BMJ Open

COVID-19 morbidity in Afghanistan: a nationwide, population-based seroepidemiological study

Sayed Ataullah Saeedzai,[1] Mohammad Nadir Sahak,[2] Fatima Arifi ,[2] Eman Abdelkreem Aly,[3] Margo van Gurp,[4] Lisa J White,[5] Siyu Chen,[5] Amal Barakat,[6] Giti Azim,[1] Bahara Rasoly,[1] Soraya Safi,[1] Jennifer A Flegg,[7] Nasar Ahmed,[8] Mohmmad Jamaluddin Ahadi,[1] Niaz M Achakzai,[9,10] Alaa AbouZeid[11]

To cite: Saeedzai SA, Sahak MN, Arifi F, *et al*. COVID-19 morbidity in Afghanistan: a nationwide, population-based seroepidemiological study. *BMJ Open* 2022;**12**:e060739. doi:10.1136/bmjopen-2021-060739

► 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-2021-060739).

Received 21 January 2022
Accepted 11 July 2022

For numbered affiliations see end of article.

Correspondence to
Fatima Arifi;
fatima.arefi@gmail.com

ABSTRACT

Objective The primary objectives were to determine the magnitude of COVID-19 infections in the general population and age-specific cumulative incidence, as determined by seropositivity and clinical symptoms of COVID-19, and to determine the magnitude of asymptomatic or subclinical infections.

Design, setting and participants We describe a population-based, cross-sectional, age-stratified seroepidemiological study conducted throughout Afghanistan during June/July 2020. Participants were interviewed to complete a questionnaire, and rapid diagnostic tests were used to test for SARS-CoV-2 antibodies. This national study was conducted in eight regions of Afghanistan plus Kabul province, considered a separate region. The total sample size was 9514, and the number of participants required in each region was estimated proportionally to the population size of each region. For each region, 31–44 enumeration areas (EAs) were randomly selected, and a total of 360 clusters and 16 households per EA were selected using random sampling. To adjust the seroprevalence for test sensitivity and specificity, and seroreversion, Bernoulli's model methodology was used to infer the population exposure in Afghanistan.

Outcome measures The main outcome was to determine the prevalence of current or past COVID-19 infection.

Results The survey revealed that, to July 2020, around 10 million people in Afghanistan (31.5% of the population) had either current or previous COVID-19 infection. By age group, COVID-19 seroprevalence was reported to be 35.1% and 25.3% among participants aged ≥18 and 5–17 years, respectively. This implies that most of the population remained at risk of infection. However, a large proportion of the population had been infected in some localities, for example, Kabul province, where more than half of the population had been infected with COVID-19.

Conclusion As most of the population remained at risk of infection at the time of the study, any lifting of public health and social measures needed to be considered gradually.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ This is a large-scale, large sample-size, nationwide, population-based, seroepidemiological study conducted in Afghanistan.
⇒ Further analysis is conducted to adjust the seroprevalence for test sensitivity and specificity.
⇒ Due to security concerns, not all areas could be surveyed where the government lacked control, and this may have affected the findings.
⇒ The findings may not reflect the current situation with regards to the new SARS-CoV-2 delta and omicron variants of concern.
⇒ The data were entered in the District Health Information Software-2 database, which created many challenges for data verification, household matching and the subsequent analysis.

INTRODUCTION

The COVID-19 pandemic has resulted in more than 248 million confirmed cases and in excess of 5 million deaths globally to November 2021.[1] Many countries are continuing to experience epidemic waves of COVID-19, including Brazil, India and Nepal.[2–4] The first reported case of COVID-19 in Afghanistan was in Herat province on 24 February 2020; as of 20 July 2021, Afghanistan has reported 156 363 confirmed cases of COVID-19 and 7284 deaths from the disease.[5]

When the COVID-19 pandemic began, there were no vaccines or specific treatments available for COVID-19, so non-pharmaceutical interventions (NPIs) were recommended, including social distancing, home quarantine, closure of schools and universities, and bans on public gatherings. Afghanistan introduced NPIs as soon as the first case of COVID-19 was detected in the country. Case detection and isolation were seen as key features in helping to reduce the spread of COVID-19. With the recent

political transition in the country and disruption of the health system, public health and social measures to tackle COVID-19 have been completely neglected, which may pose a major risk of increasing the spread of COVID-19 in Afghanistan.

The initial focus of the Afghanistan Ministry of Public Health (MoPH) was on patients with severe COVID-19 disease and ways to decrease mortality associated with the disease. Serological testing of patients can be used to provide useful information about an individual's status in terms of a current or previous COVID-19 infection. IgM and IgG antibodies arise at around the same time, between 1 and 3 weeks after infection; however, IgM antibodies decay more rapidly than IgG antibodies.[6] Therefore, for public health studies, IgM is used as a marker of current infection while IgG is used as a marker of previous infection, that is, within the previous few months. There are various rapid diagnostic tests (RDTs) available that can be used to simultaneously test blood samples for IgM/IgG antibodies against COVID-19.

