic (February-March in China, prior to the optimization of clinical management) [11].

Knowledges, attitudes, behaviors, practices outcomes measures

The current at-risk practices have been measured using a four bipolar Likert Items on practices during the seven past days assessing: wearing mask when not at home, washing hands with soap, going to crowned areas during the day or the night. Regarding behavior questions, six bipolar Likert Items (from systematically/very often to never) on behavior changes since the start of the epidemic focusing on: washing hands, visiting friends and relatives, going to crowned areas, touching each other, sneezing into elbow, reducing travel. Regarding knowledge questions, a scale-score based on 13 items (True/False/Don't know) on prevention, treatment, symptoms, and transmission of SARS-CoV-2 has been build up. At least, regarding cultural beliefs, four bipolar Likert Items (from strongly agreed to strongly disagreed) assessed opinion about the disease focusing on infection origin: a divine punishment, a spell casting, a white people illness, a way to get money for rich people.

Data analysis

First, descriptive analyses estimated mean, prevalence and frequencies, associated with 95% confidence intervals (CI95%).

Household profiles were determined by using a 2 step descriptive approach [12]: first a multiple component analysis (MCA), second a Hierarchical Ascendant Classification (HAC). Based on household level variables, this approach led to determine classes according to the different household profiles. Each individual was assigned to its household profile.

Second, in order to estimate factors associated with SARS-CoV-2 seropositivity, we used logistic generalized additive multilevel models (GAMM) [13]. We analyzed the effects of age and sex at individual level, as well as household profile [14]. Intra-household contamination was assessed as a binary variable (more than 1 positive case or not). The GAMM approach allowed also verifying the non-linear effect of continuous covariates by using spline smoothing [15]. The model included random effects for household, compound and district sector to reflect sampling structure and potential correlations between participants sharing the same living space (household nested in compound sampled in the same sector). Main statistical tests were performed using an α-probability threshold of 5%, but with Bonferroni correction for sub-group analyses.

Data analyses were performed using the SPSS software (IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp) for the questionnaire data management and descriptive analyses, and the R software (version 4.0.0, R Core Team 2020. R Foundation for Statistical Computing, Vienna, Austria.) with the following specific packages: {FactoMineR}, {lme4}, {gamm4}.

Ethics and regulations

The authorization to conduct the study was obtained on August 28th, 2020, from the Ministry of Health and Social Affairs of Mali (decision letter number 2020-001424-MSAS-SG). Clearance from the ethics committee of the Faculties of Medicine and Odonto-Stomatology and Pharmacy, University of Sciences, Technics and Technologies of Bamako (Mali) was obtained on August 10th, 2020 (clearance letter number 2020/162/CA/FMOS/FAPH). First, a community agreement was obtained from district leaders, local religious leaders, community associations and municipal authorities after explanation and discussion about the study protocol. Second, consents and/or assents of participants or their parent/guardian were obtained. The study team administered consent in French and local languages, and, if the participant or parent/guardian was not literate, in the presence of a witness. Individuals from each family consented separately. This study was registered in the registry of the ethics committee of the Faculty of Medicine and Odonto-Stomatology and the Faculty of Pharmacy, Bamako, Mali, under the number: 2020/162/CA/FMOS/FAPH.

Patients and Public involvement

The national federation of community health associations is part of the COVID-19 national committee, contacted during study design. For recruitment, the local Community Health Association appointed community health workers as part as the field investigation team. The mayor of the commune, after receiving information on the study, issued a radio announcement to inform the population of the survey and to solicit their participation. A community representative, selected by the neighborhood head and independent from the research team, participated to the field study as a witness, ensuring that participants understand the study and that they have given their informed consent.

The field study team provided a report to the local authorities and to the community health association. All participants who wanted to have personal results (or any question about the study) had 2 medical contacts (telephone numbers). Public feedback meetings were held with the local community health association and the local authorities.

Results

Inclusions

A sample of 174 housing units (separate living quarter) were investigated including 2,015 inhabitants grouped in 306 identified household units.

Of 2,015 inhabitants, 1,526 (75.7%) participants aged ≥1 year provided a blood sample for the seroprevalence survey and 962 participants aged ≥12 years answered the KABP survey (Appendix table A1). Data on housing conditions were collected for 220 of the 306 household units included, *i.e.* 78.9% of the household members tested (n=1,204) (Figure 2).

Figure 2: flowchart of the seroprevalence survey

SARS-CoV-2 seroprevalence

Out of 1,526 participants, 2 did not provide samples, 170 had no interpretable test results for both IgG and IgM, and 27 inconclusive results due to a missing IgG and negative IgM results or inversely. Overall, interpretable serological results were available for 1,327 participants, corresponding to 227 SARS-CoV-2 seropositive (by either IgG, IgM or both) and 1,100 seronegative individuals. The crude seroprevalence rate was estimated at 17.1% (95% Confidence interval (CI95%) [15.1-19.1], ranging from less than 10% to upper than 30% across genders and age groups (Figure 3).

Figure 3: Seroprevalence by age and sex (Bamako, n=1327, September 2020).

