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Sero-prevalence of SARS-CoV-2 in certain cities of Kazakhstan

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Abstract

Background and Aims: Seroprevalence studies are needed to determine the cumulative prevalence of SARS-CoV-2 infection and to develop pandemic mitigation strategies. Despite the constant monitoring and surveillance, the true level of infection in the population of Kazakhstan remains unknown. The aim of this study was to determine the sero-prevalence of SARS-CoV-2 in the main cities of Kazakhstan.

Methods: The research was conducted as a cluster-randomized cross-sectional national household study in three cities of Kazakhstan. The study covered the period: from October 24, 2020, to January 11, 2021. A total of 5739 people took part in the study. All participants agreed to be tested for antibodies to IgM/IgG. Demographic characteristics were analyzed. The presence of symptoms of respiratory diseases and the results of polymerase chain reaction (PCR) testing were determined. The antibodies to the SARS-CoV-2 virus were detected using the method of enzyme-linked immunosorbent assay (ELISA).

Results: There was significant geographic variability with a higher prevalence of IgG/IgM antibodies to SARS-CoV-2 in Almaty 57.0%, in Oskemen 60.7% than in Kostanay 39.4%. There were no significant differences in prevalence between men and women ($p \geq 0.05$). In Almaty, only 19% of participants with antibodies reported the presence of respiratory symptoms during a pandemic. At the same time, the percentage of patients with antibodies who had respiratory symptoms was 36% in Oskemen and 27% in Kostanay.

Conclusion: The findings indicate that despite reasonable level of seroprevalence, the country has not yet reached the baseline minimum of herd immunity scores. The prevalence estimates for asymptomatic or subclinical forms of the disease ranged from 64% to 81%. Thus, given that almost half of the population of Kazakhstan remains vulnerable, the importance of preventive strategies such as social distancing, the use of medical masks, and vaccination to protect the population from the transmission of SARS-CoV-2 is highly critical.

KEYWORDS
antibodies, asymptomatic, COVID-19, SARS-CoV-2, seroprevalence

1 | INTRODUCTION

In December 2019, an outbreak of a new coronavirus infection (COVID-19) caused by the SARS-CoV-2 virus was reported in the Chinese province of Wuhan.[1] The first case outside China was reported on January 13, 2020, in Thailand.[2] Due to the alarming spread of the infection and the severity of the consequences, the World Health Organization (WHO) declared the COVID-19 outbreak as a pandemic on March 11, 2020.[3]

In Kazakhstan, the first cases of COVID-19 infection were registered on March 13, 2020, among persons arrived from Germany.[4] The first cases of coronavirus infection in the communities were recorded on March 28.[5] As of January 16, 2021, 167,118 cases of COVID-19 and 2397 deaths (COVID-19 related) were registered in Kazakhstan.[6] Since the beginning of the pandemic, quarantine and isolation procedures have been implemented around the world. The tough control measures have been also taken in Kazakhstan, including school closures, social distancing, strict border controls, restrictions on store opening hours, and so on.[7]

As a matter of fact, epidemiological surveillance of confirmed cases of COVID-19 covers only a fraction of all registered cases of infection, since the clinical manifestations of SARS-CoV-2 can range from asymptomatic carrier age to a serious illness with epy lethal outcome.[8] Conducting a sero-epidemiological survey on a specific population could help to quantify the proportion of the people that have antibodies against SARS-CoV-2.[9] Thus, a sero-epidemiological study can provide information on the number of people exposed to coronavirus infection. The antibodies are a marker of total or partial immunity, but they can also provide information about the percentage of the population that remains susceptible to the virus.[8]

To date, a few epidemiological studies of COVID-19 cases among the adult and child population have been carried out on the territory of Kazakhstan since the beginning of the pandemic.[10,11] However, no studies have been conducted to determine the level of sero-prevalence in the local population yet. Therefore, the aim of this study was to determine the sero-prevalence of SARS-CoV-2 in the main cities of Kazakhstan.

This study was carried out after the approval of the Ministry of Health of the Republic of Kazakhstan with the technical and financial support of the WHO country office. The study methodology was based on the WHO protocol.

