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COVID-19 surveillance in fragile health systems, armed conflict and humanitarian crisis, the case of Yemen

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ABSTRACT

Background: Yemen is a poor country facing armed conflict which significantly disrupted the Health System. Yemen reported fewer COVID-19 cases than neighbouring countries, yet the case fatality rate (19.6%) remained five times the global average. Conflict typically hinders surveillance, however obtaining representative mortality and morbidity indicators remains essential to efficacious epidemic planning. We aimed to explore challenges hindering COVID-19 surveillance in Yemen and opportunities for addressing them, to increase surveillance effectiveness in such conflict and resource-constraint settings.

Methods: Qualitative study question guide was used for in-depth interviewswith 30 healthcare workers who worked in Yemen's surveillance system during the pandemic. Participants were recruited through in-country gatekeepers using a 'snowball' sampling technique. Thematic framework analysiswas used.

Findings: A basic level of preparedness existed following responses to previous epidemics, including activating Rapid Response Teams (RRTs), and electronic disease surveillance.

Key challenges included the ongoing conflict, an unstable health system, minimal infrastructure restorations, misinformation, community incompliance, and inadequate laboratory diagnostics or transportation capabilities. Participants recommended addressing these barriers through strengthening RRTs, transportation and laboratory testing capacities, implementing community awareness campaigns, alongside improving primary health care services and inter-governorate governance.

Conclusion: Active community surveillance by RRTs supplemented with community volunteers is imperative and necessary nationwide. National community awareness campaigns on case detection, reporting, and addressing misinformation are essential to implementing such community surveillance. Increased utilization of mobile laboratories could enhance laboratory testing capacity in underserved areas. For each recommendation to be effectively implemented, the international community must provide sufficient resources and financial aid.

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What does this study add?

- This study is important as it provides insight into why Yemen reported a low number of COVID-19 cases on the WHO dashboard, indicating a prevalence of 4% in Yemen, significantly lower than the 27.4% prevalence estimated by the sole seroprevalence study conducted there.
- Using Yemen as an example of a fragile health system operating in times of war and humanitarian crisis, this study examines barriers that hindered COVID-19 surveillance.
- The findings revealed the Yemeni surveillance system's unpreparedness to report COVID-19 cases and deaths during the pandemic, due to socio-cultural, capacity, financial, and political reasons, which significantly restricted performing both facility-based and community-based surveillance.
- The study identified what needs to be done to improve surveillance effectiveness in Yemen as an example of conflict- and resource-constrained settings for robust global pandemic control.

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Introduction

The COVID-19 pandemic has remained a global concern [1] since January 2020 when the World Health Organization (WHO) declared it a Public Health Emergency of International Concern [2–4]. By 18 October 2023, 771,407,825 confirmed cases, including 6,972,152 deaths, were reported to WHO [5] by over 200 countries [1, 6]. Several of these nations are Low-middle-income countries (LMICs) with limited surveillance resources, which delayed case reporting and identification when compared with high-income countries at different stages of the pandemic [6–9].

Surveillance involves a continuous, systematic collection, analysis, and interpretation of data about cases and deaths which is essential for pandemic control responses [10]. Maintaining functional surveillance systems is important to identify the COVID-19 burden, deaths, and long-term implications, as well as reducing transmission of infections [11–15]. The WHO guideline provides case definitions for confirmed, probable, and suspected cases, which allow for comparisons of the burden between countries [16]. Cases may be identified utilizing each component of the WHO surveillance framework: (1) monitoring suspect and probable cases, (2) community surveillance, and (3) active case finding, in addition to (4) laboratory testing data and (5) modelling, seroprevalence, and (6) mortality studies [17]. Modelling involves mathematical estimations of the epidemiological situation after considering transmission parameters alongside interventions' effectiveness, but its relevance decreases if health system capacity and other contextual factors are not properly considered [18]. Seroprevalence studies provide greater accuracy since they detect SARS-CoV-2 antibody prevalence in the community therefore incorporating asymptomatic and mild cases, hence their use in monitoring community transmission and case fatality rate [19]. While mortality studies provide an unbiased understanding of the epidemic impact by identifying total excess (direct and indirect) mortality and comparing variations in mortality with expected seasonal levels [20].

The WHO recommends immediate isolation of probable/suspected cases in epidemic situations, using Rapid Response Teams (RRTs) for case identification and obtaining samples for Polymerase Chain Reaction (PCR) testing [21]. WHO recommends ten days of isolation from COVID-19 positive results or symptoms onset [12, 15]. When testing is inaccessible or unaffordable, probable cases should be identified and isolated [6, 12, 16]. Home isolation is preferential for mild and moderate cases, whilst medical treatment is required for severe cases [12, 15]. Contacts of both probable and confirmed cases should be traced and quarantined for 14 days if they experienced face-to-face contact [12, 15, 22].

In epidemic situations, notifications of symptomatic cases (passive surveillance) should be complemented by active case finding (active surveillance) which involves proactive monitoring and identification of undetected cases within communities [14]. Community surveillance necessitates involving community members in detecting and reporting both suspected cases, and those who rely on self or alternative medication and are unwilling or unable to access health services [23]. Active surveillance enhances case identification and isolation, especially asymptomatic cases which account for 30% of infections, thus preventing further infection transmission if combined with testing [24]. Passive community surveillance (through volunteers or hotlines) complements routine surveillance and bolsters the early warning capability of health systems during epidemics [25]. Adequate testing capacity is essential for effective surveillance, and establishing a system for collecting and analysing laboratory data facilitates reliable epidemic monitoring and guidance of interventions [14].

Countries utilized multiple methods for case identification during the pandemic to prevent the rapid transmission of COVID-19, these included checking travellers' temperature and screening at border points, schools, universities, workplaces, health facilities, and other public spaces [22, 26–33]. Resource availability played a vital role in maintaining effective surveillance activities and thus proper case identification, reporting, and notification; inadequacies of such health and government resources remain a barrier and challenge to surveillance and pandemic control [8, 27–32, 34–37], especially within LMICs [6, 14, 31].