Due to the limited testing and surveillance capacity in Afghanistan, it seemed likely there was considerable under-reporting of cases and deaths; therefore, robust scientific studies are required to determine the actual burden of COVID-19 in the country. Serological studies can be used to estimate levels of past exposure and thus position a population in their epidemic timeline. However, serology results might underestimate the total exposure in a population[7] because of decaying antibody titres over time.[8–10] Here, we describe a national seroepidemiological survey initiated by the MoPH and conducted throughout Afghanistan between June and July 2020, involving a questionnaire survey and antibody testing of participants for COVID-19 infection using RDTs. The primary objectives of the study were: (1) to determine the magnitude of COVID-19 infection in the general population and age-specific cumulative incidence, as determined by seropositivity and clinical symptoms of COVID-19; and (2) to determine the magnitude of asymptomatic or subclinical infections. The WHO protocol for population-based age-stratified seroepidemiological investigations for COVID-19 infection was adapted for the Afghanistan context to obtain seroprevalence estimates.[11] To adjust the seroprevalence for test sensitivity and specificity, as well as seroreversion, we further adapted a methodology[12] that was originally developed for the England setting and used this to infer the population exposure and undocumented mortality associated with COVID-19 in Afghanistan.

METHODS

Patient and public involvement statement

As this study was not a clinical trial and it did not involve patients, no members of the public or patients were directly involved. The study results were disseminated through public workshops in universities, seminars and workshops, and through the media for the general public. Consent was obtained to be included in the study, and any personal identifier information was excluded during data processing and analysis.

Study design

This was a population-based, cross-sectional, age-stratified seroepidemiological study. Participants were interviewed to complete a questionnaire, and RDTs were used to test for SARS-CoV-2 antibodies. The survey was conducted during June and July 2020.

Population and sampling

This was a national study conducted in the eight regions of Afghanistan plus Kabul province, which was considered as a separate region, making nine regions in total (online supplemental figure S1). The total sample size was 9514 and the number of participants required in each region was estimated proportionate to the population size of each region (online supplemental table S1). Two-stage cluster sampling was used. In the first stage, an updated list of enumeration areas (EAs) was used as the study sampling frame, with 31–44 EAs (clusters) randomly selected per region, resulting in a total of 360 clusters. Due to time constraints and to ensure data validity, insecure or inaccessible EAs were excluded from the study.

In the second stage, all households in an EA were listed and 16 households per EA were selected using a random sampling table. For the age-stratification, two individuals from each household were randomly selected for testing: one aged 5–17 years and one aged ≥18 years.

Serological testing

Finger-prick blood samples were collected from the randomly selected household members in each age category. The antibody RDTs for COVID-19 were performed in the presence of the participant, and the results were shared with them. The COVID-19 RDT used was the COVID-19 IgG/IgM Rapid Test Cassette developed by Healgen Scientific LLC, USA. The RDT is US Food and Drug Administration-authorised, with IgM relative sensitivity and specificity of 95.7% and 97.3%, respectively; IgG relative sensitivity and specificity of 91.8% and 96.4%, respectively; and both IgG-positive and/or IgM-positive specificity of 97.5%.

Data collection and analysis

The survey used a validated questionnaire that was initially piloted in Kabul province. All participants were interviewed by the survey team members, who completed a questionnaire that included questions about the demographics of each participant and their household members, their history of exposure to COVID-19, and deaths in the family during the 15-month period beginning in March 2019.

Data collection teams comprised two members, one male and one female; there were 191 teams in total. Due to the need for blood-drawing for samples, the team members were either nurses, midwives or laboratory technicians.

Regional COVID-19 data were entered into DHIS2 (District Health Information Software-2) by disease surveillance officers in the provinces. DHIS2 is the national data warehouse for Afghanistan's health information and includes data that inform the country's COVID-19 dashboard.[5] Various steps were taken for data quality assurance at both regional and central levels within the MoPH; data collection teams were monitored by master trainers in the regional capitals and by disease surveillance staff in the provinces. Prior to being entered into the system, questionnaires were quality checked and some participants whose phone numbers were available in the questionnaire were contacted at random by phone call to confirm that their details were correct.

Data were imported into STATA V.15[13] for the statistical analyses. To ensure a representative sample and results, weighted analysis was applied to adjust for the complex survey design. Sample weighting, non-response weighting and poststratification weighting were performed. The proportions of infections and 95% CIs were calculated and adjusted to take the survey design into account. The H0 was tested against alternative/research hypothesis at there are differences in prevalence COVID-19 among social demographic and regional characteristics. To determine the overall levels of current and past infection of COVID-19, individuals who tested positive for IgG, IgM or both were summed. To determine the incidence of COVID-19 during the survey period, IgM positivity alone was used.

Adjustment of seroprevalence and exposure inference

We first used a simple Bernoulli model to estimate the regional SARS-CoV-2 (the virus that causes COVID-19) seroprevalence, after adjusting the proportion of individuals in each region with current or past COVID-19 infection according to the sensitivity and specificity of the serology test.[14] (The term 'seroprevalence' below denotes the serology-positive ratio already adjusted by the test.) Further details of the method used can be found in online supplemental method, appendix 1. We revised the mathematical model[12] to estimate the total exposure in the population by region after taking into account waning antibody levels. Further details of the method used can be found in online supplemental method, appendix 1.

