Empowering the crowd: Feasible strategies to minimize the spread of COVID-19 in informal settlements

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Abstract

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Introduction

There is still a substantial number of low-income countries in which the COVID-19 pandemic has not reached its fullest potential. In the beginning of August 2020, the number of cases reported in African countries per inhabitant was XXX. These numbers are still far from those reported in (XXX e.g. Europe). The fragile health-systems in these countries [Ref], in particular regarding critical care [Ref], and the often lack of access to basic services such as water sanitation [Ref], may have major implications in the spread of the disease [Ref].

These figures become even worse in regions immerse in armed conflicts, in which informal settlements of Internally Displaced Population (IDP) are widespread. In these settlements, the number of inter-personal contacts is very high, with people often living in overcrowded tents. For the region we take as a reference in this study, the North West of Syria, XX% of the households are IDP living in tents with XX people on average [Verify and Ref]. Moreover, populations in these regions often have a high proportion of individuals suffering from comorbidities. In the NW Syria, 10% of the population has a chronic disease, with 17% of them having no access to medicines [REF Reach doc], and it is often dependent on humanitarian organizations [data?]. At a regional scale, the political instability in areas affected by armed conflicts hinders the efficiency of coordinated actions, and military operations often prompt the exodus of the population. These movements could facilitate the transmission of the disease, also making tracing interventions unfeasible. At the local scale, a large number of informal camps (not registered by the WHO [APG, please precise]) have limited or no management [REF Reach], again precluding the implementation of interventions to limit the spread of the virus.

To investigate feasible interventions in informal settlements (hereafter named "camps"), we considered a Susceptible-Exposed-Infectious-Recovered model in which the population is divided into classes, reflecting the age-structure and the existence of comorbidities [Ref]. We use this model to propose a number of interventions aimed at reducing the contacts within and between population classes in general, and with symptomatic individuals in particular. In order to incorporate these interventions, the model includes an explicit parametrization of the contacts that the populations have per day, an approximation that was previously used to model the effect of similar interventions in minimizing the spread of the COVID-19 in African cities [Zandvoort]. We build upon this approximation making a more explicit representation of the contacts, and of other parameters in the model. We paid special attention on the assumptions that the different interventions would have under the living conditions that exist in these camps.

We considered a worst-case scenario in which there is no access to any health-care facility. We modelled previously proposed interventions [Zandvoort] such as self-distancing, isolation of symptomatic individuals and the creation of a 'safety zone' in which more vulnerable population becomes less exposed to the virus. We elaborated in more detail previous models [Ref, Zandvoort] to take into account the micro-dynamics of the interactions, considering questions such as the time than an individual takes to recognize the symptoms before self-isolating, the effect of having carers to attend isolated individuals, or the existence of a buffering zone in which exposed and protected population classes could interact under certain rules, among other details. Since empowering the local communities to understand how to control the virus is possibly the most (and perhaps unique) effective way to minimize its spread, the details we modelled become of outmost importance for a realistic implementation of the interventions.

Methods

The model

We considered a discrete-time stochastic model simulating the spread of the virus in a single camp. The model is divided in compartments, containing individuals at different possible epidemiological stages along the progression of the disease (see Supplementary Material). The model additionally considers that the population is divided in different classes depending on the age-structure and comorbidities. The simulation starts with a population of susceptible individuals and then one individual becomes exposed. The progression of the disease in the individual goes through a series of infectious stages: a presymptomatic stage, and then either a symptomatic or asymptomatic stage, eventually infecting other suceptible individuals. Individuals are no longer infectious if they recover or if they die. The simulations run for 365 days, and we verified that a steady state was always reached before the limit of the simulation was achived. We did not considered any additional entry of infectious individuals in the camp during the simulation. Births and deaths due to other causes were not considered in the model, since populations changes due to the disease are much larger than those related to these processes, provided that there are no conflicts during the period simulated.

Population structure

We considered data from the NW of Syria as a reference to parametrize the models [SOURCE]. The population size of informal camps was log-normally distributed, with a mean size of 600 individuals. We simulated population sizes of 500, 1000 and 2000 individuals. Unless stated otherwise, the results presented refer to populations of 2000 individuals, because interventions tend to be less effective in larger camps. The original data was structured in three population ages: age 1 (0-13 years old), age 2 (14-50 yrs.) and age 3 (>50 yrs). For the classes correspondent to age 2 and 3, we additionally considered two subclasses comprising health individuals and individuals with comorbidities, respectively. Therefore, in the absence of interventions, we considered 5 population classes, whose proportions are shown in Table [create Table].