Yemen is a LMIC [38] facing political instability which predates the current war starting in 2014. Yemen consists of 22 governorates and 333 districts [39], yet the conflict has divided the nation further into several regions with different ideological and political directions [40, 41]. A resultant fragmented health system has developed, managed by two separate Ministries of Public Health and Population (MoPHP); one in Sanaa, which represents the Houthi authorities in the North, and one in Aden, which represents the Internationally Recognised Government (IRG) in the South [42–44]. Yemen faces the 'world's worst humanitarian crisis' [45] as many health, social, and educational facilities, including schools, citizens including healthcare workers, and infrastructure such as roads, water, and sanitation facilities have been targeted during the conflict [41, 46, 47]. This has disrupted numerous services, worsened living conditions therefore forcing external migration and internal displacement, and increased poverty, food insecurity, and severe undernutrition in Yemen [42, 48–51]. The first laboratory-confirmed COVID-19 case in Yemen was identified in April 2020 but community transmission was reported prior to this [52,53]. By 18 October 2023,

11,945 cases and 2159 death were reported in Yemen – lower than that reported in neighbouring countries such as Saudi Arabia which reported 841,469 cases and 9646 deaths throughout the same period [5].

The disrupted and fragile Health System in Yemen is expected to face challenges in undertaking surveillance, especially in the North governorates under the Houthi authorities [52,54,55]. However, the challenges of national fragmentation such as inadequate resources and technical capacity also resulted in few epidemic response interventions being implemented by the IRG MoPHP after the first case reported. Interventions which were implemented included establishment of a COVID-19 preparedness and response higher committee, closure of borders and airports with screening at entry points, restrictions on public gatherings and assignment of a few health facilites solely for COVID-19 cases [52]. Public health risk communications for the public and healthcare providers was also carried out, however healthcare workers raised concerns immediately about Personal protective equipment (PPE) and medical supplies shortages necessary to manage COVID-19 cases [52].

Borders between the South and North governorates have been partially closed since 2015, while those between the North and neighbouring countries have been completely closed due to political constraints [56, 57]. Therefore, neither the authorities in Aden or in Sana'a made rigourous efforts to close ports of entry when COVID-19 emerged. Weak inter-governorate governance between Yemen's dual MoPHP and government agencies, and coexistent epidemics compounded these issues by necessitating increased attention from international organizations and regional MoPHP departments and obstructing any strict lockdowns [58]. With 50% of the population reliant on water and sanitation aid, the majority of the poor population could not afford face masks or disinfectant products to reduce transmission, all whilst physical distancing was not being enforced [56].

Although surveillance activities are hampered in conflict settings, accuratel and updated mortality and morbidity indicators are critical for response planning, allocating limited resources, monitoring the effectiveness of response interventions, and supporting the advocacy for peacebuilding and post-conflict resolutions [59–61]. This study aims at exploring challenges to COVID-19 surveillance in Yemen as well as potential solutions to them, to contribute evidence on the rising surveillance effectiveness in Yemen and other conflict and resource-constraint settings.

Methods

Study population and period

Between June 2021 to June 2022, in-depth interviews were conducted with 30 healthcare workers who were involved with coordinating COVID-19 surveillance within Yemen. The intention was to include a nationally representative sample, for participants' safety it was not possible to recruit people in governorates under Houthi authorities as they restricted information sharing about COVID-19 [55]. Therefore the authors opted to purposively select surveillance staff in governorates outside the Houthi authority. However, to gather information about COVID-19 surveillance in governorates under Houthi authorities, our sample also included individuals who worked closely with the surveillance team in governorates under Houthi authorities during the COVID-19 pandemic. We explored preparedness and barriers to COVID-19 surveillance in both the South and North governorates of Yemen since the pandemic began in 2020. Therefore, the study findings represent the COVID-19 surveillance situation across various Yemeni governorates, although most participants were based at the time of interviews in governorates under the control of the IRG.

Sample and participant recruitment

A snowball purposive sampling was used to recruit potential participants through in-country gatekeepers who were healthcare workers familiar with surveillance teams in Yemen. In-person verbal informed consent witnessed by researchers was obtained for all participants. The participants were deemed an elite population due to the small population satisfying the inclusion criteria, therefore full anonymization could not be guaranteed which was stated within the consent form. Some individuals declined to participate but instead recommended others to be interviewed. Stated reasons for declining interviews included concerns about declaring surveillance information or being afraid to be identified by opposing forces.

The sample size was initially determined by the number of individuals who could be reached and met the inclusion criteria, alongside time constraints of the study; however the saturation point was reached after conducting 30 interviews [62, 63].

Data collection

Interviews were conducted (by SD, MB, and MS) online via Zoom video software, each lasting approximately 60 min. A question guide was used during interviews, generated using themes identified through a literature review of COVID-19 surveillance in LMICs. The guide contained pre-determined prompts to explore *a-priori* themes with participants. Areas of discussion included how their department performed surveillance in terms of RRTs, case identification and reporting, what the main challenges hindering surveillance were

and how best to address them, and awareness of the WHO RRTs training programme.

Participants were given opportunities to provide their answers to the study questions before or after the interview if they preferred, or recalled additional information post-interview, or needed more time to collect information. Each interview was audio-recorded then transcribed and analysed (by SD, MB, and MS) before conducting subsequent interviews.

Analysis

All the collected data was analysed using framework analysis [64] through NVivo-10 software, to identify both inductive and deductive themes [65]. A thematic framework table was developed using *a-priori* codes obtained through a literature review and *inductive* codes that emerged during analysis.

Findings

Participants' characteristics

Thirty participants were recruited from rural and urban, North and South Yemeni governorates, and the following categories were included: males and females, junior and senior surveillance staff, community surveillance officers, RRT members, district and governorate health officers, and laboratory technicians in COVID-19 testing centres. The number of years working in the surveillance system ranged from two to 18 among participants. Due to the political instability and the limited surveillance staff in Yemen, participants' characteristics have been disaggregated and names of governorates and sites omitted in this paper to maintain participants' confidentiality and safety.

Preparedness

This section explains the preparedness for COVID-19 surveillance in Yemen using the WHO framework.

The majority of participants explained that RRTs were established in 2017 in response to Cholera and Polio epidemics in both North and South governorates. Following the emergence of COVID-19, RRT capacity increased twofold in most South governorates, sufficient for one RRT per district although population density dictated their distribution. Each RRT comprise a minimum of five individuals: Director of the district health office, District surveillance coordinator, Doctor, Lab technician, and District health education coordinator. Some governorates deployed eight doctors/health assistants and eight lab technicians to supplement RRTs during the COVID-19 pandemic. Participants indicated that no changes were made to the quantity or training of the pre-existing RRTs in the governorates under Houthi authorities in response to COVID-19. Where RRTs were trained, the 'training of trainers' WHO online RRT training programme was utilized, several participants explained. However, RRT personnel training was conducted face-to-face due to inadequate internet connectivity – including COVID-19 training in March 2020. The role of RRTs is similar throughout all governorates, which is explained below:

> RRTs role is field investigation within 24 hours of receiving a report of a suspected case, to stabilise the early stage of the outbreak. – P.6

Most participants highlighted WHO suspected case management guidance was implemented. Suspected cases were reported to operations rooms in district MoPHP offices via health/isolation centres or community hotlines. RRTs were dispatched to investigate, and take swabs for testing when available and the case definition was satisfied. RRTs also identified and informed close contacts to isolate for 14 days. Moderate and severe cases were then admitted to isolation centres and tertiary hospitals respectively. Mild cases were informed to complete ten days home isolation, with daily monitoring through visits or telephone.