RESULTS

Demographic details

This seroepidemiological study has provided estimates of the prevalence of SARS-CoV-2 antibodies across Afghanistan, in urban and rural areas, and in the nine regions of the country. Of the 360 clusters identified for participation in the study, 338 (94%) were included; the remainder were excluded due to insecure or inaccessible EAs and time constraints. Similarly, of the total planned 5408 households in 338 clusters, 5177 (96%) households completed the survey. A total of 9514 household members from these 338 clusters were interviewed and tested for COVID-19. The mean age of respondents was 27 years, 53.9% were male and 46.1% were female, 73% were from rural areas (online supplemental table S2), and most participants (79.2%) were married.

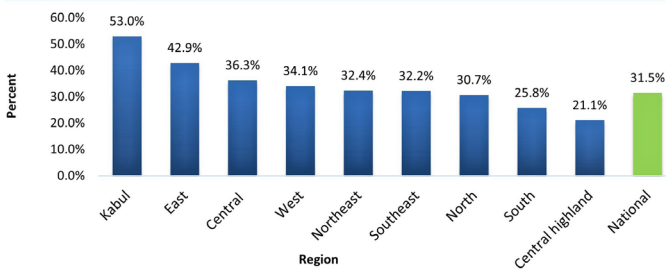

Figure 1 Seroprevalence of SARS-CoV-2 antibodies (including all positive results: IgG-positive, IgM-positive or both) among all age groups by region in Afghanistan.

COVID-19 infections in Afghanistan

The total proportion of COVID-19 infections (including all positive results, the average of both current and past infection) for the whole of Afghanistan was 31.5%. By region, Kabul had the highest proportion of COVID-19 infections (53%), while the Central highlands region had the lowest proportion, at 21.1% (figure 1).

Based on further analysis, the adjusted seroprevalence by region was consistent with the serosurvey results. Kabul still had the highest adjusted seroprevalence (51.8%) (table 1 and figure 2).

RDT results for participants aged 18 years or more

In total, 5618 participants aged ≥18 years were interviewed and tested for this survey. Among this age group, 2056 (35.1%) of individuals tested positive for antibodies against SARS-CoV-2 (table 2). There were 885 (37.2%) females and 1170 (33.9%) males who tested positive, and there was a higher proportion of positive tests in individuals who lived in urban areas compared with the proportion in people who lived in rural areas (773, 42.3% vs 1323, 31.7%, respectively) (table 2). Kabul region had the highest proportion of participants aged ≥18 years who tested positive for antibodies against SARS-CoV-2 (357, 56.8%) (table 2). The survey results revealed that 164 (2.6%) of participants aged ≥18 years were IgM-positive for COVID-19, that is, they had a current infection, with the highest proportion of current infections in the Southeast region (37, 7.0%) (table 1).

RDT results for participants aged 5–17 years

There were 4346 participants aged 5–17 years interviewed and tested for this survey. Among this age group, a total of 850 (25.3%) individuals tested positive for antibodies against SARS-CoV-2 (table 2), 401 (27.8%) females and 446 (24.2%) males. Again, there was a higher proportion of positive tests in individuals who lived in urban areas compared with the proportion among people who lived in rural areas (322, 30.8% vs 528, 23.4%, respectively) (table 2). Kabul region had the highest proportion of participants aged 5–17 years who tested positive for

Table 1 Seroprevalence of SARS-CoV-2 antibodies and proportion of IgM-seropositive in participants aged ≥18 years by region, area of residence and sex

	Number of positive COVID-19 tests†	Seroprevalence % (95%CI)	Adjusted seroprevalence (95% CI)	Number of IgM-positive COVID-19 tests	IgM-seropositive % COVID-19 tests (95%)
National	2056	35.1 (31 to 39.5)	29.8 (28.8 to 30.7)	164	2.6 (2.0 to 3.5)
Region***				Region***	
Central	254	45.5 (37.8 to 53.4)	34.6 (31.6 to 37.6)	28	4.3 (2.4 to 7.6)
Central highlands	105	24.9 (17.9 to 33.7)	19.0 (16.4 to 21.8)	5	1.0 (0.4 to 2.3)
East	294	49.1 (41.5 to 56.8)	41.5 (38.6 to 44.4)	16	2.5 (1.4 to 4.5)
Kabul	357	56.8 (52.0 to 62.0)	51.8 (48.8 to 54.8)	17	2.7 (1.4 to 5.0)
North	212	35.3 (28.1 to 43.4)	28.9 (26.3 to 31.8)	7	1.4 (0.6 to 3.4)
North-east	263	39.3 (31.9 to 47.4)	30.7 (28.1 to 33.3)	26	4.0 (2.1 to 7.8)
South	115	26.6 (19.0 to 36.0)	23.9 (20.7 to 27.1)	8	1.6 (0.7 to 3.4)
South-east	221	40.9 (34.4 to 47.9)	30.5 (27.4 to 33.6)	37	7.0 (3.7 to 12.9)
West	235	39.8 (34.8 to 45.1)	32.4 (29.7 to 35.2)	20	3.4 (1.8 to 6.3)
Area of residence					
Rural		31.7 (26.5 to 37.4)		121	3.7 (1.7 to 7.9)
Urban		42.3 (35.7 to 49.2)		43	2.3 (1.2 to 4.2)
Sex					
Male	1170	33.9 (29 to 39.2)		104	2.4 (1.4 to 4.0)
Female	885	37.2 (32 to 42.6)		60	4.1 (1.8 to 9.2)
Age (years)					
18–39	1109	33.7 (28.5 to 39.2)		96	2.7 (1.9 to 3.9)
40–59	657	36.5 (31.9 to 41.3)		50	2.4 (1.6 to 3.7)
60+	290	40.0 (31.8 to 48.2)		18	2.1 (1.1 to 4.2)

