BMJ Open

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

Mady Cissoko,[1,2] Jordi Landier,[1] Bourema Kouriba ,[3] Abdoul Karim Sangare,[3] Abdoulaye Katilé,[1,2] Abdoulaye A Djimde,[2] Ibrahima Berthé,[2,4] Siriman Traore,[2] Ismaila Thera,[2] Maiga Hadiata,[3] Elisabeth Sogodogo,[3] Karyn Coulibaly,[3] Abdoulaye Guindo,[4] Ousmane Dembele,[4] Souleymane Sanogo,[5] Zoumana Doumbia,[5] Charles Dara,[5] Mathias Altmann,[6] Emmanuel Bonnet,[7] Hubert Balique,[4] Luis Sagaon-Teyssier,[1,8] Laurent Vidal,[1] Issaka Sagara,[2] Marc-Karim Bendiane,[1] Jean Gaudart [1,9]

To cite: Cissoko M, Landier J, Kouriba B, *et al*. SARS-CoV-2 seroprevalence and living conditions in Bamako (Mali): a cross-sectional multistage household survey after the first epidemic wave, 2020. *BMJ Open* 2023;**13**:e067124. doi:10.1136/bmjopen-2022-067124

► Prepublication history and additional supplemental material for this paper are available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2022-067124).

Received 08 August 2022
Accepted 29 March 2023

For numbered affiliations see end of article.

Correspondence to
Dr Jean Gaudart;
jean.gaudart@univ-amu.fr

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 3086 confirmed cases and 130 deaths. Most reports originated from Bamako, with 1532 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 behaviours and knowledges associated with SARS-CoV-2 seropositivity.

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

Participants We recruited 1526 inhabitants in 3 areas, that is, 306 households, and 1327 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 behaviours 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% (95% CI 15.1% to 19.1%) after adjusting on the population structure. This suggested that ~400 000 cases and ~2000 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 behaviours, and avoiding the spread of false information remain key pillars, regardless of the developed or developing setting.

Ethics 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.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ A multistage 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, behaviours and practices.

⇒ A multilevel generalised 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 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 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 travellers, 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 25 March 2020 (coming from France on 12 March), Mali has recorded, 6 months later (at the time of the survey), 3086 cases of SARS-CoV-2 diagnosed by RT-PCR, that is, an incidence rate of 0.015% for the whole country. Spread over 38 health districts (among 75), they led 130 reported deaths, that is, a case fatality rate of 4.2%.[4]

Among the cases recorded in September 2020, ~50% were reported in the district of Bamako, that is, 1532 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 hospitalisation rates.[5] In Mali, a multisite study including a periurban 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 hospitalisation 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 behaviours, 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 behaviours, knowledges according to COVID-19.

METHODS

Study design and sample size calculation

In accordance with the WHO guidelines protocol for age-stratified population-based seroepidemiological surveys for COVID-19 infection, a cross-sectional household survey was conducted[8] in the three most affected and populated neighbourhoods 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 neighbourhoods, representing 0.07 cases/100 inhabitants, and 54% of the total reported cases in Commune VI.

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 CI of 95%. Considering 15% loss, 1500 participants were expected to be included. A multistage 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 (four or more) of relatively equal subpopulation 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 centre 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 years 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, a 2 mL of blood was collected from all voluntary participants by venipuncture (September 2020), to perform serological tests. Following the blood