Most participants explained WHO COVID-19 case definitions were utilized nationally. However, the North's definition was inaccurate initially some participants revealed, before modification by WHO with advice from Yemeni doctors in the diaspora.

Each participant revealed COVID-19 hotlines were established to facilitate suspected case notification within communities in various South and North governorates. However, nationwide initiatives to complement hotlines for community surveillance were not highlighted. Some participants explained community education was problematic at first, undertaken through social media within some South governorates.

> Yemen is relying on social media to raise awareness - can you imagine what it is like. – P.2

Most participants emphasized active and passive surveillance was being performed in the South, with an increased attentiveness on active case finding since 2021. Yet beyond contact tracing, no participants discussed further initiatives to bolster active surveillance, in both the North and South. However, limited RRT and diagnostics capacities significantly weakened the capability for active surveillance across the country given symptomatic suspected cases received testing prioritization.

Insufficient PCR laboratory capacity was stressed by most participants, with five PCR machines available nationwide initially. By July 2021, PCR capacity had increased to ten laboratories across the country. Several participants cited the existence of the electronic Integrated Disease Early Warning System (eIDEWS),

a health-facility-based surveillance system established in 2013 utilized for the surveillance of 28 notifiable diseases. Within eIDEWS, aggregated health-facility data facilitates early outbreak detection through either 24-hour notification alerts or weekly epidemiological bulletins depending on the disease.

> By distributing mobiles in health facilities, they have a system to send electronic reports to district level every Sunday then to governorate level then MoPHP level every Monday. – P.13

However, some participants explained that eIDEWS was not modified for COVID-19 surveillance across the country, with a reliance upon hotlines and presentation at health/isolation centres.

Several participants revealed that one seroprevalence study was, funded by WHO and its partners, performed only in one of the South governorates, Aden, in December 2020. The prevalence of SARS-CoV-2 antibodies was 27.4%. No participants discussed mathematical modelling utilization in COVID-19 surveillance. Since case reporting was not properly performed across the country, it appeared that modelling was not considered in Yemen. Similarly, participants were not aware of any mortality studies used in Yemen.

Challenges to surveillance

All participants stressed ongoing conflict remained the fundamental barrier to surveillance, with numerous challenges experienced occurring secondary to it. Several participants highlighted its impact on governance, producing weakened inter-governorate coordination between policymakers, exacerbating the challenges WHO faced as intermediaries.

> Scattered, interrupted, not strong – everyone is working as if it's a Federation, but without state governors. – P.22

Poor community engagement with RRTs and containment measures including self-isolation and contact quarantine was highlighted by most participants. Several participants cited this responsible for the fatigue in RRT contact follow-up. Numerous participants also accredited this to Yemen's unsustainable economic climate and resultant fight for survival, with face-mask prices rising ten-fold since COVID-19 emerged.

> People are dying from starvation, from diseases like Malaria and Cholera. People have no salaries – what is COVID-19 in front of all this? – P.12

Further explanations included weak community health education campaigns, especially in the North with their policy of not transparently declaring cases and societal stigmatization of COVID-19 existed.

> The North's decision to not declare cases makes gaining community support harder because you cannot support if there is no declaration of cases. – P.25

The majority of participants classified challenges concerning RRTs into inadequate skill sets due to suboptimal training provisions, or insufficient quantities since concurrent epidemics including Cholera required resources. It was explained that some large districts are covered by few RRTs, for example, one large governorate had only two RRT members responsible for contact tracing 275,000 people. Most participants accredited this deficiency to a lack of salaries/incentives, with RRTs frequently going months without payment or seldom receiving reduced amounts.

> Sometimes they receive payments quarterly, but only 50% of one month's payment which is nothing – especially as exchange rates leave this without real value. – P.15

The majority of participants stated Yemen's deteriorated health system presented a critical barrier, with 50% of health facilities functional due to conflict-related infrastructural damage. This reduced accessibility resulted in suspected cases often remaining unreported, by not engaging with health services because of extensive travel distances.

> The war has led to the deterioration of the health system, with the closure of many health facilities, making surveillance much more difficult. – P.16

The majority of participants explained war displacement or casualties, and absent salary provisions have created an insufficient health workforce. With insufficient RRT capacity for comprehensive active surveillance, passive surveillance through health facilities remained the primary approach. However, participants revealed many exceedingly overstretched health workers often failed to report cases.

Shortages in PCR machines, reagents, swabs, and rapid diagnostics were a barrier the majority of participants stated, confining tests to highly suspected cases. Symptomatic testing prioritization had considerable implications for case detection due to asymptomatic COVID-19 transmission. Initial difficulties distinguishing COVID-19 from endemic febrile illnesses including dengue fever was highlighted by several participants, however, implementation of WHO COVID-19 case definitions reduced this. Several participants revealed some governorates relied upon wealthy diaspora donors to increase testing capacity during the pandemic.

Several participants discussed transportation challenges, particularly in rural areas, including few MoPHP vehicles capable of traversing poor-quality roads worsened by floods and conflict. Delays resulted for RRTs undertaking case management, contact

tracing, and transporting test samples to laboratories therefore prolonging test turnaround time. According to numerous participants, medical and diagnostic supplies distribution from WHO stores presented logistical challenges, especially between the North and South due to frequent checkpoints, or conflicted zones where vehicles were frequently intercepted.

> There are many hot zones throughout this journey [Aden WHO stores to another governorate] where cars have been stolen or not allowed passage. – P.11

The majority of participants stated denial and misinformation hindered surveillance. In the North, participants explained this originated from the policymaker's strategy of COVID-19 denial and non-declaration of cases – attributed to conflict prioritization. No participants highlighted this issue in the South. Further explanations for misinformation participants identified were the impact of poverty on education, and existing greater threats to life including malnutrition. Misinformation including RRTs receiving money-per-case and health workers intentionally killing COVID-19 patients, reduced engagement with health facilities and hotlines resulting in significant case underreporting.