*p<0.05, **p<0.01, ***p<0.001.
†The total number of positive COVID-19 tests includes all positive results: both current and past infections that is, IgG-positive, IgM-positive or both.

antibodies against SARS-CoV-2 (177, 46.4%) (table 2). There were 89 (3.3%) participants aged 5–17 years who were IgM-positive for COVID-19, with the highest proportion of current infections in the South region (7, 4.7%) (table 2).

Predictions for cumulative exposure in the population up to 21 July 2020 in the nine regions of Afghanistan are shown in figure 3. The method used for the modelling analysis, which was developed by the COVID-19 International Modelling Consortium (CoMo Consortium), is detailed in online supplemental method, appendix 1.

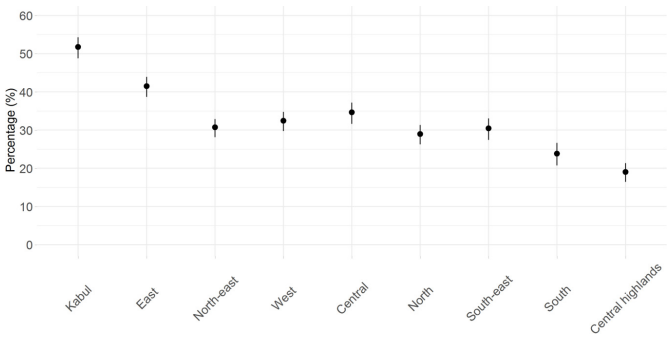

Figure 2 Adjusted seroprevalence by region by the sensitivity and specificity of the serology test for IgG-positive and/or IgM-positive.

The solid orange circles and black error bars in the panel for each region represent the observed seroprevalence data and the associated credible interval (CrI) after adjusting for the sensitivity and specificity of the antibody test. The green and orange lines show the median predictions for exposure and seroprevalence, respectively, while the shaded areas correspond to 95% CrI. The median predicted exposure levels by region (expressed as the proportion of the population that has been infected) as of 21 July 2020 are shown on the map of Afghanistan.

DISCUSSION

This national survey of COVID-19 morbidity in Afghanistan, which was conducted during June and July 2021, revealed that around 10 million people (31.5% of the population) were seropositive for antibodies against

Table 2 Seroprevalence of SARS-CoV-2 antibodies and proportion of IgM-seropositive results in participants aged 5–17 years by region, area of residence and sex

	Number of positive COVID-19 tests†	Seroprevalence % (95% CI)	Number of IgM-positive COVID-19 tests	IgM-seropositive % COVID-19 tests (95% CI)
National	850	25.3 (20.5 to 30.8)	89	3.3 (1.8 to 6.3)
Region*			Region**	
Central	79	21.0 (14.5 to 29.3)*	10	2.8 (1.2 to 6.3)
Central highlands	42	14.6 (8.6 to 23.8)	3	1.6 (0.4 to 6.6)
East	172	32.4 (26.8 to 38.6)	10	1.4 (0.7 to 3.1)
Kabul	177	46.4 (40.8 to 52.1)	14	3.5 (1.6 to 7.3)
North	96	23.0 (16.8 to 30.8)	6	1.2 (0.4 to 3.7)
North-east	108	20.9 (15.1 to 28.2)	18	2.8 (1.0 to 7.6)
South	55	24.4 (14.5 to 38.0)	7	4.7 (1.6 to 13.1)
South-east	42	17.6 (10.6 to 27.6)	9	2.4 (0.8 to 6.8)
West	79	24.5 (18.4 to 31.8)	12	3.2 (1.7 to 6.0)
Area of residence				
Rural	528	23.4 (17.5 to 30.6)	60	3.7 (1.7 to 7.9)
Urban	322	30.8 (24.8 to 37.5)	29	2.3 (1.2 to 4.2)
Sex				
Male	446	24.2 (18.5 to 31)	47	2.4 (1.4 to 4.0)
Female	401	27.8 (21.3 to 33)	42	4.1 (1.8 to 9.2)
Age (years)**			Age**	
5–9	175	(13.4 to 26.2)	20	3.3 (1.1 to 9.5)
10–14	365	(20.8 to 33.8)	40	3.7 (1.7 to 7.9)
15–17	310	(23.5 to 35.6)	29	2.8 (1.5 to 5.2)

*p<0.05, **p<0.01, ***p<0.001.
†The total number of positive COVID-19 tests includes all positive results: both current and past infections that is, IgG-positive, IgM-positive or both.