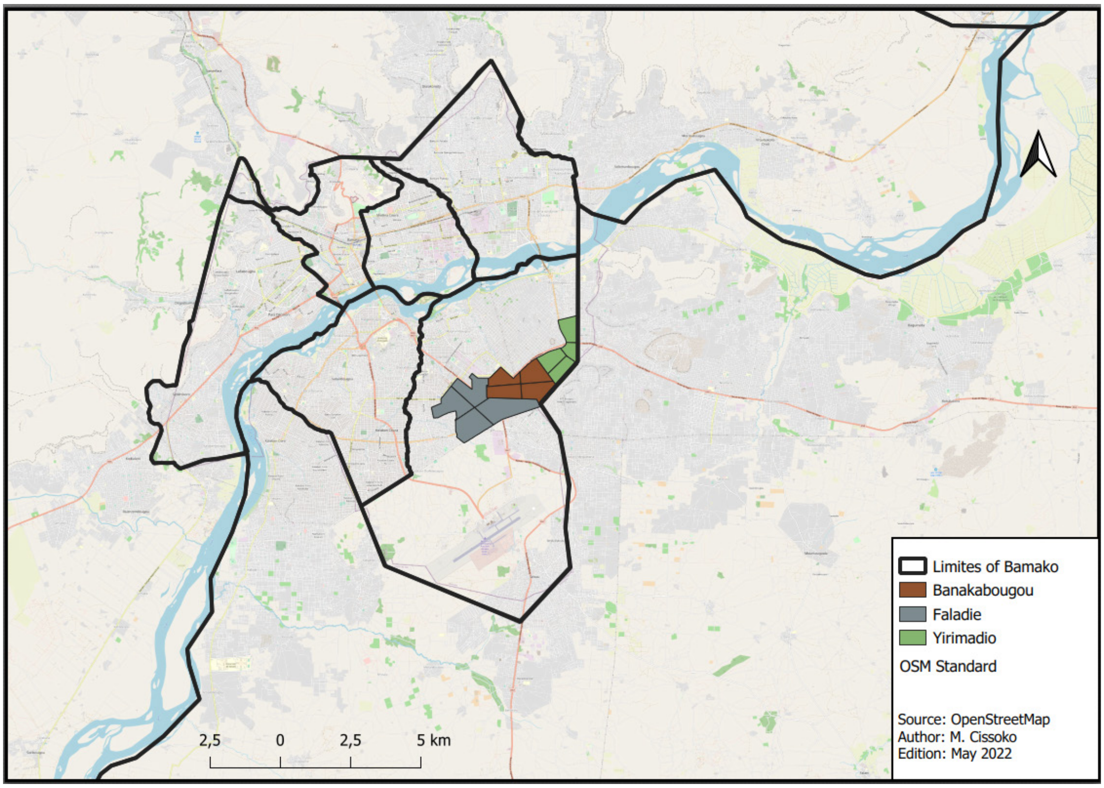

Figure 1 Map of Bamako showing the location of the three investigated neighbourhoods within the commune VI (in red).

sampling, a face-to-face questionnaire was administered to collect the following demographic and sociological factors: gender, age, history of recent travel within and outside Bamako, socioeconomic 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, television, 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 with 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 uninfected 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-specific and sex-specific mortality data reported early in the pandemic (February–March in China, prior to the optimisation of clinical management).[11]

Knowledges, attitudes, behaviours, practices outcomes measures

The current at-risk practices have been measured using a four bipolar Likert Items on practices during the seven