> When people are in such a situation, they are willing to trust rumours more than facts – it is a defence mechanism. – P.5

Methods to address challenges

Some participants explicitly proposed conflict resolution to improve surveillance. However, it is improbable most participants do not believe this is the principal solution, but rather prioritized more attainable interventions.

> Addressing the conflict and political situation will be the key to dealing with the COVID-19 situation as in other countries. – P.23

An emphasis on strengthening governance of COVID-19 surveillance amongst all 22 governorates was recommended by several participants. By establishing continuous communication pathways between regional policymakers, the finite human and diagnostic resources could be redistributed as acutely required.

> There are the resources in Yemen, it's the lack of resourcefulness – they are not used properly. – P.13

Some participants stressed the necessity to establish comprehensive community health education campaigns. Through national dissemination of WHO case definitions, plus how to report (via isolation centres and hotlines) and manage suspected cases, participants explained early case detection could increase by utilizing enhanced community surveillance.

> Raise awareness amongst the community – this is the most important step. Reassuring them this disease can be prevented by very simple measures. – P.14

Numerous participants emphasized misinformation and stigmatization should simultaneously be addressed. However, policymakers in the North acknowledging COVID-19 as a public health emergency remained a prerequisite to such initiative's implementation. Several participants described isolated communication education initiatives within South governorates, through religious leaders during Friday prayer alongside schools and radio stations. The augmentation of such initiatives is fundamental to achieving effective community surveillance.

An emphasize on building RRTs' capacity was discussed by the majority of participants, optimally through increased recruitment; however, funding constraints could obstruct this. Therefore, participants proposed RRT COVID-19 refresher training and skills evaluation as a more feasible solution. WHO online training programmes could be utilized at MoPHP offices where internet connectivity has greater stability. However, guaranteed salary protection remained a crucial determinant several participants discussed.

> We either need to renew some of the RRTs or reinforce their skills with more training – this is the issue. – P.24

Several participants recommended revising Yemen's eIDEWS for COVID-19 surveillance. Automated suspected case alerts could be sent as SMS messages to RRTs' mobile devices to accelerate case management, whilst simultaneously producing a centralized computer database to facilitate real-time mathematical modelling. Alerts could be inputted from health centres already familiar with eIDEWS to develop sentinel surveillance capacity.

In terms of infrastructure regeneration, most participants suggested prioritizing primary care facilities since many are well located, especially within rural communities. Therefore, they remained the primary point of contact for suspected cases. RRTs could utilize them as centres to perform active surveillance and community health education from. Several participants proposed primary care facilities for the training of community health workers (CHWs) in 'monitoring suspected and probable cases' and 'active case finding', to mitigate RRT capacity deficiencies. CHWs possess pre-existing community networks, therefore, are trusted personnel more likely to attain community engagement.

Ensuring a consistent, equitable distribution of swabs and reagents many participants believed would maximize testing capacity utilization. The majority of participants endorsed mobile laboratory deployment, notably within rural and underserved areas. This could minimize sample transportation

barriers, reducing test turnaround time to facilitate earlier case detection. Several participants stressed a protocol for rapid diagnostics utilization by RRTs is necessary, to improve active surveillance of contacts whilst responding to community alerts.

> Mobile laboratories would allow us to detect cases in hard-to-reach areas at a much faster rate. – P.17

Several participants recommended expanding four-wheel drive vehicle provisions for RRTs to enable traversing difficult terrains for case investigation and contact tracing. Such provisions could simultaneously improve test sample delivery and diagnostics supply chains intra- and inter-governorate participants explained.

> We must provide a four-wheel drive vehicle for active surveillance visits and case investigation work. – P19

Discussion

By 18 October 2023, only 11,945 COVID-19 cases and 2159 COVID-19 deaths were reported in Yemen [5], where 31,450,179 inhabitants live [66]. The reported cases therefore indicate a 4% prevalence in the country, which is significantly lower than the 27.4% prevalence estimated by the only seroprevalence study conducted in Yemen [67]. Although this seroprevalence study was implemented only in one city, it was implemented by the MoPHP and the WHO in Aden, the second most populous city, thus could be used to estimate COVID-19 prevalence nationwide [67]. Using satellite imagery, 2000–2400 excess cemetery burials were identified in Aden compared to recorded mortality in April-September 2020 [68]. This demonstrates the significant increase in mortality during the early stage of the pandemic. Another study identified evidence of a peak in adult mortality before and during the first wave of the COVID-19 pandemic in nine communities of Yemen, although the estimation was imprecise [51]. Our findings revealed the unpreparedness of the surveillance system in Yemen to report COVID-19 cases and deaths during the pandemic, especially in areas under the Houthi authorities.

Despite none of the participants highlighting mortality study utilization in surveillance in Yemen, two mortality studies about Yemen were conducted and published during our data collection period [51, 68]. This demonstrates the poor coordination between individuals who work in estimating the burden of COVID-19 in Yemen.

We identified the absence of large-scale active and community surveillance initiatives, except in urban settings of one governorate, which was the most active in COVID-19 surveillance across the country. Active surveillance was successfully implemented in camps for internally displaced people, where a high population density accelerates transmission [69]. Similar initiatives showed effectiveness in Ebola epidemic surveillance in Western Africa [70].

We identified several barriers that hampered COVID-19 surveillance in Yemen and methods to address them, see Figure 1. We identified that stigmatization and misinformation increase community resistance and incompliance with preventive measures including cooperation with RRTs, which greatly hinders surveillance. Studies have emphasized the challenges stigmatization and misinformation presented during the early stage of the pandemic in Yemen [71] and other LMICs [72], especially those also facing civil war such as South Sudan [73]. Addressing stigmatization and misinformation is critical to gain community trust, which played an important role in