SARS-CoV-2, reflecting either current or previous COVID-19 infection. The population of Afghanistan is estimated to comprise approximately 33.6 million people.[15] Our finding is reasonably consistent with the results of a telephone survey conducted before July 2020 with a randomly selected sample of 713 healthcare workers to

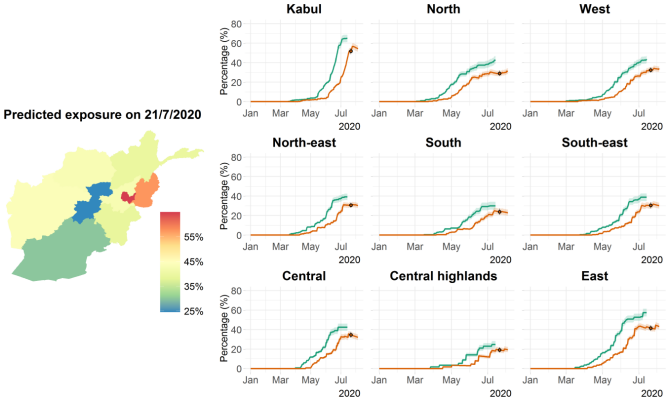

Figure 3 Time course of the COVID-19 pandemic up to 21 July 2020 for the nine regions in Afghanistan, for all age groups.

estimate COVID-19 morbidity in the country. The estimated proportion of individuals who had experienced COVID-19 signs and symptoms was 49.6%, which is close to the value for total infections for most regions reported in the present study, however, no laboratory testing was conducted for the phone survey, which only collected clinical information about symptoms. There is a discrepancy between our serosurvey results and the detected number of COVID-19 infections reported to the surveillance system in the country (36 710 cases reported by the surveillance system as of 30 July 2020 and 156 363 cases as of 5 November 2021). The under-reporting of COVID-19 cases is a problem globally due to limited testing availability, flawed test sensitivity, poor surveillance and the indeterminate proportion of asymptomatic infections.[16] However, some studies have suggested a lower prevalence of COVID-19 in countries during a similar period.[17] For example, the upper bound of COVID-19 prevalence was estimated to be 8.2% in Spain, 6.8% in Italy and 6.1% in the UK. However, the contexts, social mixing and other factors for the demographic scaling model vary across countries, particularly in resource-limited countries. In

such contexts, there are close contacts at home due to large family sizes, while social mixing in schools, communities and society might be more frequent as people rely on daily wages, and the adopted COVID-19 control measures might be less enforced and effective in such settings. Population-based seroprevalence studies are helpful to identify the true burden of disease, which might be higher compared with the burden estimated by modelling studies.

A modelling exercise was performed using the CoMo model to estimate the peak incidence of COVID-19 in Afghanistan. The CoMo model was developed by the CoMo Consortium.[18] The CoMo Consortium adopts a participatory modelling approach,[19] which places in-country subject matter experts at the forefront of model development to ensure that contextual considerations, such as local infrastructure, human resources and sociocultural considerations, are fully taken into account. The CoMo model was used to estimate the peak incidence of COVID-19 in Afghanistan under four scenarios: good, bad, very bad and appropriate, depending on the coverage of and adherence to the NPIs. If the use of NPIs (in a very bad scenario) is not considered, then the COVID-19 peak was predicted to occur in June 2020, with an estimated 69.6% of the population infected and 20 509 deaths by the end of 2020.

In communicable disease epidemiology, one of the key parameters used in decision-making is the estimate of herd immunity in a population. Herd immunity occurs when a certain proportion of the population is immune to a given infectious disease, reducing the probability that the disease will be transmitted from one individual to another, thus helping to protect the entire population from that disease.[20] Herd immunity can be achieved either through individuals being exposed or vaccinated. Determining a country's herd immunity threshold to a given disease is directly related to estimates of the basic reproductive number, R0, of that disease. R0 indicates the average number of individuals one infected individual can go on to infect in a fully susceptible population. Different herd immunity thresholds in different contexts have been estimated for COVID-19, ranging from 43% to 85%.[20–25] For example, one study indicated that if R0=3, that is, one infected individual can infect up to three others, 67% of the population must be immune to achieve herd immunity.[21] Estimates by Johns Hopkins University suggest that 70% of the population must be immune to achieve herd immunity and end restrictions on people's day to day lives,[20] while another study suggested that R0 values of 1–2, 2–4 and >4 would require herd immunity thresholds of 50%, 56.1%–74.8% and 77.9%–85%, respectively.[22] In addition to R0 and the herd immunity threshold, the rate of antibody decline postinfection must also be considered, with one study suggesting that antibodies to COVID-19 decline within 94 days of infection.[10]

A study conducted by Eckerle and Meyer[26] revealed that by mid-2020, an insufficient proportion of the population had been infected globally to achieve herd immunity, and these findings were confirmed by reports of low COVID-19 morbidity levels from countries such as Sweden, where an infection rate of 7% was reported by the end of April despite no lockdown; the mentioned study also states that obtaining herd immunity by exposing the population to the disease results in the simultaneous infection of the majority of the population and paves the way for a second wave of the disease.