Applying estimated prevalence, by age and sex, to the population of the district of Bamako (2.42 million inhabitants), we estimated around 400,000 the number of infections in the city between the onset of the epidemic and the time of the survey (September 2020), compared to 1,532 recorded cases for the district of Bamako. This corresponded to an adjusted prevalence of 16.4% [8.0-24.9] (adjusted on the population age and sex distribution) *vs* an observed prevalence of 0.06%. Using the age- and sex-specific mortality data reported early in the pandemic, we roughly estimated 1,725 COVID-19 deaths occurred between the onset of the pandemic and the date of the survey, *i.e.* more than twenty times the 81 official reported deaths (table 1). According to these estimates, the detection rates were low, with only 0.4% of cases and 5% of deaths reported.

Table 1: SARS-CoV-2 seroprevalence in the study sample, and estimated *vs* reported cases and deaths at Bamako city level after accounting for age population structure (Bamako, n=1,526, September 2020).

		N= [95% confidence interval]	Prevalence (%) [95% confidence interval]
SARS-CoV-2 serological status	positive	227	17.1% [13.7-20.5]
	negative	1,100	
Population (inhabitants in 2020)		2,420,000	
COVID-19 in Bamako	Cases, reported after confirmation*	1,532	0.07%
	Infections, estimated	397,321 [192,452-602,183]	16.4% [8.0-24.9]
Mortality	Deaths, reported*	81	0.003%
	Deaths, estimated based on infections	1,725 [476-2,970]	0.07% [0.02-0.12]
* reference: COVID-19 in Mali situation report n°121 (21-27 September 2020), Ministry of Health, Mali			

Household profile as social proxy

Among the 220 households documented, 64.6% (n=142) lived in a private house, 19.1% (n=42) shared their house with another family and 12.3% (n=27) with two others. Only 0.9% (n=2) shared their house with more than two other families (three or four).

The first profile selected was labelled "Low Income Small Family" units (LISF, n=62), and the second "Low Income Large Family" units (LILF, n=117). These two profiles, mainly located at Yirimadio and Banankabougou, were associated with a low level of incomes or goods, and poor housing conditions. The main difference between these two profiles came from the household size: 8.1% of large family

(>10 members) *vs* 27.4% (p=0.002). The LISF profile showed also slightly (but significant) less livestock than the LILF profile (8.1% *vs* 12.8%, p<0.001), slightly more private toilets (24.2% *vs* 19.7%, p<0.001), and less rooms (14.5% *vs* 33.3%, p<0.001). Both profiles showed a low level of education (resp. 35.5% and 46.2% of no education), and around 50% of private house (Table 2).

The third and last profile, mainly located at Faladie (68%), showed significant high level of incomes (75.6% with a private car, 41.5% having an external financial help, 43.9% having livestock) and best housing conditions (95.4% having a private house, 51.2% having private toilets, 80.5% having more than 4 rooms), and, consequently, was labelled "High Income Family" units (HIF, n=41).

Table 2: Household units' main characteristics (Bamako, n=220, September 2020)

				p-value	Subgroup analysis	
	LISF* (ref-%)	LILF* (%)	HIF* (%)	Global	LILF *vs* LISF	LILF *vs* HIF
Dimension 1: Location and family structure						
Location				<0.001§	0.052	<0.001§
BANAKABOUGOU	30.6%	22.2%	22.0%			
YIRIMADIO	58.1%	51.3%	9.8%			
FALADIE	11.3%	26.5%	68.3%			
Large family (>10members *vs* less)	8.1%	27.4%	46.3%	<0.001§	0.002§	<0.001§
Family chief with low level of education (no school *vs* education)	35.5%	46.2%	7.3%	<0.001§	0.169	<0.001§
Family chief with high level of education (post-graduate *vs* no)	14.5%	16.2%	78.8%	<0.001§	0.763	<0.001§
Dimension 2: Incomes and goods of Household unit						
Help from outside (members living outside Mali *vs* no)	4.8%	3.4%	41.5%	<0.001§	0.641	<0.001§
Goods: private car (yes *vs* no)	9.7%	9.5%	75.6%	<0.001§	0.952	<0.001§
Goods: livestock (yes *vs* no)	8.1%	12.8%	43.9%	<0.001§	<0.001§	<0.001§
Dimension 3: Housing conditions						
Private house (yes *vs* no)	45.2%	49.6%	85.4%	<0.001§	0.574	<0.001§
House with private toilets (yes *vs* no)	24.2%	19.7%	51.2%	<0.001§	<0.001§	<0.001§
Size of the housing unit (>4 *vs* 4<= rooms)	14.5%	33.3%	80.5%	<0.001§	<0.001§	<0.001§

**Household profiles defined by hierarchical clustering on components after MCA ('LISF' Low Income Small Family, 'LILF' for Low Income Large Family, 'HIF' for High Income Family)*

§*significant after Bonferroni correction*

Factors associated with SARS-CoV-2 seropositivity

Factors associated with SARS-CoV-2 seropositivity were identified with a multilevel logistic regression approach (Table 3) (individual, household and neighborhood levels). There were no significant differences between the three neighborhoods. Women and older age were significantly associated with increased odds of seropositivity, showing respectively adjusted Odd Ratios (aOR [CI95%]) of 1.75 [1.27;2.43] and 1.06 [1.01;1.11]. Having a positive household member was associated with an increased odd of seropositivity (aOR=1.54 [1.08;2.19]). Household corresponding to the highest socio-demographic status appeared to have increased (but not significant, p=0.06) odds of seropositivity compared to households of low-income status living in (aOR=1.74 [0.99;3.07]).