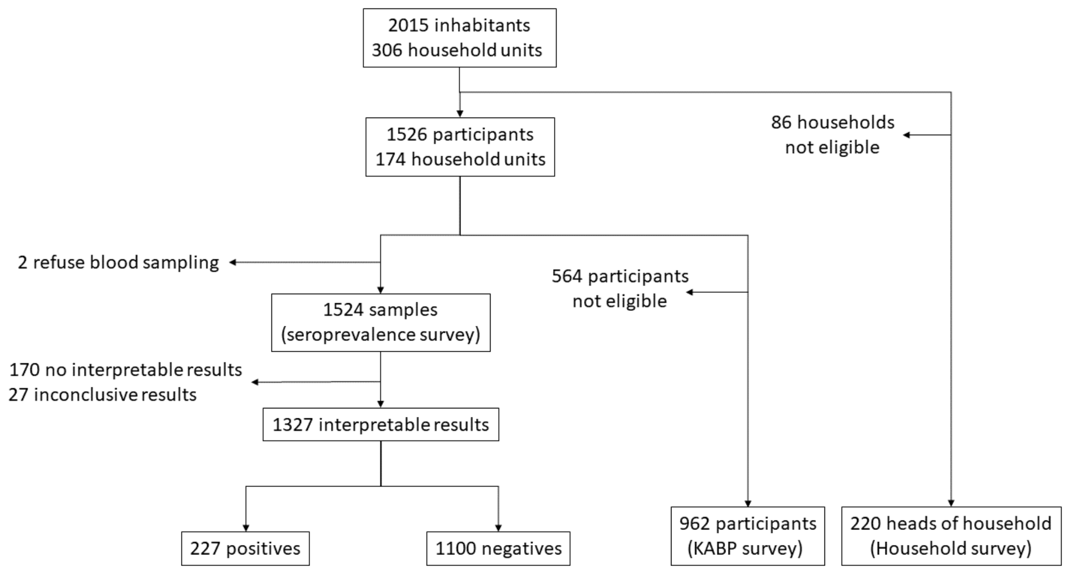

Figure 2 Flow chart of the seroprevalence survey. KABP, Knowledge, Attitudes, Behaviours, Practices.

past days assessing: wearing mask when not at home, washing hands with soap, going to crowned areas during the day or the night. Regarding behaviour questions, six bipolar Likert Items (from systematically/very often to never) on behaviour 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% CI.

Household profiles were determined by using a two-step descriptive approach:[12] first a multiple component analysis, second a Hierarchical Ascendant Classification. 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 generalised additive multilevel models (GAMM).[13] We analysed the effects of age and sex at individual level, as well as household profile.[14] Intrahousehold contamination was assessed as a binary variable (more than one 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 subgroup analyses.

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

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 neighbourhood 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 two medical contacts (telephone numbers). Public feedback meetings were held

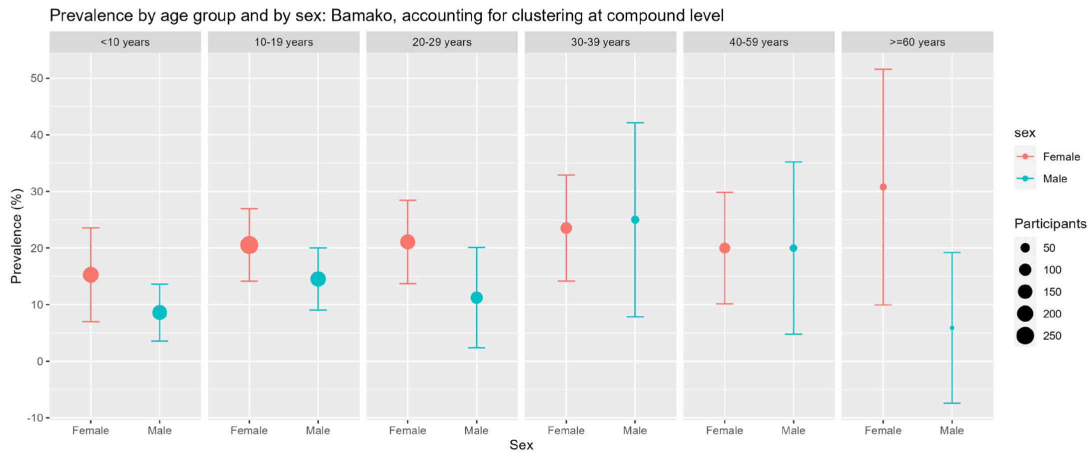

Figure 3 Seroprevalence by age and sex (Bamako, n=1327, September 2020).

with the local community health association and the local authorities.

RESULTS

Inclusions

A sample of 174 housing units (separate living quarter) was investigated including 2015 inhabitants grouped in 306 identified household units.

Of 2015 inhabitants, 1526 (75.7%) participants aged ≥1 year provided a blood sample for the seroprevalence survey and 962 participants aged ≥12 years answered the Knowledge, Attitudes, Behaviours, Practices (KABP) survey (online supplemental appendix table A1). Data on housing conditions were collected for 220 of the 306 household units included, that is, 78.9% of the household members tested (n=1204) (figure 2).

SARS-CoV-2 seroprevalence

Out of 1526 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 1327 participants, corresponding to 227 SARS-CoV-2 seropositive (by either IgG, IgM or both) and 1100 seronegative individuals. The crude seroprevalence rate was estimated at 17.1% (95% CI) (15.1% to 19.1%), ranging from less than 10% to upper than 30% across genders and age groups (figure 3).