2 | METHODS

2.1 | Ethical issues

The study protocol was approved by the local High Ethics Committee of the National Public Health committee of the Ministry of Health of the Republic of Kazakhstan (protocol of the Local Ethics Commission No. 2 dated September 11, 2020). Before the study, all study participants signed informed consent.

2.2 | Study participants and data collection

For the study (September 2020), the following three cities (Figure 1) with different levels of morbidity were selected: Almaty (cumulative incidence rate 720.8 per 100 thousand population), Oskemen (642.1), and Kostanay (709.0). The city choice was dictated by the geographical location (south, east, and north, respectively). At the end of the study (January 2021), high cumulative incidence rates were detected in Kostanay (2021.2 per 100 thousand population) and Oskemen (1637.4). The low levels of incidence rates were observed in Almaty city (1108.3).

Household inclusion criteria: one or more people living independently or together in a residential building with a common kitchen or common access to a living space.

Household exclusion criteria: persons living in residential institutions such as boarding schools, dormitories, hostels or prisons, households where healthcare workers live.

Inclusion criterions: all individuals selected to participate in the study, aged 5 years or older, regardless of history of COVID-19 infection, as well as cases of suspected or confirmed acute or previous COVID-19 infection, to avoid underestimating the prevalence of infection in the population.

Exclusion criterions: the lack of informed consent; the presence of contraindications to venipuncture; children under 5 years old.

2.3 | Sampling

The study samples were formed by using the clusters. The clusters were arranged on the sites of medical organizations providing primary health care (PHC) for the local population.

At the first stage, we identified a complete list of all sites (clusters) providing PHC in the three selected cities. The number of sites for each city was determined in accordance with the minimum required number of clusters, depending on the number of attached population and taking into account the population and the average size of households. A simple random sample was used to select clusters.

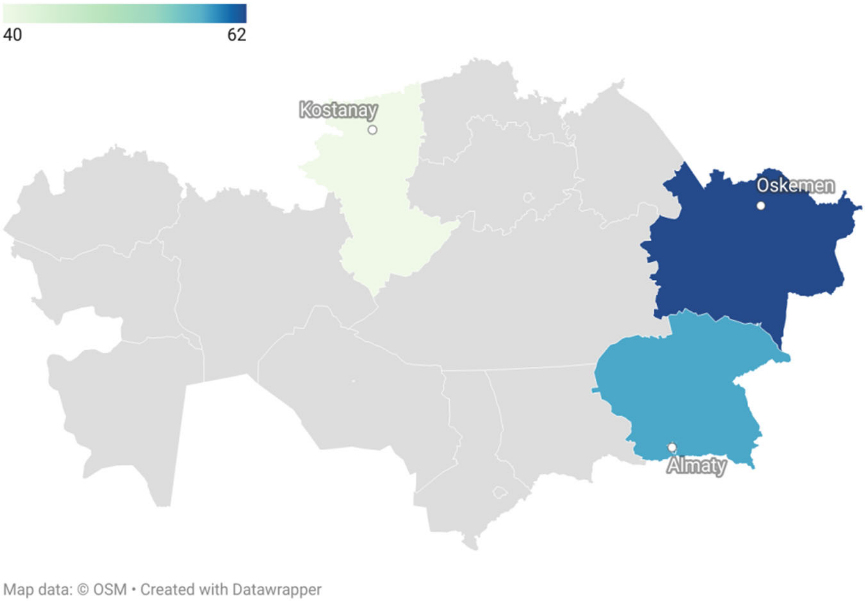
At the second stage, lists of the local population (covered by polyclinic) with home addresses were obtained in randomly selected PHC sites (chosen clusters). To select addresses, a systematic sample model was used with the determination of the step and the choice of the first random number.

Initially, 7786 people were identified as living in the selected households. The total sample for the study was 5739 people, including Almaty (4461), Oskemen (664), and Kostanay (614). The percentage of participation in the study is 73.7%.

The study was conducted in the period from October 24 to January 11, 2021.