Table 3: Factors associated with SARS-CoV-2 seropositivity

		SARS-CoV-2 serology n(%)/median (IQR)		Univariate*		Multivariate*	
		Negative (n=)	Positive N; % [CI95%]	**OR [CI95%]**	**p**	**aOR [CI95%]**	**p**
Sex	Male	456	67; 12.8% [9.0-16.6]	1		1	
	Female	644	160; 19.9% [15.2-24.6]	1.78 [1.28;2.49]	<0.001§	1.75 [1.27;2.43]	<0.001§
Age**		16 (9-25)	18; [11-30]	1.07 [1.02;1.12]	0.008§	1.06 [1.01;1.11]	0.017§
Household profile***	LISF	304	54; 15.1% [6.9-23.3]	1		1	
	LILF	456	93; 16.9% [11.7-22.2]	1.08 [0.67;1.74]	0.75	1.14 [0.74;1.74]	0.56
	HIF	119	39; 24.7% [14.1-35.2]	1.66 [0.88;3.12]	0.12	1.74 [0.99;3.07]	0.06
	Unclassified	221	41; 15.6% [10.2-21.1]	0.91 [0.52;1.58]	0.74	1.03 [0.62;1.72]	0.91
Already 1 case in the household	No	412	65; 12.6% [5.0-20.2]	1		1	
	Yes	688	162; 20.0% [15.0-25.0]	1.37 [0.96;1.95]	0.085	1.54 [1.08;2.19]	0.018§
Neighbor-hoods	Banankabougou	454	96; 17.5% [10.6-24.3]	1	0.98	Not included	
	Faladie	229	49; 17.6% [10.3-24.9]	0.98 [0.57;1.70]			
	Yirimadio	417	82; 16.4% [10.8-22.0]	1.03 [0.67;1.59]			

§significant test result

** n=1327*

*** n=1323 (4 participants showing negative serology with missing ages)*

**** 'LISF' Low Income Small Family, 'LILF' for Low Income Large Family, 'HIF' for High Income Family*

Knowledge, attitudes, behaviors, practices (KABP)

The KABP score, using the 13 items (false/true/don't know questions) described in table 4, showed no mean differences according to gender, with respectively mean=7.9 *vs* 7.6, p=0.065. Men and women differ in their risk behaviors and practices toward COVID-19 regardless of age. Despite reporting social restriction from the beginning of the epidemic, mainly contact with friends, women were less likely than men to wear a mask outdoors and to avoid going to crowded places. (Appendix Tables A2 and A3). Attitudes, behaviors and practices measured by age and gender (Tables 5a and 5b) showed, at first, a high level of denial on COVID-19 disease: a large part believed that COVID-19 was a punishment from God (43.7%), a belief mainly shared by older people (mean=25.1 years) compared to others (mean=21.7 years). Many participants believed that COVID-19 was introduced in Mali by white people (45.3%). Other opinion was less held among participants: almost one-third (30.3%) thought that COVID-19 was a way used by Malian politicians to take money from developed countries. This last opinion was shared more among men than women (33.6% *vs* 26.2%, p=0.01). A small proportion of participants believed that COVID-19 was due to a spell (14.8%).

Concerning changes in daily preventive behaviors from the start of the COVID-19 pandemic, hand washing was reported as the most used by people: only 4.9% of the participants declared rarely, very rarely or never washing hands in their daily life, compared to 29.9% who declared washing hands systematically. Conversely, few participants reported adopting systematically other preventive behaviors in their daily life, such as blowing into the elbow (12.9%), stop touching other people (15.0%), traveling less frequently (11.1%), avoid populated places (9.3%), and avoiding seeing friends

(6.6%). Regarding results displayed by age and sex (tables 5a and 5b), the youngest participants were more reluctant to change their daily behaviors regardless their gender.

Finally, most of the participants declared having at-risk practices during the 7 last days, such as never wearing mask when outside (32.7%), visiting very often or daily highly populated public places (31.0%), going out very often or every night (26.1%), not washing hands most of the time (43.2%), staying in closed spaces more than two hours daily or very often (22.4%), or participating to social or family events daily or very often (40,3%). Young participants declared wearing mask less systematically or very often: mean age=22 years *vs* mean age=25 years). Young women also declared more visiting populated public places than men (40.2% *vs* 24.2%, 20–39-year-old).

Table 4: Knowledge on COVID-19 (Bamako, n=962, September 2020).