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 with 1532 recorded cases for the district of Bamako. This corresponded to an adjusted prevalence of 16.4% (95% CI 8.0%–24.9%) (adjusted on the population age and sex distribution) versus an observed prevalence of 0.06%. Using the age-specific and sex-specific mortality data reported early in the pandemic, we roughly estimated 1725 COVID-19 deaths occurred between the onset of the pandemic and the date of the survey, that is, 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 versus reported cases and deaths at Bamako city level after accounting for age population structure (Bamako, n=1526, September 2020)

		N= (95% CI)	Prevalence (%) (95% CI)
SARS-CoV-2 serological status	Positive	227	17.1% (13.7% to 20.5%)
	Negative	1100	
Population (inhabitants in 2020)		2 420 000	
COVID-19 in Bamako	Cases, reported after confirmation*	1532	0.07%
	Infections, estimated	397 321 (192 452 to 602 183)	16.4% (8.0% to 24.9%)
Mortality	Deaths, reported*	81	0.003%
	Deaths, estimated based on infections	1725 (476 to 2970)	0.07% (0.02% to 0.12%)

*Reference: COVID-19 in Mali situation report no 121 (21 September 2020–27 September 2020), Ministry of Health, Mali.

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

	LISF* (ref-%)	LILF* (%)	HIF* (%)	P value Global	Subgroup analysis LILF versus LISF	LILF versus 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 (>10 members 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 (postgraduate 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.
†Significant after Bonferroni correction.
HIF, high-income family; LILF, low-income large family; LISF, low-income small family; MCA, multiple component analysis.

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 2 others. Only 0.9% (n=2) shared their house with more than 2 other families (3 or 4).

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 (respectively, 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).

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 neighbourhood levels). There were no significant differences between the three neighbourhoods. Women and older age were significantly associated with increased odds of seropositivity, showing, respectively, adjusted ORs (aOR (95% CI)) of 1.75 (1.27 to 2.43) and 1.06 (1.01 to 1.11). Having a positive household member was associated with an increased odd of seropositivity (aOR=1.54 (95% CI 1.08 to 2.19)). Household corresponding to the highest sociodemographic status appeared to have increased (but not significant, p=0.06) odds of seropositivity compared with households of low-income status living in (aOR=1.74 (95% CI 0.99 to 3.07)).

Knowledge, attitudes, behaviours, practices

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 behaviours and practices towards 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 (online supplemental appendix tables A2 and A3). Attitudes, behaviours and practices measured by age and gender (tables 5 and 6) showed, at first, a high level of denial on

Table 3 Factors associated with SARS-CoV-2 seropositivity

		SARS-CoV-2 serology n (%)/median (IQR)		Univariate*		Multivariate*	
		Negative (n=)	Positive N; % (95% CI)	OR (95% CI)	P value	aOR (95% CI)	P value
Sex	Male	456	67; 12.8% (95% CI 9.0% to 16.6%)	1		1	
	Female	644	160; 19.9% (95% CI 15.2% to 24.6%)	1.78 (95% CI 1.28% to 2.49%)	<0.001†	1.75 (95% CI 1.27% to 2.43%)	<0.001†
Age‡		16 (9–25)	18 (95% CI 11% to 30%)	1.07 (95% CI 1.02% to 1.12%)	0.008†	1.06 (95% CI 1.01% to 1.11%)	0.017†
Household profile	LISF	304	54; 15.1% (95% CI 6.9% to 23.3%)	1		1	
	LILF	456	93; 16.9% (95% CI 11.7% to 22.2%)	1.08 (95% CI 0.67% to 1.74%)	0.75	1.14 (95% CI 0.74% to 1.74%)	0.56
	HIF	119	39; 24.7% (95% CI 14.1% to 35.2%)	1.66 (95% CI 0.88% to 3.12%)	0.12	1.74 (95% CI 0.99% to 3.07%)	0.06
	Unclassified	221	41; 15.6% (95% CI 10.2% to 21.1%)	0.91 (95% CI 0.52% to 1.58%)	0.74	1.03 (95% CI 0.62% to 1.72%)	0.91
Already one case in the household	No	412	65; 12.6% (95% CI 5.0% to 20.2%)	1		1	
	Yes	688	162; 20.0% (95% CI 5.0% to 25.0%)	1.37 (95% CI 0.96% to 1.95%)	0.085	1.54 (95% CI 1.08% to 2.19%)	0.018†
Neighbourhoods	Banankabougou	454	96; 17.5% (95% CI 10.6% to 24.3%)	1	0.98	Not included	
	Faladie	229	49; 17.6% (95% CI 10.3% to 24.9%)	0.98 (95% CI 0.57% to 1.70%)			
	Yirimadio	417	82; 16.4% (95% CI 10.8% to 22.0%)	1.03 (95% CI 0.67% to 1.59%)			