The demographic characteristics of the study participants were determined, such as gender and age. In addition, the presence of symptoms of respiratory diseases since March 2020 and results of polymerase chain reaction (PCR) testing was also analyzed.

FIGURE 1 The prevalence of antibodies to the SARS-CoV-2 virus, depending on the region of localization of the study participants in Kazakhstan



2.4 | Laboratory methods

Laboratory studies were carried out by enzyme-linked immunosorbent assay (ELISA)[12] in the reference laboratory (RL) for the control of viral infections "National Centre for Public Health" in Almaty (branch of the "Scientific and Practical Centre for Sanitary and Epidemiological Expertise and Monitoring"). The laboratory is part of the global network for the diagnosis of poliomyelitis, measles, rubella, influenza and is the WHO regional RL for these diseases.

After obtaining informed consent, venous blood was taken in an amount of 5 ml into vacuum tubes with a yellow cap with a separating gel of a unified volume. Blood samples were delivered to the virological laboratories of the branches of the National Centre for Expertise (cities: Kostanay and Oskemen), where the serum was separated. In the city of Almaty, blood samples were delivered within 2 h after selection in the laboratory "Scientific and Practical Centre for Sanitary and Epidemiological Expertise and Monitoring."

The samples were transported to the laboratory in compliance with the conditions of the cold chain and frozen. Serum samples were stored frozen in the RL at −20°C until testing. To determine the total antibodies to the SARS-CoV-2 virus in human serum, the ELISA-based Wantai SARS-CoV-2 total antibody assay (Wantai Biological Pharmacy; S protein receptor-binding domain-based) was employed.[12]

2.5 | Statistical analysis

For the statistical processing of the data, the R program was used. To obtain an estimate of the prevalence of antibodies in cities, the data were weighted taking into account the sex and age distribution of the urban population of Kazakhstan. Ninety-five percent confidence intervals (CIs) were calculated. The statistical significance of differences in prevalence between groups was determined using the χ^2 test. The φ coefficient was used to measure the association between two dichotomous variables.

3 | RESULTS

3.1 | Characteristics of the study sample

Characteristics of the study sample presented in Table 1. Among $n = 4461$ participants from Almaty, females made up 64.4% ($n = 2871$), and males made up 35.6% ($n = 1590$). In the cities of Oskemen and Kostanay, females prevailed among the participants, the number of which was 72.0% ($n = 478$) and 59.4% ($n = 365$), respectively.

3.2 | Prevalence of antibodies to SARS-CoV-2 virus

The overall prevalence of antibodies to the SARS-CoV-2 virus weighted by gender and age was significantly different ($p < 0.001$) in three cities: 57.0% (95% CI = 56.9%–59.8%) in Almaty, 60.7% (95% CI = 57.9%–65.5%) in Oskemen and 39.4% (95% CI = 35.8%–43.7%) in Kostanay.

The prevalence in Almaty and Oskemen did not differ significantly but was higher than in Kostanay ($p \le 0.05$). The prevalence of antibodies to SARS-CoV-2 in different subgroups are presented in Table 1.

Analysis of the prevalence of antibodies to the SARS-CoV-2 virus by sex showed that the proportion of positive results among males was higher in all cities, but the difference was not statistically significant ($p \ge 0.05$).

TABLE 1 Characteristics of the study sample and prevalence of antibodies to SARS-CoV-2