	Questions (true/false/ don't know)	Success (%)
1.	The main clinical symptoms of the disease are dry cough, fever, tiredness and muscle pain (true)	65.0%
2.	Unlike the common cold, blocked nose, runny nose and sneezing are not symptoms that are systematically associated with COVID-19. (true)	42.7%
3.	At present there is no treatment for COVID-19 but early treatment of symptoms can help patients recover (true)	67.0%
4.	Not all infected people will develop severe forms of the disease (true)	60.0%
5.	Older people, those with chronic illnesses and the obese are at greater risk of developing a severe form (true)	65.2%
6.	Eating or touching wild animals can lead to infection (false)	16.7%
7.	People with the virus, if they do not have a fever, are not contagious and therefore cannot transmit COVID-19 to others (false)	30.6%
8.	COVID-19 is primarily transmitted by respiratory droplets from infected persons. (true)	70.5%
9.	Residents of epidemic areas can wear masks to prevent infection by the COVID-19 virus (true)	73.4%
10.	COVID-19 prevention measures do not apply to children and young adults. (false)	37.2%
11.	To prevent COVID-19 infection, people should avoid going to populated places (mosques, markets, railway stations) (true)	72.7%
12.	Isolating infected people helps to reduce transmission of the virus (true)	77.9%
13.	Any person in contact with an infected person should be isolated in a suitable place for an observation period of 14 days (true)	80.2%

Mean score (SD) one point by correct answer from 0 to 13 (13 items scale)
measure of internal consistency: Cronbach's alpha (0.73).
measure of validity (factor analysis): Kaiser-Meyer-Olkin (0.882); Barlett test (p<0.001)

382 **Table 5a: Knowledges, attitudes, behaviors and practices toward COVID-19 among Bamako inhabitants (Bamako, n=962, September 2020)**

	12-19 years old			20-39 years old		
	Men	Women	p value	Men	Women	p value
Attitudes/denials towards COVID-19 measured by agreement (agreed, very agreed) with following opinions:						
Is a God Punishment	40.1%	41.7%	0.702	41.2%	44.6%	0.591
Has been introduced in Mali by the white people	46.4%	43.6%	0.487	48.5%	46.4%	0.749
Is due to a spell	14.9%	15.6%	0.822	11.5%	14.3%	0.509
Help politicians' strategy to take money from developed countries	33.8%	27.8%	0.112	**37.4%**	**24.1%**	**0.026**
Systematic daily changes in behaviors reported from the start of COVID-19 pandemic:						
Washing hands	27.5%	24.6%	0.420	35.9%	35.7%	0.979
Blowing into the elbow	12.6%	8.4%	0.099	14.4%	14.4%	0.996
Stop touching other people (systematically)	12.6%	15.2%	353	14.4%	16.1%	0.716
Traveling less frequently	8.7%	9.8%	0.616	14.4%	13.4%	0.822
Avoiding populated places	7.2%	9.1%	0.389	13.0%	11.6%	0.746
Avoiding seeing friends	3.9%	5.7%	0.299	8.4%	11.6%	0.403

At-risk practices during the seven past days declared:						
Wearing mask outside systematically or very often	27.5%	24.2%	0.361	32.8%	33.0%	0.972
Visiting populated public places every day or very often	31.4%	27.8%	0.329	**24.2%**	**40.2%**	**0.008**[§]
Going out every night or very often	21.3%	17.5%	0.250	13.0%	17.9%	0.291
Washing hands when necessary	59.1%	57.4%	0.677	51.1%	56.3%	0.426
Staying every day, or very often, more than two hours in a small closed space	22.8%	22.4%	0.926	20.5%	20.7%	0.959
Had participated to social events every day or very often	21.3%	21.6%	0.921	18.9%	24.1%	0.326

[§]*significant, after Bonferroni correction*

Table 5b: Knowledges, attitudes, behaviors and practices toward COVID-19 among Bamako inhabitants (Bamako, n=962, September 2020)

	39-64 years old			>64 years old		
	Men	Women	p value	Men	Women	p value
Attitudes/denials towards COVID-19 measured by agreement (agreed, very agreed) with following opinions:						

Is a God Punishment	41.2%	44.6%	0.591	55.1%	60.4%	0.596
Has been introduced in Mali by the white people	48.5%	46.4%	0.749	38.8%	39.6%	0.935
Is due to a spell	11.5%	14.3%	0.509	12.2%	12.8%	0.938
Help politicians' strategy to take money from developed countries	**37.4%**	**24.1%**	**0.026**	24.5%	22.9%	0.855
Systematic daily changes in behaviors reported from the start of COVID-19 pandemic:						
Washing hands	30.6%	41.7%	0.257	33.3%	33.3%	1.000
Blowing into the elbow	24.5%	12.5%	0.129	**46.7%**	**0.0%**	**0.015**
Stop touching other people (systematically)	16.3%	22.9%	0.414	33.3%	11.1%	0.224
Traveling less frequently	8.0%	20.8%	0.070	26.7%	0.0%	0.090
Avoiding populated places	8.0%	14.6%	0.302	6.7%	11.1%	0.703
Avoiding seeing friends	8.0%	12.5%	0.462	13.3%	0.0	0.253
At-risk practices during the seven past days declared:						
Wearing mask outside systematically or very often	32.7%	37.5%	0.617	46.7%	44.4%	0.916

Visiting populated public places every day or very often	40.8%	41.7%	0.932	**0.0%**	**30.0%**	**0.024**
Going out every night or very often	28.6%	20.8%	0.377	**0.0%**	**30.0%**	**0.024**
Washing hands when necessary	40.8%	47.9%	0.482	33.3%	40.0%	0.734
Staying every day, or very often, more than two hours in a small closed space	28.5%	25.0%	0.691	6.7%	30.0%	0.119
Had participated to social events every day or very often	32.7%	27.1%	0.549	6.7%	22.2%	0.265