*n=1327.
†Significant test result.
‡n=1323 (4 participants showing negative serology with missing ages).
HIF, high-income family; LILF, low-income large family; LISF, low-income small family.

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 with 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 behaviours from the start of the COVID-19 pandemic, handwashing 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 with 29.9% who declared washing hands systematically. Conversely, few participants reported adopting systematically other preventive behaviours in their daily life, such as blowing into the elbow (12.9%), stop touching other people (15.0%), travelling less frequently (11.1%), avoid populated places (9.3%) and avoiding seeing friends (6.6%). Regarding results displayed by age and sex (tables 5 and 6), the youngest participants were more reluctant to change their daily behaviours 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 2 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 years old).

DISCUSSION

SARS-CoV-2 population adjusted seroprevalence in the urban commune VI of the Bamako district was 16.4% (95% CI 8.0% to 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

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); Bartlett test (p<0.001).

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 1720 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 3098 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 periurban 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, 3258 new cases were officially reported at the Bamako district (and 172 new deaths) between 1 November 2020 and 24 January 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, that is, working time: men aged 20–60 may be underrepresented 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 (95% CI 0.99 to 3.07)). Indeed, low-income families are more likely to live outdoors, to have lower ages, to have fewer comorbidities (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

Table 5 Knowledges, attitudes, behaviours and practices towards 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 behaviours 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
Travelling 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 2 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 results before Bonferroni correction are in bold.
*significant, after Bonferroni correction

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 behaviour. According to psychological models of preventive behaviour, self-perceived exposure is a key component of individual acceptability of preventive behaviour change.[19] Nevertheless, handwashing was a common practice, perhaps associated with former epidemic (eg, 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 behaviours 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 summarised 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 geographical and socioeconomic components,[26 27] highlights the question of inequalities and individual vulnerability at

Table 6 Knowledges, attitudes, behaviours and practices towards 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	41.20%	44.60%	0.591	55.10%	60.40%	0.596
Has been introduced in Mali by the white people	48.50%	46.40%	0.749	38.80%	39.60%	0.935
Is due to a spell	11.50%	14.30%	0.509	12.20%	12.80%	0.938
Help politicians' strategy to take money from developed countries	**37.40%**	**24.10%**	**0.026**	24.50%	22.90%	0.855
Systematic daily changes in behaviours reported from the start of COVID-19 pandemic:						
Washing hands	30.60%	41.70%	0.257	33.30%	33.30%	1
Blowing into the elbow	24.50%	12.50%	0.129	**46.70%**	**0.00%**	**0.015**
Stop touching other people (systematically)	16.30%	22.90%	0.414	33.30%	11.10%	0.224
Travelling less frequently	8.00%	20.80%	0.07	26.70%	0.00%	0.09
Avoiding populated places	8.00%	14.60%	0.302	6.70%	11.10%	0.703
Avoiding seeing friends	8.00%	12.50%	0.462	13.30%	0	0.253
At-risk practices during the seven past days declared:						
Wearing mask outside systematically or very often	32.70%	37.50%	0.617	46.70%	44.40%	0.916
Visiting populated public places every day or very often	40.80%	41.70%	0.932	**0.00%**	**30.00%**	**0.024**
Going out every night or very often	28.60%	20.80%	0.377	**0.00%**	**30.00%**	**0.024**
Washing hands when necessary	40.80%	47.90%	0.482	33.30%	40.00%	0.734
Staying every day, or very often, more than 2 hours in a small closed space	28.50%	25.00%	0.691	6.70%	30.00%	0.119
Had participated to social events every day or very often	32.70%	27.10%	0.549	6.70%	22.20%	0.265

Significant results before Bonferroni correction are in bold.