Characteristics	Almaty, *N* (%)	Prevalence of antibodies to SARS-CoV-2 in Almaty % (*n*)	Oskemen, *n* (%)	Prevalence of antibodies to SARS-CoV-2 in Oskemen % (*n*)	Kostanay, *n* (%)	Prevalence of antibodies to SARS-CoV-2 in Kostanay, *n* (%)
Total (w/o weighting)	4461 (100)	57.0 (2543)	664 (100)	60.7 (403)	614 (100)	39.4 (242)
Gender						
Males	1590 (35.6)	58.3 (927)	186 (28.0)	60.8 (113)	249 (40.6)	42.6 (106)
Females	2871 (64.4)	56.3 (1616)	478 (72.0)	60.7 (290)	365 (59.4)	37.3 (136)
Age						
5–14	424 (9.5)	58 (246)*	5 (.8)	60 (3)	44 (7.2)	34.1 (15)*
15–19	237 (5.3)	53.6 (127)	13 (2.0)	84.6 (11)	19 (3.1)	57.9 (11)
20–29	565 (12.7)	61.8 (349)	114 (17.2)	62.3 (71)	114 (18.6)	36 (41)
30–39	645 (14.5)	59.4 (383)	146 (22.0)	57.5 (84)	125 (20.4)	40.8 (51)
40–49	669 (15.0)	58.1 (389)	118 (17.8)	61 (72)	103 (16.8)	49.5 (51)
50–59	664 (14.9)	63 (418)	151 (22.7)	58.9 (89)	88 (14.3)	25 (22)
60–69	767 (17.2)	53.1 (407)	93 (14.0)	60.2 (56)	70 (11.4)	42.9 (30)
70+	490 (11.0)	45.7 (224)	24 (3.6)	70.8 (17)	51 (8.3)	41.2 (21)
Have had any respiratory symptom since March 2020						
Yes	736 (16.5)	66.8 (492)*	250 (37.7)	73.2 (183)*	198 (32.2)	32.8 (65)*
No	3725 (83.5)	55.1 (2051)	414 (62.3)	53.1 (220)	416 (67.8)	42.5 (177)
Performed PCR test for SARS-CoV-2 and its result						
Positive result of any test	63 (1.4)	84.1 (53)*	70 (10.5)	84.3 (59)*	7 (1.1)	28.6 (2)
Negative result of all tests	278 (6.2)	63.3 (176)	93 (14.0)	55.9 (52)	128 (20.8)	42.2 (54)
Test was not performed	4120 (92.4)	56.2 (2314)	501 (75.5)	58.3 (292)	479 (78.0)	38.8 (186)

Abbreviation: PCR, polymerase chain reaction.
*$p < 0.05$

By age group, the prevalence of antibodies in Almaty ranged from 45.7% (95% CI = 41.2%–50.2%) among people over 70 years old to 63.0% (95% CI = 59.2%–66.7%) at the age of 50–59 years. These findings indicate that there was less prevalence in older age groups. In Oskemen and Kostanay cities, no significant relationship was found between age and prevalence.

The prevalence of antibodies to SARS-CoV-2, depending on the age category, is presented in Table 2. In the age group of children from 5 to 14 years, there was a statistically low seroprevalence rate of 55.5% ($n = 609$). The 15–19 age group had the highest levels of anti-SARS-CoV-2 antibodies at 59.4% ($n = 931$). In the oldest age groups 60–69 and 70+, there were the lowest seroprevalence rates: 53.4% ($n = 487$) and 48.2% ($n = 309$), respectively.

The prevalence of antibodies to the SARS-CoV-2 virus among those who had symptoms during this period was 66.8% in Almaty, 73.2% in Oskemen, and 32.8% in Kostanay.

The prevalence of individual symptoms among participants who had respiratory symptoms since March 2020, depending on the result of the ELISA test for SARS-CoV-2, are presented in Table 3. Symptoms such as cough ($p = 0.67$), headache ($p = 0.34$) had no statistically significant difference in prevalence among participants with positive and negative ELISA test results. Fatigue was one of the most common symptoms in participants with a positive ELISA (58.8%) compared with participants without antibodies to SARS-CoV-2 (44.4%). In addition, fever was identified in respondents with a positive ELISA test in 52.7% of cases compared to 34.7% of cases with a negative result ($p < 0.001$). However, rhinorrhea was more common in participants without antibodies to SARS-CoV-2 ($p = 0.04$), and it was negatively associated with a positive ELISA test result ($\varphi = -0.06$). Chills and myalgia in patients with a positive ELISA result were frequent symptoms in 47.2% and 50.0% of cases, respectively ($p < 0.001$). Among all symptoms, anosmia had the highest positive

TABLE 2 Seroprevalence indicators depending on age categories in all three cities