386 [§]*significant, after Bonferroni correction*

Discussion

SARS-CoV-2 population adjusted seroprevalence in the urban commune VI of the Bamako district was 16.4% [8.0-24.9]. This prevalence was much higher than the cumulative incidence reported by epidemiological surveillance since the beginning of the pandemic on the investigation site, which was 0.07% at the time of this survey (September 2020). It can be assumed that there was still active circulation of the virus in the capital city at the time of the surveys, suggested by the presence of IgM positive individuals. The corrected survey data suggest that a high number of SARS-CoV-2 infections occurred in the study site. Projected on the total population of Bamako, this prevalence would correspond to a total of 397,321 cases in September 2020. Mortality projections are crude but suggest that deaths caused by COVID-19 were also under-reported, with 81 reported for an estimated 1,720 expected deaths in Bamako in September 2020. The presence of IgM positive individuals suggests the persistence of active viral circulation at the time of the survey.

Seroprevalence was significantly lower in the Kenyan study, reporting 5.6% in a sample of 3,098 blood donors during the same period [16]. This study found a higher prevalence in urban cities and more widespread circulation of SARS-CoV-2 than reported by case-based surveillance. A similar study conducted in Kinshasa, Democratic Republic of Congo, in October-November 2020 after the first wave found a prevalence of 16.6%, a value close to that estimated here [7]. The differences between the different districts of the Congolese capital were not significant, as in the commune VI of Bamako. In Mali, Sagara *et al.* reported in the peri-urban area of Sotuba a crude seroprevalence of 13.1 % (n=587) across samples collected over a 2-month period after the first wave. But the subsequent study conducted in January 2021 in this peri-urban area showed an adjusted seroprevalence rate of 73.4%, after the second COVID-19 wave [6]. This sharp increase in the prevalence rate can be explained by a wave of intense transmission of COVID-19 related to alpha variant in Mali between November 2020 and January 2021 together with the increase of the screening capacity of the health services [4]. Indeed, 3,258 new cases were officially reported at the Bamako district (and 172 new deaths) between November 1st, 2020 and January 24th, 2021. The availability of diagnostic tests and trained staff improved reporting over time.

In our study, seropositivity was higher among older participant and women. Conversely, in Senegal, a survey of the acceptability of the measures to fight the COVID-19 found a predominance of the 25-59 years age and male group [17]. Similarly, a literature review on seroprevalence among health workers worldwide found a seroprevalence of 8.2% in Africa with a male predominance [18]. This difference may be explained by the methodology of our study, which recruited only in households and during the day, *i.e.* working time: men aged 20 to 60 may be under-represented in our sample.

The main demographic characteristics (age and gender) and proximity as a high potential contact rate (a household member already infected) remained significantly associated with seropositivity after adjusting for the contextual elements available. Although the household condition profile was not a significant determinant of seropositivity, the impact of infection among High Income Family units should be discussed (aOR 1.74 [0.99;3.07]). Indeed, Low Income families are more likely to live outdoors, to have lower ages, to have fewer co-morbidities (obesity, diabetes) in this population.

The age-related results were consistent with the epidemiological trends observed during the first wave of the epidemic worldwide: young people were less exposed than older one. The KABP survey revealed that young participants had, at the time of the survey, a higher level of risk practices, and were more reluctant to change their health behavior. According to psychological models of preventive behavior, self-perceived exposure is a key component of individual acceptability of preventive behavior change

[19]. Nevertheless, hand washing was a common practice, perhaps associated with former epidemic (*e.g.* Ebola in 2014), but not mask wearing, a little-know health practice in the Malian culture.
Conversely, the differences in results between sex show its role in the transmission of the virus in Bamako. Given the complexity of the relationship between sex, gender, and infectious disease [20], the updated medical literature reports greater vulnerability of men to COVID-19 than women due to gender-related social activities or comorbidities, but also due to significant sexual variations in the immune system [21, 22]. The vulnerability of women highlighted by our survey refers to a broader conception of the impact of SARS-CoV-2, including the carriage of the infection. However, with respect to the KABP survey results, with the exception of a tendency for women to score lower on knowledge of COVID-19, no significant statistical evidence emerged on an association between gender and health behaviors and risk practices. A possible selection bias in the serological survey could partly explain these results, but other hypotheses concerning the specific lifestyle and social position of West African women in light of exposure to infectious diseases need to be further explored. Furthermore, the results of multivariate analyses showing the role played by proximity in person-to-person transmission confirm that the spread of infectious diseases within the community involves a significant amount of within family transmissions due to asymptomatic transmission [23], particularly via children[24].

A study on factors associated with the acceptability of government measures against COVID-19 in Senegal showed a correlation between education level and the proposed measures (inter-regional travel ban, curfew, closure of places of worship and closure of markets). But those with primary education and those with no education were likely to accept of curfews and less likely to accept inter-regional travel bans and the closure of places of worship [17].
Finally, the trend of increasing positivity of the social indicator summarized in household profiles leads us to consider that understanding epidemic dynamics in populated cities involves taking into account the spatial structure of the population [25]. Additional evidence from geographic and socio-economic components [26, 27]), highlight the question of inequalities and individual vulnerability at each stage of the epidemic's spread: from dissemination including various factors such as household size [28], transmission of infection within the community to the associated societal consequences [29].
The pandemic response plan in Mali was to send suspected cases to a small number of testing and care centers, leading to a massive influx of patients. Indeed, in Bamako, only 2 health centers were dedicated to patient testing and care (“Hopital du Point G” and “Hopital du Mali”), with hospitalization of all confirmed cases, both symptomatic and asymptomatic. These 2 hospitals were rapidly overwhelmed, leading to a deterioration of the quality of care. Furthermore, at the beginning of the epidemic, the presence of health workers with white suits at patient homes stigmatized households: this situation created a denial reaction of the population according to the disease.

