Scientific Report on Progress of Punjab's Smart Sampling and Testing Strategy

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This report summarizes the findings of the Punjab Smart Sampling and Testing Strategy proposed by the Punjab Covid-19 Working Group and implemented by the Punjab Primary and Secondary Healthcare Department in Lahore in May 2020. The analysis in the report has been conducted by members of the *Smart Containment with Active Learning* consortium who are part of the Working Group.

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Smart Containment with Active Learning (SCALE) is a multidisciplinary policy response to Covid-19 that draws on the expertise of researchers and practitioners in public health, infectious diseases, epidemiology, economics, policy and public management, technology and data science as well as business & non-profit leaders. We have assembled a broad coalition of experts from leading institutions. As part of SCALE, we are producing a series of ancillary documents that provide more detail on specific topics. The following members are part of the SCALE consortium: Dr. Ali Cheema (Lahore University of Management Sciences), Dr. Jishnu Das (Georgetown / Center for Policy Research), Dr. Adnan Q. Khan (London School of Economics), Dr. Asim I. Khwaja (Harvard), Dr. Tyler McCormick (University of Washington), Dr. Farhan Majid (University of Georgia), Dr. Saad B. Omer (Yale), and Maroof Syed (CERP).

For feedback and comments, please reach out to us at covidrapidresponse@cerp.org.pk.

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Executive Summary

This report summarizes the findings of the Punjab Smart Sampling and Testing Strategy proposed by the Punjab Covid-19 Working Group and implemented by the Punjab Primary and Secondary Healthcare Department in Lahore in May 2020. The analysis in the report has been conducted by members of the Smart Containment with Active Learning consortium who are part of the Working Group. Real time analysis of this data has already been presented in the Working Group meetings held in May and June 2020.

Overall, the Smart Sampling and Testing strategy was effectively and quite successfully deployed over a two week period from early to mid May across Lahore. The testing period includes the period of strict lockdown in the city (14th April 2020 to 8th May 2020), which was then subsequently eased till 18th May 2020. The strategy was deployed at the census block-level (referred to as “blocks" in this document), which was the smallest possible geographical unit in which Covid-19 specfic response measures such as testing, quarantine and lockdowns could be effectively enforced. A total of 645 blocks were randomly selected - these blocks were adjacent to those blocks with known pre-existing Covid-19 infections. A total of over 12,000 individuals were tested in these randomly selected blocks using cost-effective pooled testing techniques. These techniques allowed us to drop the costs of testing by over 60%, costing PKR 1,334 for a pooled test compared to PKR 3,500 for an individual PCR test. These are noteworthy achievements and tremendous credit goes to the Primary & Secondary Healthcare Department for testing and successfully implementing these pooled protocols. Given the central role of testing in dealing with the pandemic, such significant cost savings are critical and can be game changing. Moreover, the implementation process revealed several logistical challenges that were addressed in real-time due to commendable efforts by all parties concerned.

Compared to earlier major viral outbreaks such as one of the dengue fever in 2011, 2015 and 2019, the Covid-19 epidemic is distinguished by its novelty and the ability to quickly spread from person-to-person, the degree of asymptomatic transmission and the differential age pattern in terms of morbidity outcomes. It has therefore posed a much bigger challenge as is evidenced by the global pandemic we are currently experiencing. Our overall results show the Covid-19 prevalence rate to be fairly high at 3.76% - with women showing slightly higher rates of infection than men (4.43% versus 3.66%). The data also revealed substantial variation in prevalence rates across various blocks suggesting that the spread was quite localized. Over time variation showed that prevalence rates did not change substantially during the lockdown period, thereby suggesting the initial lockdown may have been effective. Unfortunately, since the Punjab government has not been able to continue with Punjab’s Smart Sampling and Testing strategy during and after the Eid period, we are unable to confirm whether opening up was appropriately timed. Data from ventilator usage shared by the Specialized Health & Medication Education Department does raise concerns that opening up may have led to an substantial increase in Covid-19 spread but it is imperative that the Punjab’s Smart Sampling and Testing strategy be restarted for the Working Group to confirm this and also to determine the effectiveness of the various partial and smart lockdown policies being implemented now.