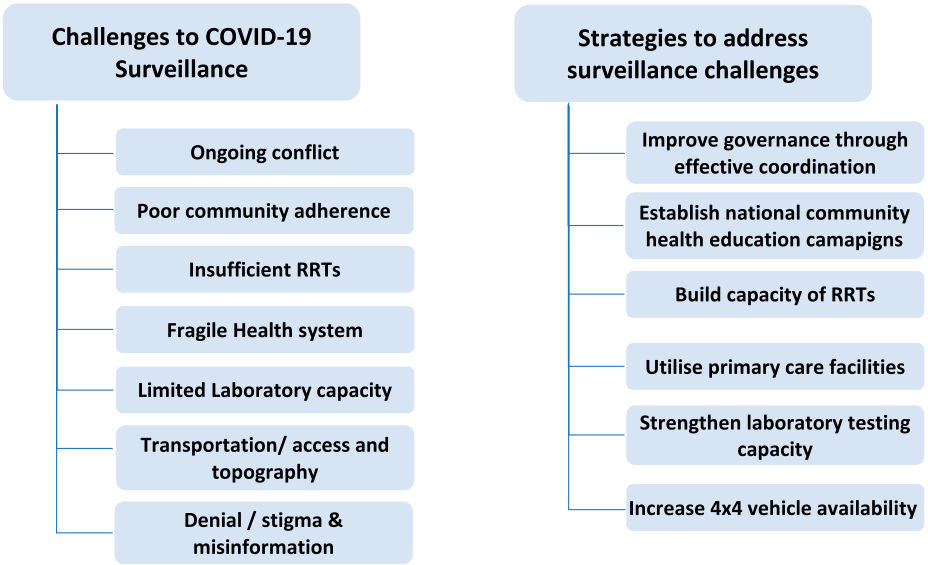

Figure 1. Challenges and opportunities of COVID-19 surveillance in Yemen.

surveillance successes during the Ebola epidemic in LMICs including Sierra Leone [74].

The insufficient quantity and capacity of RRTs challenged case reporting in Yemen, as both this and a comparable study [75] identified. A web-based survey [76] identified testing inaccessibility and poor testing capacity in Yemen, as only 1.6% of respondents who reported COVID-19 symptoms were able to access PCR testing and tested positive; however, self-reporting reduced the findings' validity. This poor laboratory capacity restricted testing and confirmation of cases even among severe and highly suspected cases, therefore, most COVID-19 cases remained probable and unconfirmed [71, 75]. Poor testing capacity and inaccessibility are challenges shared among LMICs [14]. This challenge could explain why the COVID-19 case fatality rate in Yemen is 19.6% which is five times the global average and the highest in the Middle East [77].

Health facility closures due to infrastructural damage, shortages of medical supplies and PPE, as well as unmaintainable funding for the health system hindered COVID-19 surveillance significantly in Yemen. These issues challenge overall health care provisions, predating the pandemic [58]. For example, out of the $304.6 million minimum-required fund, only 27.4% was available in 2020 [77]. These weakened health service provisions and overburdened healthcare workers contributed to the overlooking of COVID-19 case reporting and high case fatality rate. Poor health financing resulted in the lack of incentives and regular salary provisions for healthcare workers and hindered recruiting RRTs during the pandemic, as this and other literature determined [75, 78]. There are no doctors in 18% of Yemen districts and many doctors in other districts have been unpaid for over two years [78]. Together, these factors significantly restricted performing even facility-based passive surveillance.

The importance of strengthening COVID-19 surveillance governance is a key finding in this and other studies in Yemen [79] and other LMICs [80]. To alleviate these governance issues, WHO and its partners issued a 'Task Force' for coordinating, tracking, and proceeding the delivery of COVID-19 diagnostics, therapeutics, and vaccines within LMICs in June 2021 [80]. This was intended to provoke an urgent 'trickle-down', tangible effect in Yemen. However similar to other incoming aid, the impact was hindered by frequent bombings in Hodaydah port city where 90% of fuel supplies, incoming humanitarian aid, and commercial food passes through.

Most participants emphasized the importance of implementing community awareness campaigns to improve community compliance and strengthen community surveillance. The literature indicates the positive impact and feasibility of implementing this intervention in Yemen [69, 81], other LMICs such as India [82], and nations facing conflict such as Syria [83]. Rapid diagnostics were recommended alongside seroprevalence testing to mitigate suboptimal sensitivity in this WHO framework component, together with mobile laboratories [84]. Mobile laboratories have been introduced effectively at strategic roads/border points by a network of six East African countries [6]. The first mobile laboratory donations were approved by Abu Dhabi in June 2021, providing a positive addition for Yemen [85]. Senior surveillance personnel in some LMICs also advocated for facilitating COVID-19 surveillance via eIDEWS, although the lack of internet connectivity may hinder its effectiveness in LMICs [86]. This is applicable to the context of Yemen where poor electricity and internet connectivity is an issue even within the main cities.

Limitations

We interviewed solely the surveillance staff which may have limited their ability to express weakness in the current surveillance system, as highlighting weaknesses might be interpreted as them not completing their work properly. Interviewing community members and comparing their views against the surveillance teams could have provided better insight into the challenges of COVID-19 surveillance. Recruiting participants using the 'snowball' technique and senior surveillance gatekeepers is a limitation and might have created bias in sample selection. Our virtual data collection methodology restricted recruitment of surveillance staff in remote and rural areas where internet and electricity supply are continuously interrupted, which might have affected the sample characteristic. However, in-country data collection was infeasible given the ongoing conflict, travel restrictions during the pandemic, and the political unacceptability of COVID-19 discussion in the areas under the Houthi authority.

To check the accuracy and reliability of the provided information about the COVID-19 situation in the governorates under the Houthi authority, participants were required to provide specific examples which were examined for accuracy in further interviews with other participants. However, the inability to confirm the accuracy and reliability of the provided information with the surveillance teams in these governorates due to political reasons remains a limitation of our findings.

Conclusion

It is inevitably challenging to coordinate robust COVID-19 surveillance within Yemen's current unstable environment. As a result of prior epidemics, some level of preparedness had already been established in Yemen, including RRTs and electronic disease surveillance. However, the remaining challenges posed significant barriers to strengthening surveillance for COVID-

19, these include limited infrastructural regeneration, improper transportation provisions, an unstable health system, inadequate laboratory testing capacity, insufficient qualified RRTs, and community incompliance together with widely spread misinformation.

Due to the current economic situation, political instability, and limited resources in Yemen, participants focused on bolstering community-based interventions to address these barriers. To establish effective active community surveillance, community awareness campaigns should be expanded nationwide. Effective surveillance equally requires improved intergovernorate governance, enhancing testing capacity, and increasing the number and capacity of surveillance staff.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributors

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Dr Sean Donnelly is a Foundation Year 1 Doctor who currently works at Tameside General Hospital in Manchester, England. In 2023, he graduated from the University of Leeds completing his Bachelor of Medicine, Bachelor of Surgery (MBChB) degree. Between 2020 and 2021, Sean also obtained a First Class Intercalated BSc degree in International Health at the University of Leeds, a course which was delivered in collaboration with the Nuffield Centre for International Development. His dissertation focused upon COVID-19 surveillance in Yemen, investigating and exploring the country's preparedness for the pandemic, the challenges faced and opportunities to address them through in-depth interviews. He presented the findings of this research at the Fifth National Yemen Field Epidemiology Training Programme conference in 2021. At local and national conferences, Sean has presented his research on the impact of the COVID-19 pandemic on A&E mental disorder referrals to Liaison Psychiatry in Wakefield, UK. This research compared pre- and post-pandemic referral patterns to help identify population sub-groups whose mental health was most impacted by the COVID-19 pandemic, to assist service provision planning and address health inequalities. Sean currently has ambitions of applying for the Acute Care Common Stem (ACCS) training programme after completion of the Foundation Programme in 2025. Although he maintains a key interest in the field of Public Health and wishes to continue working on academic research in this field, with aspirations to integrate this work into his future career.