As a result of our work, the circulation of the virus was higher than reported. As a lesson learned from the epidemic, we recommend to strengthen the involvement of community health workers. These workers would be able to play a role in raising awareness among the population about preventive measures and directing patients and contact cases to diagnostic centers, including safe transportation of suspected COVID-19 cases. Only confirmed cases would receive appropriate care, according to clinical conditions. Only severe cases would be referred to health centers. Confirmed asymptomatic and pauci-symptomatic cases would be isolated at home with regular follow-up by community health workers. The health professionals would then supervise the community health workers and would focus on severe cases.

We also recommend to add mobile team for screening campaigns, targeted on neighborhoods, with the involvement of community health workers. Reducing the flow of patients, the health centers would be able to focus on the management of severe cases.

Conclusion

In March 2022, 2 years after the pandemic onset and 4 epidemic waves, 30,398 confirmed cases (725 associated deaths) were officially reported in Mali, 20,115 for the district of Bamako, and 60 health districts (among 75) reported cases. The Commune VI remains the most affected (or the most reporting cases) area with 5,712 reported cases. However, these reported numbers under-estimate the number of infected persons. The following waves involved variants, which were more aggressive and may also have led to a heavier death toll, and the consequences could be evaluated using revised prevalence and variant-adjusted infection fatality ratios. Conducted after the first wave, this study highlights the need for sufficient screening data to design efficient epidemic control strategies. Improving diagnostic capacities as well as awareness of populations, to encourage testing and preventive behaviors, as well as avoiding the spread of false information on the epidemic remain key pillars, not matter the developed or developing setting.

List of abbreviations

IRD: Institut de Recherche pour le Développement France
HIF: High Income Family units
LILF: Low Income Large Family units
LISF: Low Income Small Family units
SARS-CoV-2: Severe Acute Respiratory Syndrome Coronavirus 2
WHO: World Health Organization
GAMM: generalized additive multilevel models
KABP: Knowledge, Attitudes, Behaviors and Practices

Declarations

Ethics approval and consent to participate

The study was approved by the ethics committee of the Faculty of Medicine and Odontostomatology of Mali **N°2020/162/CE/FMOS/FAPH** and the Ministry of Health and Social Action **N° 001424 MASA-SG**.
A community agreement was first obtained from district leaders, local religious leaders, community associations and municipal authorities after explanation and discussion about the study protocol. Second, consents and/or assents of participants or their parent/guardian were obtained. The study team administered consent in local languages, and, if the participant or parent/guardian was not literate, in the presence of a witness. Individuals from each family consented separately.

Consent for publication

NA (no personal details/images/video in the manuscript)

Availability of supporting data

The data that support the findings of this study are available on reasonable request from the corresponding author, JG. The data are not publicly available due to confidentiality and ethical restrictions.

Competing interests

None declared

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Author contributions

JG and HB conceived and designed the study protocol, helped by JL, IS, MC, BK, IB, AG, OD, AD, MA, EB, LST, LV and MKBD. All the authors validated the study protocol.
MKBD wrote the household and KABP questionnaires, with the help of JL, MC, JG and IS.
MC, AKS and IS organized and supervised the samples and data collections, performed by AK, SS, ZD, CD, IT, ST, HM.
ST and IT were in charge of the information system under the supervision of IS.
JL, MKBD, MC and JG conceived and designed the data analysis. JL, MKBD and MC performed the data management and analysis, under the supervision of JG.
BK and AKS designed and supervised the serological analysis, performed by HM, ES, KC.
Result interpretation and discussion was performed by MC, JL, MKBD and JG, with the help of IS, BK, IB, AG, OD, AD, MA, EB, LST, LV.
JL, MKBD, MC and JG wrote the paper, corrected by all authors.
All authors participated to the manuscript and approved its last version.