These estimates of herd immunity thresholds suggest that the present survey findings, of a SARS-CoV-2 antibody seroprevalence of approximately 32% among the population in Afghanistan, mean that less than half of the population was infected and most of the country's population remained at risk of infection. However, in some provinces, large numbers of individuals have been infected and recovered from COVID-19. In Kabul province, for example, more than half of the population has been infected. However, as the majority of the population remains at risk of infection, preventive measures and NPIs should be lifted gradually, as per WHO guidelines.[27] It should also be noted that this survey was conducted at a time when the SARS-CoV-2 alpha variant was the most prevalent variant in Afghanistan; it is unclear what effect the arrival of new variants, such as the delta and omicron variants, and vaccination will have on population immunity.

As in many low-income and middle-income countries, COVID-19 vaccination rates in Afghanistan are low, with just 12% of the population currently fully vaccinated.[5] With the disruptions to the health system as a result of the evolving political situation in the country, the COVID-19 response may deteriorate if control measures are not implemented and vigilantly maintained.

Based on the evidence outlined above, the NPIs currently in place in Afghanistan should not have been lifted, as large numbers of the population are yet to become immune through natural infection or vaccination. If the NPIs are lifted, the rates of hospitalisation will increase, as will the number of patients requiring ventilation; this will place the already fragile health system under considerable pressure. However, after July 2021, the restrictions were reduced and since then the country has focused on school closures alone as a mitigation measure to balance the economy, social life and the impact of COVID-19 on the health system. It is worth mentioning that with the recent transition of government in Afghanistan and decreased funding for the country's health system, there are evolving challenges that will ultimately lead to the increased spread of COVID-19 and other infectious diseases. Greater levels of poverty, a displaced population and poor sanitation will further exacerbate this problem. The influx of refugees from Afghanistan to other countries might also facilitate the cross-border spread of disease. Particularly with the emergence of new variants and low vaccination coverage, it is crucial to have continued public health and social measures to mitigate the impact of COVID-19 in a conflict-affected and unstable country. For health services to continue,

functional hospitals, surveillance systems and laboratories, as well as a skilled healthcare workforce, are needed to mitigate the spread of COVID-19 and other infections within Afghanistan and prevent the regional and even global spread of disease.

This study had some limitations. First, the time available to conduct the survey was limited. Second, security concerns meant that not all areas could be surveyed; the inability to conduct proper household listing and create maps for EAs in those areas where the government lacked control may have affected the findings. Third, the findings may not reflect the current situation with regards to the new SARS-CoV-2 delta and omicron variants of concern, as the R0 for these variants is not well-established. Once a stable estimate of the R0 for these variants has been established then our findings can be adjusted accordingly to assist with programme planning. Fourth, the data were entered in the DHIS2 database, which created many challenges for data verification, household matching and the subsequent analysis. All data were re-entered in DHIS2 at the central level to ensure data quality and to match the households for reliable and valid analysis. In future surveys, it would be preferable to collect data by entering them directly via a tablet or similar appropriate research data entry tool to improve the data quality.

CONCLUSION

Although the immunity threshold may have been reached in some localities within Afghanistan, specifically Kabul, this threshold has not yet been reached among the country's entire population. In particular, the proportion of the population that is seropositive for antibodies against SARS-CoV-2 is much lower in rural areas than urban areas. The seroprevalence represents a lower estimate of herd immunity and the predicted exposure represents an upper limit. Given the large proportion of the population that remains susceptible to COVID-19 infection, and the limited COVID-19 vaccination coverage, NPIs and vigilance should remain in place to protect the health system from an unmanageable burden of hospitalisations. The link between the presence of antibodies and immunity has yet to be established, as has the link between prior exposure and immunity. As antibody levels wane, seroprevalence may provide an underestimate of immunity but, conversely, if immunity wanes, then prior exposure would provide a higher estimate of immunity.

Author affiliations
[1]Monitoring, Evaluation and Health Information System, Ministry of Public Health, Kabul, Afghanistan
[2]WHE, World Health Organization, Kabul, Afghanistan
[3]Information Systems for Health Unit, WHO Eastern Mediterranean Regional Office, Cairo, Egypt
[4]KIT Royal Tropical Institute, Amsterdam, Netherlands
[5]Big Data Institute, Li Ka Shing Centre for Health Information and Discovery, Nuffield Department of Medicine, Universiry of Oxford, Oxford, UK
[6]Infectious Hazard Preparedness Unit, WHO Eastern Mediterranean Regional Office, Cairo, Egypt
[7]School of Mathematics and Statistics, University of Melbourne, Melbourne, Victoria, Australia
[8]Department of Epidemiology, Robert Stempel College of Public Health, Florida International University, Miami, Florida, USA
[9]Department of Molecular Biology, Forensic Medicine Directorate, Ministry of Public Health, Kabul, Afghanistan
[10]Central Public Health Laboratory (CPHL), Ministry of Public Health, Kabul, Afghanistan
[11]Department of Public Health, Cairo University Kasr Alainy Faculty of Medicine, Cairo, Egypt