Antibodies to SARS-CoV-2 in the different age groups	Negative		Positive		
	Count	% within age group	Count	% within age group	Count
5–14	489	*44.5*	609	55.5	1098
15–19	151	41.8	210	58.2	361
20–29	378	40.6	553	59.4	931
30–39	455	42.2	624	57.8	1079
40–49	335	42.5	453	57.5	788
50–59	288	41.9	399	58.1	687
60–69	227	46.6	260	53.4	487
70+	160	51.8	149	48.2	309
Total	2483	43.3	3257	56.7	5740

association with the presence of antibodies to SARS-CoV-2 according to ELISA results ($\varphi = 0.29$). It was statistically significantly higher in respondents with a positive ELISA result (41.6%), in contrast to 14.0% of participants with negative ELISA test results ($p < 0.001$).

4 | DISCUSSION

The serological prevalence of antibodies specific to SARS-CoV-2 was estimated in three big cities of Kazakhstan with different geographic locations. The prevalence of SARS-CoV-2 at the time of the study was from moderate (in Almaty, Kostanay: R value = 1.03–1.4, respectively) to high (in Oskemen: R value = 1.85).

The prevalence of antibodies in Almaty and Oskemen was about 60%, and it was significantly higher than in Kostanay city (about 40%). The study did not reveal a significant difference in the prevalence of antibodies between men and women in all cities and age groups ($p \geq 0.05$).

The obtained results indicate that the lowest prevalence of antibodies to the SARS-CoV-2 virus was noted in the age group of children from 5 to 14. A decline in the presence of antibodies to SARS-CoV-2 was observed in people over 60 years of age in 53.4% of cases and up to 48.2% of cases are over the age of 70, respectively.

However, it is difficult to say that the infection was less common among children and adolescents than among adults, because of the difference in immunological reactions of children from adults.[13] These results are consistent with the fact that infected children are less likely to develop the severe disease than adults.[10]

The statistical significance of differences in antibody prevalence across age groups was observed in Almaty, where prevalence was lowest in the 70 and older age group, where it was approximately 45% versus 60% in the general population. Low prevalence in the older age group could be associated with better adherence to

TABLE 3 Prevalence of selected symptoms among participants who experienced respiratory symptoms since March 2020 depending on the result of the total body ELISA test for SARS-CoV-2

Symptoms	Positive ELISA test results ($N = 740$)	Negative ELISA test results ($N = 444$)	φ	p value
Fever (temperature > 38°C)	390 (52.7)	154 (34.7)	0.18	<0.001
Chills	349 (47.2)	120 (27.0)	0.20	<0.001
Fatigue	435 (58.8)	197 (44.4)	0.14	<0.001
Muscle pain	370 (50.0)	137 (30.9)	0.19	<0.001
Sore throat	370 (50.0)	181 (40.8)	0.09	0.002
Cough	366 (49.5)	226 (50.9)	-0.01	0.67
Rhinorrhea	314 (42.4)	216 (48.6)	-0.06	0.04
Apnea	211 (28.5)	94 (21.2)	0.08	0.006
Wheezing	102 (13.8)	43 (9.7)	0.06	0.04
Chest pain	191 (25.8)	75 (16.9)	0.10	<0.001
Headache	402 (54.3)	228 (51.4)	0.03	0.34
Nausea, vomiting	127 (17.2)	40 (9.0)	0.11	<0.001
Stomach ache	104 (14.1)	41 (9.2)	0.07	0.02
Diarrhea	136 (18.4)	58 (13.1)	0.07	0.02
Loss of smell (anosmia)	308 (41.6)	62 (14.0)	0.29	<0.001

Abbreviation: ELISA, enzyme-linked immunosorbent assay.