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 centres, leading to a massive influx of patients. Indeed, in Bamako, only two health centres were dedicated to patient testing and care ('Hopital du Point G' and 'Hopital du Mali'), with hospitalisation of all confirmed cases, both symptomatic and asymptomatic. These two 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 stigmatised 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 learnt 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 centres, 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 centres. Confirmed asymptomatic and paucisymptomatic 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 neighbourhoods, with the involvement of community health workers. Reducing the flow of patients, the health centres 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 5712 reported cases. However, these reported numbers underestimate 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 behaviours, as well as avoiding the spread of false information on the epidemic remain key pillars, not matter the developed or developing setting.

Author affiliations
[1]SESSTIM UMR1252, Aix Marseille Univ, IRD, INSERM, ISSPAM, Marseille, France
[2]Malaria Research and Training Centre Ogobara Doumbo (MRTC-OD), Université des Sciences, des Techniques et des Technologies de Bamako, FMOS-FAPH, Mali-NIAID-ICER, Bamako, Mali
[3]Centre d'Infectiologie Clinique Charles Mérieux, Bamako, Mali
[4]Direction générale de la santé et de l'hygiène publique du ministère de la santé et du développement social, Bamako, Mali
[5]Direction régionale de Tombouctou et établissement public hospitalier de Tombouctou, Tombouctou, Mali
[6]Bordeaux Population Health, INSERM, IRD, Bordeaux, France
[7]Résiliences, IRD, Bondy, France
[8]ARCAD Santé Plus/Centre Intégré de Recherche, de Soins et d'Action Communautaire (CIRSAC), Bamako, Mali
[9]Biostatictics & ICT, AP-HM, Marseille, France

Twitter Jean Gaudart @GeoEpidemiology

Acknowledgements We acknowledge the populations of the Commune VI, Bamako, the community health association and all the community leaders.

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

Funding This study was funded by IRD (French National Research Institute for Sustainable Development); the JEAI DynaSTEC (Spatio-Temporal Dynamics of Epidemics and Environmental Changes research team); the French Embassy in Mali (field data collection) and the Charles Mérieux Foundation, Lyon (laboratory analyses); the NGO Prospective and Cooperation.

Disclaimer The funders had no role in the study design, data collection plan, analysis, decision to publish, or preparation of the manuscript.

Competing interests None declared.

Patient and public involvement Patients and/or the public were involved in the design, or conduct, or reporting, or dissemination plans of this research. Refer to the Methods section for further details.

Patient consent for publication Not applicable.

Ethics approval The authorisation to conduct the study was obtained on 28 August 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 10 August 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.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available on reasonable request. 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.

ORCID iDs
Bourema Kouriba http://orcid.org/0000-0002-3419-5972
Jean Gaudart http://orcid.org/0000-0001-9006-5729

REFERENCES

1 Dhama K, Khan S, Tiwari R, *et al*. Coronavirus disease 2019-COVID-19. *Clin Microbiol Rev* 2020;33:e00028-20.
2 Van Damme W, Dahake R, Delamou A, *et al*. The COVID-19 pandemic: diverse contexts; different epidemics-how and why? *BMJ Glob Health* 2020;5:e003098.
3 Bonnet E, Bodson O, Le Marcis F, *et al*. The COVID-19 pandemic in francophone West Africa: from the first cases to responses in seven countries. *BMC Public Health* 2021;21:1490.
4 INSP Mali. *Rapport institut nationa de la santé publique mali*. 2020.
5 Moraga P, Ketcheson DI, Ombao HC, *et al*. Assessing the age- and gender-dependence of the severity and case fatality rates of covid-19 disease in spain. *Wellcome Open Res* 2020;5:117.
6 Sagara I, Woodford J, Kone M, *et al*. Rapidly increasing SARS-cov-2 seroprevalence and limited clinical disease in three malian communities: a prospective cohort study. *MedRxiv* 2021:2021.04.26.21256016.
7 Nkuba AN, Makiala SM, Guichet E, *et al*. High prevalence of anti-SARS-cov-2 antibodies after the first wave of COVID-19 in kinshasa, democratic republic of the congo: results of a cross-sectional household-based survey. *Clin Infect Dis* 2021.
8 World Health Organization. *Population-based age-stratified seroepidemiological investigation protocol for COVID-19 virus infection*. World Health Organization, 2020.
9 Bennett S, Radalowicz A, Vella V, *et al*. A computer simulation of household sampling schemes for health surveys in developing countries. *Int J Epidemiol* 1994;23:1282–91.
10 BIOMÉRIEUX SA. BioMérieux | VIDAS® SARS-COV-2. n.d. Available: https://go.biomerieux.com/SEROLOGIE-VIDAS-SARS-COV-2
11 The Novel Coronavirus Pneumonia Emergency Response Epidemiology Team. The epidemiological characteristics of an outbreak of 2019 novel coronavirus diseases (COVID-19) - china, 2020. *China CDC Wkly* 2020;2:113–22.
12 Lê S, Josse J, Husson F. FactoMineR: an R package for multivariate analysis. *J Stat Softw* 2008;25:1–18.
13 Kim J, Zhang Y, Day J, *et al*. MGLM: an R package for multivariate categorical data analysis. *R J* 2018;10:73–90.
14 Milligan P, Njie A, Bennett S. Comparison of two cluster sampling methods for health surveys in developing countries. *Int J Epidemiol* 2004;33:469–76.