Twitter Giti Azim @GitiAzim

Acknowledgements We would like to acknowledge the regional master trainers and the National Statistics and Information Authority (NSIA) team for their support in conducting the survey. We would additionally like to thank the following for their efforts during the survey: the WHO team, USAID, World Bank, CDC Atlanta, Performance Management Office (PMO), Grants and Contracts Management Unit (GCMU), Afghanistan National Public Health Institute (ANPHI), all Provincial Public Health Directorates (PPHDs), Health Promotion Department (HPD), all Basic Package of Health Services (BPHS) and Essential Package of Hospital Service (EPHS)-implementing NGOs, the survey steering committee team, and the data management team. We acknowledge the national and provincial surveillance teams for their extensive support in conducting the survey. We also appreciate all those individuals who supported the data collection, data entry and listing of households for the survey frame. Medical writing assistance and editorial support was provided by Adam Bodley, according to Good Publication Practice guidelines. The views expressed in this manuscript are those of the authors and do not necessarily reflect the views of the authors' affiliated organisations or the organisations listed here.

Contributors SAS planned the study, lead the study design and tools in the country, coordinated with national authorities, provided Training of Trainers (ToT), monitored process of data collection, analysed the data and contributed to writing and finalising the report and findings of the study and organised dissemination workshops, seminars in the country and acting as guarantor for overall content of study. MNS supported in planning the study, supported in scientific study design, coordinated internally for sharing scientific WHO tools and protocol, supported in data analysis, contributed to writing and finalising the study report. FA supported in the design and tools of the study, contributed in analysing and interpreting the results, supported in drafting the report and communicated with all authors for compiling and incorporating the feedback in the final version. EAA supported in the study design and tools, contributed to data cleaning, analysis and interpretation, and writing the report and finalisation of the study report. MvG supported in study design, complex and multi-level analysis, reviewed and revised the study findings and report. LJW supported in study method, analysis, interpretation of findings and modelling based on the serosurvey data, reviewed and revised the final study report. SC supported in study method, analysis, interpretation of findings and modelling based on the serosurvey data, reviewed and revised the final study report. AB supported in proper laboratory testing of the study method, selection of testing kits, contributed to the interpretation of findings, reviewed the draft report and provided inputs to the revision and finalisation of the study report. GA supported in planning the study, facilitated internal coordination within MoPH, provided ToT training, supervised the data collection in a cluster, supported in drafting the study report and contributed to finalising the study findings. BR supported in planning the study, provided ToT training, supervised the data collection in a cluster, supported data entry and cleaning, drafting the study report and contributed to finalising the study findings. SS supported in planning the study, provided ToT training, supervised the data collection in a cluster and collected data where needed, supported data entry and cleaning, drafting the study report and contributed to finalising the study findings. JAF contributed to the study method, interpretation of serosurvey findings for the context, analysing the data, reviewed the draft report and provided inputs to the finalisation of the study report. NA contributed to the study method, interpretation of serosurvey findings for the context, analysing the data, reviewed the draft report and provided inputs to the finalisation of the study report. MJA supported the planning of the study, provided ToT training, supervised the data collection in clusters and collected data where needed, supported data entry and cleaning, drafting the study report and contributed to finalising the study findings. NMA supported correct laboratory testing protocol of the study method, selection of testing kits, contributed to interpretation of findings, reviewed the draft report and provided inputs to the revision and finalisation of the study report. AA supported the scientific study

design, internal WHO coordination, supported data analysis, and contributed to writing and finalising the study report.

Funding This SARS-CoV-2 seroprevalence in Afghanistan: a population-based study has been supported by WHO Unity Studies, a global seroepidemiological standardisation initiative, with funding to WHO by the COVID-19 Solidarity Response Fund and the German Federal Ministry of Health (BMG) COVID-19 Research and Development Fund. We would like to acknowledge the Monitoring and Evaluation and Health Information System General Directorate, which led the study in Afghanistan. The study was funded by Ministry of Public Health.

Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval Ethical and technical clearance to conduct the survey was obtained from the Institutional Review Board of the Afghanistan MoPH, Reference number: A.0321.0278. Informed consent was obtained from participants aged ≥18 years, and assent from family members was obtained for those aged 5–17 years. Individuals who did not provide consent were excluded. Survey team members provided advice about home isolation to participants who tested IgM-positive for COVID-19 during the survey.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available. Survey serology data are stored in the Ministry of Public Health national database and are available on reasonable request. For adjusting the COVID-19 seroprevelance, all data, code and materials used in the analyses can be accessed at: https://github.com/SiyuChenOxf/AfghanistanSerologyStudy/tree/master. All parameter estimates and figures 3 and 4 can be reproduced using the code provided. This work is licensed under a Creative Commons Attribution 4.0 International (CC BY 4.0) license, which permits unrestricted use, distribution and reproduction in any medium, provided the original work is properly cited.