Epidemiological severity assumptions

An important question to consider in the model is the access to health care. In the case of the region we are considering as a reference, NW Syria, there are available XXX beds in hospitals (XXX UCIs) and XX ventilators for 4.5 million people [Ref]. Basic estimations predicted a collapse of the health facilities after 8 weeks of the outbreak []. Given the additional difficulties that people living in the camps has to access these facilities [how to show this?], we considered a worst-case scenario in which individuals will not have access to health care. As a consequence, we assumed that symptomatic individuals requiring an ICU would die. More problematic is to estimate the fate of those individuals that would have symptoms with a severity requiring hospitalization but not necessarily ICU care, since in the absence of hospitalization their fate is uncertain. To address this point, and departing from previous models [Refs], we considered a hospitalization compartment. Since, as we said, hospitalization is unfeasible, these individuals are considered to stay in the camp and being infectious. Hence, the role of this compartment is to account for a longer infectious period for these individuals. This compartment will also help us to model more realistically some interventions, for example noting that the severity of the symptoms for these individuals is incompatible with self-isolation. From this compartment, we simulated two possible extreme scenarios, one in which all these individuals would recover, and another in which these individuals will all die. This strategy allowed us to estimate upper and lower bounds for the different variables. In the simulations presented in the Main Text, we considered a worst-case scenario, namely the one in which all individuals die.

Another consideration comes from the estimation of the fraction of the population that will suffer severe or very severe symptoms (parameters h_i and g_i, see Table [Table]). These parameters are class-specific, but we gathered this data from studies in countries in which the living conditions are more favourable [Refs], and in which there is access to health care. Following previous work [Zandvoort], we considered that in, our setting, the fraction of individuals showing severe symptoms will be larger, and we implemented this fact mapping the population-classes in our model to population-classes 10 years older in the studies we took as a reference.

Transmissibility assumptions

In our model, individuals from the presymptomatic, asymptomatic, symptomatic and hospitalized compartments are equally infectious. Although asymptomatic individuals are often considered less infectious [Ref], the fraction of asymptomatic we considered was of 16% [Ref], which might be an underestimation after recent findings reporting up to 49% [Ref], and hence we opt to considered them equally infectious than symptomatic ones. The length of the time intervals that individuals spend in each compartment was retrieved from literature (see Table [Table] and Supplementary Material).

To model the contacts between individuals we considered that the number of contacts between individuals of different classes was the product of the mean number of contacts that an individual has per day ($\bar{c}_i$, see Supplementary Materia) times the probability of finding an individual of other class, which is proportional to the proportion of that class in the total population. The $\bar{c}_i$ values were estimated from direct conversations with people managing the camps, although it was not possible to perform a formal survey. We estimated that individuals of age 1 have 25 contacts per day on average, those of age 2 have 15 contacts per day, and we fix to 10 contacts per day those of age 3.

The probability of getting infected after a contact with an infectious individual, τ, was estimated considering a Gaussian distribution of the basic reproduction number R_0 with mean 4 and 99% CI=(3–5). These values were a compromise between values reported in the literature from cities including favelas, ranging from R_0=2.77, 3.44 in Abuja and Lagos, respectively (Nigeria, [Ref]); R_0 =3.3 in Buenos Aires (Argentina, [Ref]), to Rohinya's refugee camps that were estimated to be as high as R_0=5 [Ref]. The probability distribution for τ was estimated randomly generating a value for R_0, and dividing the value by the real part of the main eigenvalue of the Next Generation Matrix (see Supplementary Material).

Interventions

Self-distancing

We considered a situation in which all the population reduce the mean number of contacts per day by a certain amount (20% and 50%). Since the mean number of people per tent in a camp is 7 [verify], we considered that the number of contacts per day cannot be reduced by more than a 50%. Note that, for an adult, this would mean having 7.5 contacts per day.