COVID-19 prevention measures. These findings correlate with the results of a population study in Switzerland, where people over 65 also had a low sero-prevalence. At the same time, sero-prevalence was high in the age group 20–49 years that can be associated with a high level of abidance the social distance measures by people in this category.[13] However, some studies have not found differences in sero-prevalence between age groups.[14]

Studying the prevalence of symptoms and their relationship with the presence of antibodies to SARS-CoV-2 makes it possible to assess the impact of a new coronavirus infection on respiratory morbidity, to assess the proportion of asymptomatic cases, and subclinical course of COVID-19. The incidence of symptoms in Oskemen and Kostanay was twice as high as in Almaty. There were no significant gender differences in the incidence of symptoms. Our findings indicate a tendency to an increase in the onset of symptoms among persons of older age groups (Kostanay and Oskemen). At the same time, in Almaty, symptoms appeared more often among people of working age (20–59 years).[12]

Previously published data showed that the viral load for SARS-CoV-2 is similar in asymptomatic and symptomatic patients. Moreover, it was revealed that asymptomatic patients may persist a positive test result for up to 21 days.[15] However, in Kostanay city, the prevalence of antibodies was practically independent of the presence of symptoms, which may indicate the influence of other pathogens on respiratory morbidity in this city. According to the sentinel epidemiological surveillance of the circulation of influenza viruses and other noninfluenza viruses, influenza viruses in the country in the current epidemic season can be detected from Week 45 (first decade of November). For the first time, an influenza virus was isolated from samples obtained from patients with respiratory diseases in the Kostanay region.

We observed the high prevalence of antibodies among participants who did not experience respiratory symptoms. In the cities included in the study, it ranges from 40% to 57%.

Of particular interest is the analysis of the prevalence of symptoms depending on the test result for antibodies to SARS-CoV-2, since it allows one to assess the proportion of asymptomatic infection and subclinical course of the disease. The prevalence estimate for asymptomatic new coronavirus infection in three cities ranged from 64% to 81%. The rapid transmission of SARS-CoV-2 infection and the high prevalence of asymptomatic carriers suggest that a universal testing approach rather than a symptom-based approach is needed to prevent the spread of infection to vulnerable populations from asymptomatic carriers.[16] The prevalence of antibodies among “contacted” population was higher than among people who were not contacted COVID-19 patients in two cities Almaty and Oskemen. In Kostanay city, no significant difference in prevalence was found between the two categories.

A statistically significant relationship between the prevalence of antibodies among people who have been in contact and who have not been in contact with known cases of COVID-19 was determined only in Almaty.

Previous sero-prevalence studies undoubtedly differ in terms of the population involved, the sampling strategy and laboratory tests chosen, the study design and methodology, and the variable circulation of SARS-CoV-2 in the populations involved.[17] For example, the prevalence of antibodies to SARS-CoV-2 in Kazakhstan is significantly higher than in European and Asian countries such as Iran (17.1%),[18] Sweden (15.0%),[19] Chile (10.7%),[19] Switzerland (6.4%),[20] Italy (7.27%),[19] South Korea (7.6%),[21] Spain (5.0%),[8] and United States (4.4%).[19] The high prevalence of antibodies in Kazakhstan might be explained by the fact that studies in these countries were carried out earlier than ours (April to June 2020). In the cities of Kazakhstan, the peak incidence of COVID-19 was observed in June to July, while the study was conducted from the end of October 2020 to January 2021.

A significant difference between the officially reported number of confirmed cases of COVID-19 and the estimate of cases based on serological prevalence (according to the study result) must be taken into account. Thus, as of December 31, 2020, 27,344 cases of COVID-19 were registered in three cities, our estimate suggests that the true incidence of COVID-19 is up to 60.3 times (Almaty city) higher than official statistics. It has been assumed that the level of detection of SARS is CoV-2 ranges from 1.7% to 3.6%. This kind of data discrepancy also presents in previously published reports. According to a nationwide sero-epidemiological study conducted in the Netherlands, 2.8% of the population were infected with SARS-CoV-2, and it was 30 times higher than reported official statistics.[22]

Common symptoms of COVID-19 include cough, fever, and respiratory distress. About 80% of infected people have only mild symptoms or no symptoms at all. Some patients develop severe pneumonia, multiple organ failure, or even death.[23] In Almaty, 81% of people with SARS-CoV-2 antibodies had no symptoms of the disease, 64% in Oskemen and 73% in Kostanay city. It should be noted that a positive result of the serological test can be associated and caused by other pathogens.