ORCID iD

Fatima Arifi http://orcid.org/0000-0003-3923-689X

REFERENCES

1 COVID-19 dashboard. Johns Hopkins COVID-19 dashboard Johns Hopkins University, 2021. Available: https://coronavirus.jhu.edu/map.html
2 Burki T. No end in sight for the Brazilian COVID-19 crisis. *Lancet Microbe* 2021;2:e180.
3 Thiagarajan K. Why is India having a covid-19 surge? *BMJ* 2021;373:n1124.
4 ReliefWeb. Second wave of Covid-19 causes alarm: ReliefWeb, 2021. Available: https://reliefweb.int/report/nepal/second-wave-covid-19-causes-alarm
5 Ministry of Public Health. COVID-19 Dashboard 2021, 2021. Available: http://covid.moph-dw.org/ [Accessed 11 Jun 2021].
6 CDC. Interim guidelines for COVID-19 antibody testing Atlanta: centers for disease control and prevention, 2021. Available: https://www.cdc.gov/coronavirus/2019-ncov/lab/resources/antibody-tests-guidelines.html2021
7 Burgess S, Ponsford MJ, Gill D. Are we underestimating seroprevalence of SARS-CoV-2? *BMJ* 2020;370:m3364.
8 Ibarrondo FJ, Fulcher JA, Goodman-Meza D, *et al*. Rapid decay of Anti-SARS-CoV-2 antibodies in persons with mild Covid-19. *N Engl J Med* 2020;383:1085–7.
9 Harris RJ, Whitaker HJ, Andrews NJ, *et al*. Serological surveillance of SARS-CoV-2: six-month trends and antibody response in a cohort of public health workers. *J Infect* 2021;82:162–9.
10 Seow J, Graham C, Merrick B, *et al*. Longitudinal observation and decline of neutralizing antibody responses in the three months following SARS-CoV-2 infection in humans. *Nat Microbiol* 2020;5:1598–607.
11 WHO. *Population-Based age-stratified seroepidemiological investigation protocol for COVID-19 virus infection*. Geneva: WHO, 2020.
12 Chen S, Flegg JA, White LJ, *et al*. Levels of SARS-CoV-2 population exposure are considerably higher than suggested by seroprevalence surveys. *PLoS Comput Biol* 2021;17:2021.01.08.21249432.
13 StataCorp. *Stata statistical software: release 15*. College Station, TX: StataCorp LLC, 2017. https://www.stata.com/stata15/
14 Healgen Scientific LLC. COVID-19 IgG/IgM rapid test cassette (whole Blood/Serum/Plasma) instruction for use, 2020. Available: https://www.fda.gov/media/138438/download
15 NSIA. Estimated population of Afghanistan 2021-22: NSIA, 2021. Available: https://www.nsia.gov.af:8080/wp-content/uploads/2021/06/Estimated-Population-2-of-AFG-New-Design-14.pdf
16 Wu SL, Mertens AN, Crider YS, *et al*. Substantial underestimation of SARS-CoV-2 infection in the United States. *Nat Commun* 2020;11:4507.
17 Bohk-Ewald C, Dudel C, Myrskylä M. A demographic scaling model for estimating the total number of COVID-19 infections. *Int J Epidemiol* 2021;49:1963–71.
18 CoMo Consortium. CoMo Consortium: BMJ, 2021. Available: https://como.bmj.com/2021
19 Aguas R, White L, Hupert N, *et al*. Modelling the COVID-19 pandemic in context: an international participatory approach. *BMJ Glob Health* 2020;5:e003126.
20 D'Souza G, Dowdy D. What is herd immunity and how can we achieve it with COVID-19? Maryland: Johns Hopkins Bloomberg school of public health, 2021. Available: https://www.jhsph.edu/covid-19/articles/achieving-herd-immunity-with-covid19.html2021
21 Randolph HE, Barreiro LB. Herd immunity: understanding COVID-19. *Immunity* 2020;52:737–41.
22 Kwok KO, Lai F, Wei WI, *et al*. Herd immunity - estimating the level required to halt the COVID-19 epidemics in affected countries. *J Infect* 2020;80:e32–3.
23 Gomes MGM, Corder RM, King JG. Individual variation in susceptibility or exposure to SARS-CoV-2 lowers the herd immunity threshold. *medRxiv*2020:2020.04.27.20081893.
24 Altmann DM, Douek DC, Boyton RJ. What policy makers need to know about COVID-19 protective immunity. *Lancet* 2020;395:1527–9.
25 Britton T, Ball F, Trapman P. The disease-induced herd immunity level for Covid-19 is substantially lower than the classical herd immunity level. *arXivorg*2020:arXiv:2005.03085v1.
26 Eckerle I, Meyer B. SARS-CoV-2 seroprevalence in COVID-19 hotspots. *Lancet* 2020;396:514–5.
27 World Health Organization. *Considerations for implementing and adjusting public health and social measures in the context of COVID-19*. Geneva: World Health Organization, 2021.