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Dr Dhekra Amin Annuzaili is a pediatrician and public health specialist with over 25 years' professional experience in health and human development at the project and country levels in the MENA region. Her engagement spanned governments, UN agencies, donors, and key partners in the development and analysis of polices, strategies, technical and operational guidelines and research; she has also pioneered the identification of innovative and strategic approaches to program delivery based on a human right framework and multi-sectoral approaches to human capital development. Dhekra has provided key contributions and proposed innovative solutions in project management areas covering health systems, population, nutrition, and neglected tropical diseases (NTDs). She has assisted regional

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Dhekra has a solid employment track record spanning international and UN agencies, projects, and initiatives (i.e., UNICEF, World Bank, Schistosomiasis Control Initiative/ Imperial College London) and international consulting missions (WHO-EMRO, WFP Regional, FHI360/USAID, EU and LNGOs). She has also served as the NTDs' program manager for L&MICs (Yemen & Sudan) and consulted on key health projects and initiatives in Egypt, Sudan, Tajikistan, and several Eastern Mediterranean countries. Currently she is a free-lance senior public health and human peace nexus development senior consultant working on the Update Of MASNAP-II (Multisectoral Nutrition Action Plan) funded by UNICEF and led by SUN Yemen.

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References

[1] WHO. (2022). Novel coronavirus (2019-nCoV) situation reports [cited 2022 Dec 12]; Available from: WHO Coronavirus (COVID-19) Dashboard | WHO Coronavirus (COVID-19) Dashboard With Vaccination Data.

[2] WHO. (2020). Statement on the second meeting of the International Health Regulations (2005) Emergency Committee regarding the outbreak of novel coronavirus (2019-nCoV). [cited 2022 Dec 12]; Available from: https://tinyurl.com/2c6(9psn

[3] Cucinotta D, Vanelli M. WHO declares COVID-19 a pandemic. Acta Biomed. 2020;91(1):157–160.

[4] Sohrabi C, Alsafi Z, O'Neill N, et al. World Health Organization declares global emergency: a review of the 2019 novel coronavirus (COVID-19). Int J Surg. 2020;76:71–76. doi:10.1016/j.ijsu.2020.02.034

[5] WHO. (2022). WHO coronavirus (COVID-19) dashboard. [cited 2022 Dec 22]. Available from: https://covid19.who.int/

[6] Tyrovolas S, Giné-Vázquez I, Fernández D, et al. Estimating the COVID-19 spread through real-time population mobility patterns: surveillance in Low- and middle-income countries. J Med Internet Res. 2021;23(6):e22999, doi:10.2196/22999

[7] Bong C-L, Brasher C, Chikumba E, et al. The COVID-19 pandemic: effects on low-and middle-income countries. Anesth Analg. 2020;131(1):86–92.

[8] Henry R. COVID-19 in Latin America: a humanitarian crisis. Lancet. 2020;396(10261):1463. doi:10.1016/S0140-6736(20)32328-X

[9] Bagaria J, Jansen T, Marque DF, et al. Rapidly adapting primary care sentinel surveillance across seven countries in Europe for COVID-19 in the first half of 2020: strengths, challenges, and lessons learned. Eurosurveillance. 2022;27(26):2100864.

[10] WHO. (2021). Surveillance in emergencies [cited 2021 Jul 15]. Available from: https://www.who.int/emergencies/surveillance

[11] Alwan NA. Surveillance is underestimating the burden of the COVID-19 pandemic. Lancet. 2020;396(10252):e24.

[12] WHO. (2020). Public health surveillance for COVID-19: interim guidance, 7 August 2020 [cited 2022 Dec 22]. Available from: https://www.who.int/publications/i/item/who-2019-nCoV-surveillanceguidance-2020.7

[13] Caruana G, Croxatto A, Coste AT, et al. Diagnostic strategies for SARS-CoV-2 infection and interpretation of microbiological results. J Clin Microbiol Infect. 2020;26(9):1178–1182. doi:10.1016/j.cmi.2020.06.019

[14] Ibrahim NK. Epidemiologic surveillance for controlling COVID-19 pandemic: types, challenges and implications. J Infect Public Health. 2020;13(11):1630–1638. doi:10.1016/j.jiph.2020.07.019

[15] WHO. (2022). COVID-19 technical guidance: Surveillance strategies for COVID-19 human infection [cited 2022 Dec 22]. Available from: https://www.who.int/publications/i/item/surveillance-strategies-for-covid-19-human-infection

[16] WHO. Public health surveillance for COVID-19: Interim Guidance 16th December 2020. Geneva.: World Health Organization; 2020.

[17] WHO. Laboratory testing strategy recommendations for COVID-19: interim guidance, 21 March 2020. World Health Organization; 2020.

[18] Metcalf CJE, Morris DH, Park SW. Mathematical models to guide pandemic response. Science. 2020;369(6502):368–369. doi:10.1126/science.abd1668

[19] Public Health England. (2020). Public Health England - research and analysis: sero-surveillance of COVID-19 [cited 2021 Jul 7]. Available from: https://www.gov.uk/government/publications/national-covid-19-surveillance-reports/sero-surveillance-of-covid-19

[20] Michelozzi P, de'Donato F, Scortichini M, et al. Temporal dynamics in total excess mortality and COVID-19 deaths in Italian cities. BMC Public Health. 2020;20(1):1238–1245. doi:10.1186/s12889-020-09335-8

[21] WHO. (2021). Contact tracing in the context of COVID-19 Interim Guidance 1 February 2021. [cited 2022 Mar 5]. Available from: https://www.who.int/publications/i/item/contact-tracing-in-the-context-of-covid-19