Buffering zone

When individual self-distancing cannot be achieved, a possible solution is to split the population in groups, and apply self-distancing measures to individuals belonging to different groups. We name the zones in which interactions between population groups occur "buffering zones". We assume that these zones are always open spaces, not occupied by more than 4 individuals wearing masks, and in which 2 meters of distance between individuals of different groups is guaranteed. This setting allowed us to assume a reduction in the probability of infection per contact of an 80% [Ref]. An additional intervention we considered in some simulations, is that symptomatic individuals cannot access to a buffering zone.

Safety zone

In this intervention, it is considered that the camp is divided in two areas: a safety zone, in which more vulnerable people lives (that we will refer to as "green" zone following previous studies [Ref]), and an exposed (orange) zone with the remainder population. In the simulations, it is always considered that the first exposed individual belongs to the orange zone. Contrary to the nomenclature followed in other studies (see e.g. [Ref]), we avoided the use of the term “shielding” for this intervention, since it may lead to a (misleading) picture in which it is believed that the vulnerable population is isolated into a closed space, such as a separated building. Such intervention would require additional assumptions on how contacts occur in such a space . In our simulations, we instead assumed that the camp is split in two separated areas, and that the number of contacts between individuals living in different areas is reduced, while the living conditions within both areas remain otherwise the same. Therefore, the number of contacts per day and individual does not change unless self-distancing is implemented. In practice, this means that, for every individual, reducing the number of contacts with individuals living in the other zone, implies an increase in the number of contacts with the individuals in their own zone (see Supplementary Material). This is important to investigate undesired side-effects that the split may have.

We also considered that individuals living in the green zone cannot leave that area, which means that supplies for this population should be provided by individuals in the exposed zone, and hence the contacts between both populations never vanishes. However, we considered that this interaction will always occur in a buffering zone, and we assumed that each individual in the green zone can have a maximum number of contacts per week with individuals of the orange zone: either 10 or 2 contacts per week for each individual.

An important social question to be addressed in this intervention is how population will be distributed in the two zones, since different partitionings may have a different reception in the population. We considered the following isolation scenarios: i) elderly population only (age 3); ii) elderly population and adults (age 2) with comorbidities; and iii) elderly, adults with comorbidities, and other adults (e.g. spouses or carers) and their young kids ($<$ 13 yrs. and not exceeding 40% of the population in the green zone). For the scenario iii) we considered, in turn, three additional possibilities, in which the total population in the green zone represent 20%, 25% or a maximum of 30% of the total population.

Lockdown of the safety zone

An additional measure that can incorporated once the safety zone is implemented, is a further reduction in the number of contacts occuring in the buffering zone after the first symptomatic case in the orange zone is identified. We refer to this reduction as “lockdown” (of the safety zone). Again, since supplies for people living in the green zone cannot be disrupted, we assumed that the number of contacts per week and individual is reduced by a 50% or a maximum of a 90% (see Table XXX)

Self-isolation

A challenge in informal settlements is how self-isolation can be interpreted when households have a single, and often small space. Moreover, water should be collected at specific locations, there are communal latrines and the scarcity of food supplies do not allow for the isolation of whole families. We considered the possibility that individuals showing symptoms self-isolate in individual tents in dedicated spaces of the camps, or next to the tents of their relatives. To simulate a more realistic scenario, we considered that there is a minimum time for an individual to recognize his/her own symptoms, within a period ranging from 12 to 48 hours (see Table XXX). In addition, we considered that there are a number of carers dedicated to supply food and water to isolated individuals, interacting in a buffering zone. In Supplementary Material we show that considering one carer per individual having one contact per day, we account for both the positive effects of isolation and the negative effects derived from the contact with carers, since the probability of infection with the rest of the population cannot be neglected. In this respect, we considered that people moving to a severely symptomatic stage (hospitalized compartment) becomes fully infectious. The rationale behind this choice is that this individuals require a more intensive care, and hence it is expected that the rules imposed for a buffering zone cannot be longer fulfilled. We modelled this intervention for an increasing number of tents from 10 to an unlimited number (see Table XXX).

Evacuation

The last intervention refers to the possibility of evacuating severely symptomatic individuals, i.e. those in the hospitalization compartment. This measure does not change the fate of the evacuated individuals. Hence, we assume that the evacuation will not be to a hospital but to some sort of isolation center . In this way, the measure will reduce the infectiousness of these individuals to zero.