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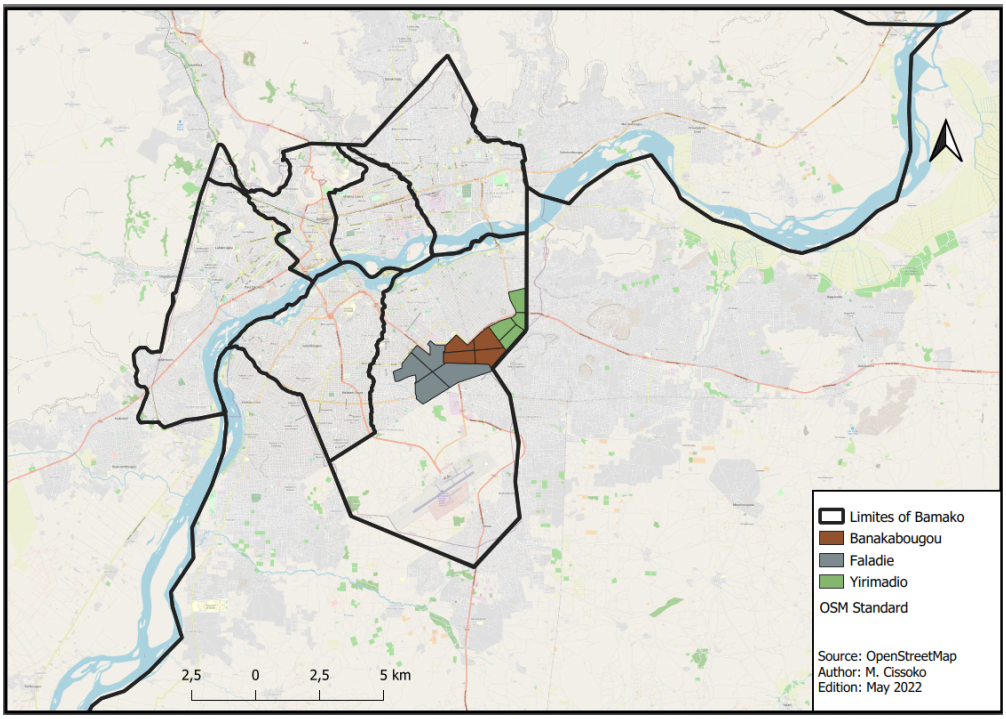

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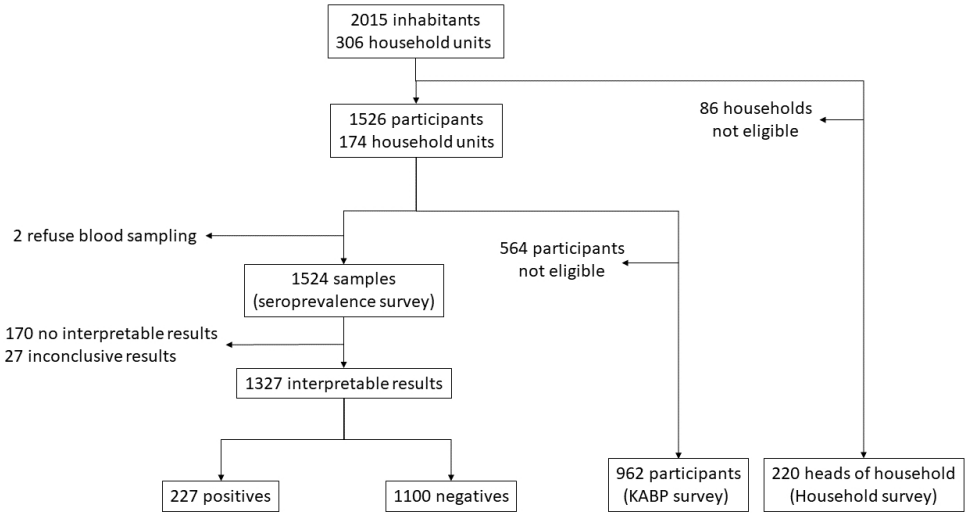

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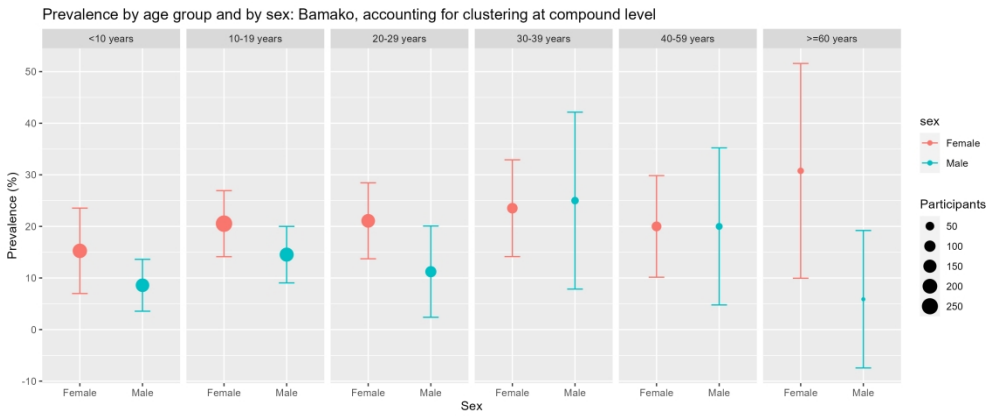

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Appendix

Table A1: Study participants' demographic characteristics and detailed serological results (Bamako, n=1,526, September 2020).

		n	%
Site			
	Banankabougou	588	38.5
	Faladie	300	19.7
	Yirimadio	638	41.8
Total		**1,526**	**100**
Gender			
	Male	599	39.3
	Female	927	60.7
Total		**1,526**	**100**
Age			
	[1-10y]	416	27.3
	[10-20y]	491	32.2
	[20-30y]	299	19.6
	[30-40y]	144	9.4
	[40-60y]	118	7.7
	[60-100]	51	3.3
	NA	7	0.5
Total		**1,526**	**100**
SARS-CoV-2 status			
	Negative	1100	72.1
	Positive	227	14.9
	NA	199	13.0
Total		**1,526**	**100**
Detailed positives			
	IgG pos only	170	74.89
	IgM pos only	17	7.49
	IgG+IgM	35	15.42
	IgG pos, IgM missing	5	2.20
Total		**227**	**100**