It is evident that despite the presence of symptoms that do not exclude COVID-19, the population did not follow the recommendations of the Ministry of Healthcare for self-isolation. According to a study carried out in the city of Taldykorgan (Almaty County), 32% of respondents seeking medical help for acute respiratory viral infections (ARVIs). The COVID-19 patients continued to visit public places, representing a source of viral infection. The use of medicines without official prescription and the underestimation of the danger of influenza can explain the low demand of the population for medical care.

In our study, antibodies were less common in individuals with at least one chronic disease than in individuals with no chronic disease. In this regard, some researchers stressed the hypothesis that people with chronic diseases may take additional precautions to prevent infection with COVID-19.[24]

Among people who have ever received a positive PCR test result, 86.5% had antibodies to the SARS-CoV-2 virus; 13.5% of COVID-19 cases based on PCR testing did not have antibodies to the virus because of the lack of their production by the organism. It can be also explained either by the decrease in their concentration down to an undetectable level, or the result of the PCR test was false positive.

Despite the high prevalence of antibodies to the SARS-CoV-2 virus in the cities studied, there is a significant difference in prevalence between them. It indicates uneven incidence and the potential for further spread of infection. However, it is worth noting that antibody testing is not a reliable screening method for asymptomatic carriers due to the time lag between exposure to the virus and antibody development, the persistence of antibodies beyond the clearance of infection, and false-negative readings with low titres.[25]

Given that the duration of antibody retention after infection varies individually and tends to decrease over time (40% of asymptomatic cases will become seronegative after 2 months),[26] the vaccination campaign among the population plays a key role in ending the epidemic. With SARS-CoV-2 vaccination becoming more widely available globally, the use of serology as a pandemic control tool could transform from a diagnostic modality to a criterion of vaccination efficacy.[27]

Despite the high prevalence of antibodies in the study (from 39.7% to 61.7%), this is not enough to stop the COVID-19 pandemic. With a baseline reproductive number of $R0 = 3$, two-thirds of the population must be immune to infection to stabilize its spread.

However, the acquired immunity (after an illness or vaccination) does not guarantee complete protection against infection. Moreover, variants that cause impaired immunity (*α* and especially delta) are able to overcome the immune defence, and they have a higher infectivity. Thus, it is impossible to achieve complete elimination of the virus at this stage. It is evident that the SARS-CoV-2 pandemic will continue,[28] but large-scale vaccination can mitigate its effects.

5 | CONCLUSION

The prevalence of antibodies to the SARS-CoV-2 virus in the three Kazakhstan cities selected for the study ranged from 39.7% to 61.7%. The results indicate that despite reasonable seroprevalence, the country has not yet reached the baseline minimum of herd immunity scores. The prevalence estimates for asymptomatic or subclinical forms of the disease ranged from 64% to 81%. Thus, given that almost half of the population of the Republic of Kazakhstan remains vulnerable, the importance of preventive strategies such as social distancing, the use of medical masks, and vaccination to protect the population from the transmission of SARS-CoV-2 is critical. The analysis of the data obtained showed the need for further research on a national scale to develop an effective strategy to monitor and curb the SARS-CoV-2 pandemic.

5.1 | Study limitations

This study has a few limitations. First, despite an important role in the pathogenesis of COVID-19, indicators of secretory IgA, as well as IgM and IgG were not included in the analysis. Second, all household members aged 5 years and older were included in the study that creates an additional cluster effect (caused by high infectivity of the SARS-CoV-2). The prevalence of antibodies to the virus in households was homogeneous. Therefore, if any member of the family became ill, the rest of the family was highly likely to become infected. Third, the study determined the prevalence of common antibodies to the SARS-CoV-2 virus, but not only neutralizing antibodies. Although the presence of common antibodies is highly correlated with the presence of neutralizing antibodies, the prevalence of common antibodies may not coincide with the prevalence of neutralizing antibodies. Thus, the sero-prevalence results cannot directly characterize the proportion of the population immune to COVID-19. Finally, some of the selected households or participants were not available to participate in the study, which could potentially be a source of selection bias.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

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DATA AVAILABILITY STATEMENT

All relevant data are included in the article.

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