Analysis of the interventions

For each implementation of the interventions, we run 500 simulations, analysing results arising from the incorporation of an intervention with respect to a set of simulations in which the intervention was absent. The main variables we considered in the comparisons were the fraction of casualties in the population, the case fatality rates (CFR), the fraction of population recovered and the time at which it is observed a peak in the number of symptomatic. We focused on the symptomatic population, because it is the most informative measure in settings in which there is no access to other tests. We additionally considered the fraction of simulations in which at least one death is observed as a proxy for the probability of outbreak. For consistency, when we compared the statistics of a given variable between two interventions, only simulations in which there was an outbreak were considered. When it was needed to individuate if differences between interventions were significant, we conducted statistical analysis: t– or Welch–tests for pairwise comparisons depending on whether normality is fulfilled, and Tukey tests for multiple comparisons among non-orthogonal variables.

Results

When interventions are absent, the CFR takes values around 2% when we consider that individuals that would require hospitalization (but not ICU) are recovered, raising up to ~11% when we considered that all would die . Unless otherwise stated, in the following we consider the latter scenario to evaluate the interventions. In such scenario, the probability of observing an outbreak is close to 0.85, having that 10% of the population in the camp would die and that ~83% of the population would recover, with the number of symptomatic cases peaking after 55 days.

Self-distancing has a notable effect for the probability of outbreak, with a 10% decrease when just a reduction of a 20% in the number of contacts was considered (Fig. 2A). It was, however, needed a reduction of up to 50% to observe a more nuanced decrease in the fraction of population dying, that could be reduced as much as a 35% (Fig. 2B). The same occurs for the time to the peak of symptomatics (Fig. 2C), which increases up to 110 days, hence doubling the values when there are no interventions in place.

Self-isolation brings a strong decrease close to a 30% in the fraction of population dying, when only 10 tents are available for a population of 2000 individuals, i.e. a 0.5% of the total population (Fig. 2). Interestingly, increasing the number of tents does not improve much this reduction and, when the number of tents represent a 10% of the population, the fraction of deaths even increases. This effect is due to the assumption that each individual requires one carer (see Supplementary Material). A side effect of this policy is that, when the number of isolated population increases, it also increases the number of healthy individuals in contact with the isolated population. Still, the Case Fatality Rate experience a continuous, albeit small, reduction with an increasing number of tents (Supplementary Fig. XX). The probability of observing an outbreak and the time in whch the symptomatic cases peak have a minimum (maximum) when ~1% of tents are considered (Fig. 2).

Importantly, these results hold when we assume that the time required for individuals to recognize their symptoms is of 24h on average, and the intervention becomes less effective when this time increases (Supplementary Fig. XX). On the other hand, reducing this time to 12h does not significantly reduce the fraction of people dying , but it does increase the time in which the number of symptomatic cases peak (Supplementary Figs. XX and XX). If we additionally consider that the symptomatic cases that would require hospitalization are evacuated, it is only observed a 2% reduction in the fraction of individuals dying (Supplementary Fig. XXX). Since we assumed that the evacuation does not change their fate, the intervention only affects their infectivity. Although the period between developing more important symptoms and dying is relatively long (~10 days), the number of individuals under these conditions is small, when compared to the rest of the infected population.

Creating a safety zone improves overall the effect of previous interventions, but sometimes with different outcomes for the exposed and protected populations. For instance, the probability of outbreak decreases very strongly (almost 40%) for the protected population (see Fig. XX). Notably, approximately 16% of this reduction is due to the health checks performed to get into the buffering zone, which exclude symptomatic individuals (Suppl. Fig. XX). On the other hand, the probability of outbreak may increase for the exposed population if the contacts per week and per individual occuring in the buffering zone are reduced to 2. This is a consequence of an increased number of contacts within subpopulations, which may also explain the increase in the CFR of the protected population (Supplementary Fig. XX), . Despite of this side-effect, the fraction of individuals dying for the protected subpopulation and, in turn, globally, is reduced. Another important observation from this intervention is the notable increase of the time to peak of symptomatics, raising up to 35% globally, and to 70% for the protected population. Regarding the population that should move to the safety zone, having only elderly or at most elderly and adults with comorbidities, guarantee a low probability of outbreak, which would otherwise increase the global fraction of population dying (Supplementary Fig. XX). Positive effects of the safety zone are even more marked for smaller population sizes, except for the time to peak of symptomatic, which has a weaker effect for smaller populations (Supplementary Fig. XXX and XXX).