Table A2. Knowledges, attitudes, behaviors and practices toward COVID-19 among Bamako inhabitants, by sex (Bamako, n=962, 2020)

		Sex %		Univariate* [Women vs Men]		Multivariate* [Women vs Men]	
		Men	Women	OR [CI95%]	p-value	aOR [CI95%]	p-value
Age							

	12-19 y	55.9%	44.1%	1			
	20-39 y	53.9%	36.1%	1.25 [0.54;2.90]	0.62	--	--
	29-64 y	50.5%	49.5%	1.35 [0.57;3.20]	0.49	--	--
	>64y	62.5%	37.5%	1.54 [0.62;3.87]	0.35	--	--
Level of Knowledge toward Covid-19							
13 items- score	Mean [SD]	7.90[2.67]	7.57[2.94]	0.96 [0.91;1.00]	0.063	--	--
Attitudes/denials towards COVID-19 measured by agreement (agreed, strongly agreed) with following opinions							
Help politicians' strategy to take money from developed countries	No	52.4%	47.6%	1	0.012	1	0.013
	Yes	61.3%%	48.7%	0.70 [0.53;0.92]		0.70 [0.52;0.93]	
Systematic daily changes in behaviors reported from the start of COVID-19 pandemic							
Blowing into the elbow	No	53.7%	46.3%	1	0.030	1	0.023
	Yes	64.5%	35.5%	0.65 [0.44;0.96]		0.59 [0.38;0.93]	
Avoiding seeing friends	No	55.7%	44.3%	1	0.173	1	0.004
	Yes	46.9%	53.1%	1.42 [0.86;2.37]		2.03 [1.30;4.20]	
At-risk practices during the seven past days declared $							
Wearing mask outside	No	57.7%	42.3%	1	0.055	1	0.005
	Yes	51.6%	48.4%	0.78 [0.60;1.01]		0.68 [0.52;0.89]	
Visiting populated public places	No	50.5%	49.5%	1	0.001	1	0.001
	Yes	61.9%	38.1%	1.59 [1.23;2.07]		1.71 [1.30;2.26]	

$ Binary variable: yes [systematically, very often, often] and no [rarely, never]
*Logistic regression

Table A3: Score of knowledge on COVID-19 by sex and age (Bamako, n=962, September 2020).

	12-19y (62.2%) Mean [SD]	20-39y (25.3%) Mean [SD]	40-64y (10.1%) Mean [SD]	>64y (2.5%) Mean [SD]
All	7.5 [2.8]	8.2 [2.7]	8.1 [2.5]	8.3 [2.6]
Men (55.1%)	7.7 [2.7]	8.3 [2.7]	7.9 [2.3]	8.8 [2.2]
Women (44.9%)	7.2 [3.0]	8.1 [2.8]	8.3 [2.7]	7.4 [3.0]
p-value*	0.04	0.43	0.36	0.19

*t-test, Men VS Women

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation
Title and abstract	1	Yes, lines 1-2 and abstract lines 31:65
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found; Yes, lines 41:52 and 54:59
Introduction		
Background/rationale	2	Yes, lines 85:128
Objectives	3	Yes, lines 129:132
Methods		
Study design	4	Present key elements of study design early in the paper: Yes lines 135:141
Setting	5	Describe the setting locations: Yes lines 135:141 and Figure 1 and relevant dates Yes, line 139 including periods of recruitment: Yes, line 167 and data collection: Yes, line 139
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants: Yes, lines 147-163 and 165-172
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable: Yes, lines 174-180, 184-204, 206-216
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group: Yes, lines 174-180, 184-204, 206-216
Bias	9	Describe any efforts to address potential sources of bias: Yes lines 151-163
Study size	10	Explain how the study size was arrived at: Yes, lines138-150
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why: Yes, Lines 219-220
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding: Yes, lines 219:239
		(*b*) Describe any methods used to examine subgroups and interactions: Yes, lines 233-234
		(*c*) Explain how missing data were addressed: Complete Case analyses were performed
		(*d*) If applicable, describe analytical methods taking account of sampling strategy: Yes, lines 226-233
		(*e*) Describe any sensitivity analyses: No sensitivity analyses were performed
Results		
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed: Yes, lines 272:277
		(b) Give reasons for non-participation at each stage: Yes, figure 2
		(c) Consider use of a flow diagram: Yes, figure 2
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders: Yes, 272:277, and table A1
		(b) Indicate number of participants with missing data for each variable of interest: Yes, line 283 and table 3

Outcome data	15*	Report numbers of outcome events or summary measures: Yes, tables 2, 3, 4 and 5
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included : Yes, table 1, 2, 3
		(*b*) Report category boundaries when continuous variables were categorized: No categorization
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period: No RR estimations
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses: Qualitative analyses were performed lines 349:37_ and tables 4, 5 and A2, A3
Discussion		
Key results	18	Summarise key results with reference to study objectives: Yes lines 386:396
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias: Yes lines 426:447
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence / Yes lines 426:447 and 448:465
Generalisability	21	Discuss the generalisability (external validity) of the study results: Yes, 466:474 and 480-490
Other information		
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based: Yes, lines 522:528