[22] Gupta R, Dhamija RK. COVID-19: social distancing or social isolation? Br Med J. 2020;369:m2399.
[23] Kuehne A, Keating P, Polonsky JA, et al. Event-based surveillance at health facility and community level in low-income and middle-income countries: a systematic review. BMJ Global Health. 2019;4(6):1–15.
[24] Johansson MA, Quandelacy TM, Kada S, et al. SARS-CoV-2 transmission from people without COVID-19 symptoms. JAMA Network Open. 2021;4(1):1–8.
[25] Guerra J, Acharya P, Barnadas C. Community-based surveillance: a scoping review. PLoS One. 2019;14 (4):1–25. doi:10.1371/journal.pone.0215245
[26] Pan A, Liu L, Wang C, et al. Association of public health interventions with the epidemiology of the COVID-19 outbreak in Wuhan, China. JAMA. 2020;323(19):1915–1923. doi:10.1001/jama.2020.6130
[27] Burki T. COVID-19 in Latin America. Lancet Infect Dis. 2020;20(5):547–548. doi:10.1016/S1473-3099 (20)30303-0
[28] Gilbert M, Pullano G, Pinotti F, et al. Preparedness and vulnerability of African countries against importations of COVID-19: a modelling study. Lancet. 2020;395(10227):871–877.
[29] Schellekens P, Sourrouille DM. COVID-19 mortality in rich and poor countries: a tale of two pandemics? World Bank Policy Research Working Paper; 2020 (9260).
[30] Tariq A, Lee Y, Roosa K, et al. Real-time monitoring the transmission potential of COVID-19 in Singapore. BMC Med. 2020;18(1):1–14. doi:10.1186/s12916-019-1443-1
[31] Han E, Jin Tan MM, Turk E, et al. Lessons learnt from easing COVID-19 restrictions: an analysis of countries and regions in Asia Pacific and Europe. Lancet. 2020;396(10261):1525–1534.
[32] Sun K, Chen J, Viboud C. Early epidemiological analysis of the coronavirus disease 2019 outbreak based on crowdsourced data: a population-level observational study. Lancet Digital Health. 2020;2(4):e201–e208. doi:10.1016/S2589-7500(20)30026-1
[33] Pung R, Chiew CJ, Young BE, et al. Investigation of three clusters of COVID-19 in Singapore: implications for surveillance and response measures. Lancet. 2020;395(10229):1039–1046.
[34] Bojorquez I, Cabieses B, Arósquipa C, et al. Migration and health in Latin America during the COVID-19 pandemic and beyond. Lancet. 2021;397(10281):1243–1245.
[35] Anyanwu JC, Salami AO. The impact of COVID-19 on African economies: an introduction. Afr Dev Rev. 2021;33(Suppl 1):S1.
[36] Miguel E, Mobarak AM. The economics of the COVID-19 pandemic in poor countries. Annu Rev Econom. 2022;14:253–285. doi:10.1146/annurev-economics-051520-025412
[37] Afriyie DK, Asare GA, Amponsah SK, et al. COVID-19 pandemic in resource-poor countries: challenges, experiences and opportunities in Ghana. J Infect Dev Ctries. 2020;14(08):838–843. doi:10.3855/jidc.12909
[38] WB. (2023). World databank: World development indicators, Yemen [cited 2023 Jan 4]. Available from: https://data.worldbank.org/country/YE
[39] Dureab F. Diphtheria outbreak in Yemen: the impact of conflict on a fragile health system. Confl Health. 2019;13(1).
[40] AlKarim T, Abbara A, Attal B. Armed conflict alone does not explain the devastation of Yemen's health system. BMJ Global Health. 2021;6(2):e004740.
[41] Maxwell D, Hailey P, Kim JJ, et al. Constraints and complexities of information and analysis in humanitarian emergencies evidence from Yemen. Boston.: Feinstein International Center, Tufts University; 2019.
[42] Qirbi N, Ismail SA. Health system functionality in a low-income country in the midst of conflict: the case of Yemen. Health Policy Plan. 2017;32(6):911–922. doi:10.1093/heapol/czx031
[43] Dureab F, Hussain T, Sheikh R, et al. Forms of health system fragmentation during conflict: the case of Yemen. Front Public Health. 2021: 805.
[44] Situation of human rights in Yemen, including violations and abuses. (2019). Group of eminent international and regional experts on Yemen.
[45] United Nations. (2021). Yemen crisis: key facts [cited 2021 Jul 13]. Available from: https://una.org.uk/yemen-crisis-key-facts
[46] Tandon S, Vishwanath T. How well is humanitarian assistance targeted in fragile environments? evidence from the announcement of a food emergency in Yemen. Food Policy. 2021;102:102071, doi:10.1016/j.foodpol.2021.102071
[47] Elkahlout G, Milton S, Yaseen T, et al. Localisation of humanitarian action in war-torn countries: the experience of local NGOs in Yemen. Int J Disaster Risk Reduct. 2022;75:102921, doi:10.1016/j.ijdrr.2022.102921
[48] TLG H. Yemen needs a concrete plan—now. Lancet Glob Health. 2019;7(1):e1, doi:10.1016/S2214-109X (18)30536-9
[49] Hess W. (2019). Four years of conflict: Analysis of the violence and the humanitarian response in Yemen.
[50] ECFR. (2018). The Marib paradox: how one province succeeds in the midst of Yemen's war [cited 2021 Jul 15]. Available from: https://ecfr.eu/publication/the_marib_paradox_how_one_province_succeeds_in_the_midst_of_yemens_war/
[51] Alhaffar M, Basaleem H, Othman F, et al. Adult mortality before and during the first wave of COVID-19 pandemic in nine communities of Yemen: a key informant study. Confl Health. 2022;16(1):63, doi:10.1186/s13031-022-00497-3
[52] Dureab F, Al-Awlaqi S, Jahn A. COVID-19 in Yemen: preparedness measures in a fragile state. Lancet Public Health. 2020;5(6):e311, doi:10.1016/S2468-2667 (20)30101-8
[53] Besson ESK, Norris A, Bin Ghouth AS, et al. Excess mortality during the COVID-19 pandemic: a geospatial and statistical analysis in Aden governorate, Yemen. BMJ Global Health. 2021;6:e004564, doi:10.1136/bmjgh-2020-004564
[54] Karamouzian M, Madani N. COVID-19 response in the Middle East and North Africa: challenges and paths forward. Lancet Glob Health. 2020;8(7):e886–e887. doi:10.1016/S2214-109X(20)30233-3
[55] Al-Hamdani R, Wilson R. (2020). Yemen's response to COVID-19: Part I [Online]. [cited 2023 Mar 21]. Available from: https://peacerep.org/2020/07/27/yemens-response-to-covid-19-part-i/
[56] Noushad M, Al-Saqqaf I. COVID-19: is herd immunity, the only option for fragile Yemen? Int J Infect Dis 2021;106; doi:10.1016/j.ijid.2021.03.030. Statement from UNICEF Executive Director Anthony Lake and WHO.
[57] Alsabri M, Nightingale B, Amin M, et al. When COVID-19 hit Yemen: dealing with the pandemic in a country under pressure from the world's worst