The incorporation of a lockdown again shows the side-effect in which if there is an outbreak in the safety zone, it has more negative effects, due to the increased number of contacts of individuals within the zone (Fig. XXX). However, the probability of outbreak is very strongly reduced to a barely 10% and, consequently, when there is an outbreak in the camp (which in most of the cases will not reach the safe zone) the fraction of deaths globally reduces (Fig. XXX).

Finally, the combination of interventions add their effects approximately as it was shown when they were incorporated individually (Fig. XXX). In particular, the creation of a safety zone improves the benefits of the other interventions, and there are not noticeable side effects beyond those previously described.

Discussion

In this article, we proposed a number of feasible interventions of immediate applicability, for human informal settlements. We took as reference settlements of IDP in the NW of Syria, and we discussed the feasibility of the different interventions with local stakeholders, to individuate its economical viability and potential cultural issues. In general, we considered worst case scenarios, possibly (hopefully) leading to an overestimation of the number of casualties but that, in this way, makes more apparent the potential of the interventions. Our results are aligned with previous works XXX

Self-distancing proves to be an efficient measure, and reducing the number of contacts to a 50% has the most important effect among all the interventions. Such a reduction is, however, difficult to achieve, for example due to the large population under 14 years old which have high motility in the camps and little control.

We proposed the implementation of self-isolation with individual tents, that could be located either in a dedicated zone in the camp or next to the tents of relatives, with a buffering zone ($\sim 2\ m^2$) in-between. We think this intervention is more likely to be accepted than the evacuation to isolation centers without health care [APG. Include reference to public plans of WHO]. Without testing, it is difficult to know if symptoms are truly associated to COVID-19, and hence an increase in the contacts between individuals may increase the infectivity, also among carers if they do not have effective protection measures. Our proposal is effective even for a number of tents is as low as 0.5-1% of the total population in the camp. We considered that there is one carer per individual isolated with a daily contact in a buffering zone, and this choice shows that increasing the number of isolated individuals increases the infectivity. This could be circumvented with a more organized group of trained carers, which would reduce the number of total contacts with infectious individuals. The intervention is effective even though we assumed that individuals requiring hospitalization should leave the tents due to their need of care, and hence they become fully infectious.

The creation of a safety zone is an interesting intervention that we propose should keep the same setting in terms of number of people per tent and distance between tents. This would mitigate side-effects derived from an increase in the number of contacts between vulnerable population. Still, we implemented this increase exactly compensating the reduction in the number of contacts with the other population, and we observed in some cases side-effects such as an increase in the fraction of deaths in the protected population, justifying these concerns. However, these side-effects are compensated by the strong reduction in the probability of outbreak in the safety zone that this intervention provides, which leads to an overall reduction in the fraction of deaths in the whole camp. Moreover, it is unrealistic to think that the level of activity will be maintained in the safety zone, which would readily control for any side-effects.

An important question for the success of this intervention comes from the efficiency of the buffering zone. The reduction in the number of contacts per week, the implementation of basic health checks to identify symptomatic individuals, and the eventual lockdown, have notable effects. Also important is which population should be shielded. Protecting only elderly and at most adults with comorbidities have the most beneficial effects, and the intervention becomes less effective when more adults and kids are included. Another relevant consideration is the fraction of population recovered, that may help to reach herd immunity. We observed that unless a self-distancing of 50% is considered, the fraction of population recovered is close to a 75%, which is quite promising to prevent future outbreaks.

Decisions on which population should be protected are one example of social challenges that may become more complex in practice. Another example we did not address is that it is unlikely that a kid becomes isolated alone in a tent. The number of exceptions to the cases proposed are possibly endless, but we should ask if it is needed to run a simulation to predict the outcome of these exceptions. In this respect, we believe that the importance of these results comes from the fact that the examples may help individuals to understand the dynamics of the virus, and then to adapt to new situations and to look for alternatives. Given the highly dynamic environment existing in the camps and the slow reaction of the local and international authorities, empowering the local population is possibly the best, if not the only way, to help these communities.