15 Wood SN. Generalized additive models: an introduction with R. 2006:392.
16 Uyoga S, Adetifa IMO, Karanja HK, *et al*. Seroprevalence of anti-SARS-cov-2 IgG antibodies in Kenyan blood donors. *Science* 2021;371:79–82.
17 Diallo AI, Faye A, Tine JAD, *et al*. Factors associated with the acceptability of government measures to address covid-19 in senegal. *Rev Epidemiol Sante Publique* 2022;70:109–16.
18 Naranbhai V, Chang CC, Beltran WFG, *et al*. High seroprevalence of anti-SARS-cov-2 antibodies in chelsea, Massachusetts. *J Infect Dis* 2020;222:1955–9.
19 Malloy TE, Fisher WA, Albright L, *et al*. Interpersonal perception of the AIDS risk potential of persons of the opposite sex. *Health Psychol* 1997;16:480–6.
20 Gay L, Melenotte C, Lakbar I, *et al*. Sexual dimorphism and gender in infectious diseases. *Front Immunol* 2021;12:698121.
21 Tazerji SS, Shahabinejad F, Tokasi M, *et al*. Global data analysis and risk factors associated with morbidity and mortality of COVID-19. *Gene Rep* 2022;26:101505.
22 Bienvenu LA, Noonan J, Wang X, *et al*. Higher mortality of covid-19 in males: sex differences in immune response and cardiovascular comorbidities. *Cardiovasc Res* 2020;116:2197–206.
23 Ravindra K, Malik VS, Padhi BK, *et al*. Asymptomatic infection and transmission of covid-19 among clusters: systematic review and meta-analysis. *Public Health* 2022;203:100–9.
24 Song W-L, Zou N, Guan W-H, *et al*. Clinical characteristics of COVID-19 in family clusters: a systematic review. *World J Pediatr* 2021;17:355–63.
25 Rader B, Scarpino SV, Nande A, *et al*. Crowding and the shape of COVID-19 epidemics. *Nat Med* 2020;26:1829–34.
26 Markovič R, Šterk M, Marhl M, *et al*. Socio-Demographic and health factors drive the epidemic progression and should guide vaccination strategies for best COVID-19 containment. *Results Phys* 2021;26:104433.
27 Fortaleza CMCB, Guimarães RB, de Almeida GB, *et al*. Taking the inner route: spatial and demographic factors affecting vulnerability to COVID-19 among 604 cities from inner São Paulo state, Brazil. *Epidemiol Infect* 2020;148:e118.
28 Martin CA, Jenkins DR, Minhas JS, *et al*. Socio-demographic heterogeneity in the prevalence of covid-19 during lockdown is associated with ethnicity and household size: results from an observational cohort study. *EClinicalMedicine* 2020;25:100466.
29 Zhang Y, Wang L, Zhu JJH, *et al*. The spatial dissemination of covid-19 and associated socio-economic consequences. *J R Soc Interface* 2022;19:20210662.