humanitarian crisis. Global J Med Public Health. 2020;9(2):1–6.
[58] Al-Awlaqi S, Dureab F, Annuzaili D, et al. COVID-19 in Conflict: the devastating impact of withdrawing humanitarian support on universal health coverage in Yemen. Public Health Pract (Oxf). 2020;1:100015, doi:10.1016/j.puhip.2020.100015
[59] Checchi F, Warsame A, Treacy-Wong V, et al. Public health information in crisis-affected populations: a review of methods and their use for advocacy and action. Lancet. 2017;390:2297–2313. doi:10.1016/S0140-6736(17)30702-X
[60] Checchi F, Les R. Documenting mortality in crises: what keeps US from doing better? PLoS Med 2008;5:e146. doi:10.1371/journal.pmed.0050146
[61] Jawad M, Hone T, Vamos EP, et al. Estimating indirect mortality impacts of armed conflict in civilian populations: panel regression analyses of 193 countries, 1990–2017. BMC Med. 2020;18:266. doi:10.1186/s12916-020-01708-5
[62] Fusch PI, Ness LR. Are we there yet? Data saturation in qualitative research. Qual Rep. 2015;20(9):1408.
[63] Malterud K, Siersma VD, Guassora AD. Sample size in qualitative interview studies. J Qual Health Res. 2016;26(13):1753–1760. doi:10.1177/1049732315617444
[64] Gale NK, Heath G, Cameron E, et al. Using the framework method for the analysis of qualitative data in multi-disciplinary health research. BMC Med Res Methodol. 2013;13(1):117), doi:10.1186/1471-2288-13-117
[65] Green J, Thorogood N. Qualitative methods for health research. 3rd ed. London: Sage Publications; 2014.
[66] WB. World databank: total population of Yemen, Republic 2022 [cited 2022 Dec 25]. Available from: https://data.worldbank.org/country/YE
[67] MoPHP, et al. (2021). SARS-CoV-2 Seroprevalence-Aden, Yemen 2021 [cited 2021 Jul 7]. Available from: https://www.humanitarianresponse.info/sites/www.humanitarianresponse.info/files/documents/files/10.03.2021_minutes_of_covid_19_response_meeting_english.pdf
[68] Koum Besson ES, Norris A, Ghouth ASB, et al. Excess mortality during the COVID-19 pandemic: a geospatial and statistical analysis in Aden governorate, Yemen. BMJ Global Health. 2021;6(3):4564–4573.
[69] Baaees MSO, Schantz C, Traoré B, et al. In the era of humanitarian crisis, young women continue to die in childbirth in Mali. Confl Health. 2021;15(1):1–15. doi:10.1186/s13031-020-00334-5
[70] Namukose E, Bowah C, Cole I, et al. Active case finding for improved Ebola virus disease case detection in Nimba County, Liberia, 2014/2015: lessons learned. Adv Public Health. 2018;2018(1):1–7.
[71] Al-Waleedi AA, Naiene JD, Thabet AAK, et al. The first 2 months of the SARS-CoV-2 epidemic in Yemen: analysis of the surveillance data. PLoS One. 2020;15(10):e0241260.
[72] Chowdhury R, Luhar S, Khan N, et al. Long-term strategies to control COVID-19 in low and middle-income countries: an options overview of community-based, non-pharmacological interventions. Eur J Epidemiol 2020;35(8):743–748. doi:10.1007/s10654-020-00660-1
[73] Waya J, Lako R, Bunga S, et al. The first sixty days of COVID-19 in a humanitarian response setting: a descriptive epidemiological analysis of the outbreak in South Sudan. Pan Afr Med J. 2020;37(384):1–5.
[74] Boland S, Polich E, Connolly A, et al. Overcoming operational challenges to ebola case investigation in Sierra Leone. Glob Health Sci Pract. 2017;5(3):456–467. doi:10.9745/GHSP-D-17-00126
[75] Devi S. Fears of "highly catastrophic" COVID-19 spread in Yemen. Lancet. 2020;395(10238):1683.
[76] Dhabaan G, Chahin A, Buhaish A, et al. COVID-19 pandemic in Yemen: a questionnaire based survey, what do we know? J Infect Dev Ctries. 2020;14(12):1374–1379. doi:10.3855/jidc.13966
[77] WHO. COVID-19 situation updates for week 26 (27 June - 3 July). Cairo: World Health Organization Eastern Mediterranean Regional Office; 2021.
[78] Looi M-K. COVID-19: deaths in Yemen are five times global average as healthcare collapses. Br Med J. 2020;370(1):2997.
[79] Noushad M, Al-Saqqaf IS. COVID-19 case fatality rates can be highly misleading in resource-poor and fragile nations: the case of Yemen. Clin Microbiol Infect. 2021;27(4):509–510. doi:10.1016/j.cmi.2021.01.002
[80] WHO. (2021). First meeting of the task force on COVID-19 vaccines, therapeutics and diagnostics for developing countries.
[81] Dahab M, van Zandvoort K, Flasche S, et al. COVID-19 control in low-income settings and displaced populations: what can realistically be done? Confl Health. 2020;14(1):1–6. doi:10.1186/s13031-019-0247-4
[82] Menon JC, Rakesh PS, John D, et al. What was right about Kerala's response to the COVID-19 pandemic? BMJ Global Health. 2020;5(7):3212–3216.
[83] Ekzayez A, al-Khalil M, Jasiem M, et al. COVID-19 response in northwest Syria: innovation and community engagement in a complex conflict. J Public Health (Bangkok). 2020;42(3):504–509. doi:10.1093/pubmed/fdaa068
[84] Dhabaan G, Al-Soneidar W, Al-Hebshi N. Challenges to testing COVID-19 in conflict zones: Yemen as an example. J Glob Health. 2020;10(1):1–3.
[85] McArthur R. South Korean 'lab on wheels' coming to MENA region via new partnership. Mobi Health News. 2021: 1–2.
[86] Moradi, G., H. Asadi, M.-M. Gouya, et al., The communicable diseases surveillance system in Iran: challenges and opportunities. Arch Iran Med, 2019. 22(7): p. 361-368.