Analysis from data collected reveals that in addition to women, the elderly were indeed more likely to be symptomatic and Covid-19 positive. In addition, the majority (close to 95%) of Covid-19 cases were asymptomatic. The results also show a person was more likely to be infected if they had an infected person in their vicinity, had pre-existing conditions, and lived in a densely populated area. These results emphasize the need to target Punjab's policy response and messaging to focus on the elderly, women, and those with pre-existing conditions. Moreover, individuals need to be informed of local prevalence rates in their vicinity so they can take appropriate mitigating measures. The fact that the majority of infected reported being asymptomatic is also critical to note since this implies that policy messages need to be directed towards all and precautionary measures - including wearing masks and regular hand washing - should be taken by all, especially the asymptomatic as they are more at risk of unknowingly spreading the virus.

While Covid-19 indeed raises a unique set of challenges, Punjab does have the experience to tackle the threat effectively. Although there does not exist any vaccine for dengue (like Covid-19), in 2019 the Punjab government strengthened Vector Surveillance and environmental management to manage the outbreak. Efforts were made to implement SOPs with micro plans for all districts, centrally coordinated by the Central Emergency Response Committee. It was recognized that community awareness and participation were key to prevent mosquito breeding and supplement efforts by the Primary & Secondary Health Department. There are lessons from this for the Covid-19 epidemic as well - success with administrative action relies not only in identifying the issue but also ensuring coordination among various administrative actors combined with effective public outreach.

We conclude the report by suggesting next steps including the critically needed resumption and expansion of the scale and scope of Punjab's Smart Sampling and Testing, the importance of designing and implementing systematic and data-driven contact tracing, and the imperative to collect data that follows the health outcomes and needs for those detected as Covid positive.

1. Background & Context

Key to an effective response strategy for Covid-19 is to understand the benefits and costs of various policy interventions such as smart lockdowns and containment, and the impact these interventions may have on the prevalence of Covid-19 as well as on other health and economic outcomes. With symptoms appearing several days after infection and potentially many others who are not symptomatic at all, it is critical that we be able to enact cost-effective and scalable Covid-19 prevalence measures.

However, it is also clear that national health systems can no longer solely rely on traditional disease reporting mechanisms as these are not explicitly designed to recognize the emergence and potential of new threats such SARS-CoV-2. At present, when the course of the outbreak is rapidly evolving, traditional disease reporting mechanisms such as the number of symptomatic cases reported by healthcare providers may only offer limited real-time insight for an effective policy response since they may suffer from mis-reporting and mis-classification.

Understanding transmission vectors and disease prevalence in real-time is key to building a toolkit that can help in countering the spread of infectious diseases such as Covid-19, which affect people in vastly different ways with high rates of asymptomatic and mild cases. To advise the Government of Punjab on the public health impacts of Covid-19 through data analysis and smart testing, the provincial government constituted a Working Group (as per notification No.SO(G)/P&SHD/3-8/2020 dated 28-04-20) comprising the following government departments and research entities:

1. Primary & Secondary Healthcare Department (P&SHD)
2. Specialized Healthcare & Medication Education Department (SH&ME)
3. Finance Department
4. Planning & Development Board (P&D)
5. Home Department
6. HQ4 CORPS
7. Provincial Disaster Management Authority (PDMA)
8. Urban Unit
9. Smart Containment with Active LEarning consortium (SCALE) consisting of epidemiologists, public health specialists, applied economists, and statisticians belonging to the Center for Economic Research in Pakistan (CERP), Harvard Center for International Development (CID), London School of Economics (LSE), Mahbub-ul-Haq Research Center (MHRC) at the Lahore University of Management Sciences (LUMS), Yale Institute for Global Health, Georgetown University and the University of Washington.

The Terms of Reference (TOR) of the Working Group are as follows:

a) Design and share smart sampling, testing and data collection methodologies to help establish prevalence and transmission rates of Covid-19
b) Based on analysis, assist the government to understand immediate health and economic impact
c) Provide analysis of relevant data on Covid-19 related to smart sampling/testing provided by the Government of Punjab and report on the findings, and where possible, support the government to conduct its own analysis
d) Provide technical input to government about Covid-19 policy response

In line with the TORs of the Working Group, the purpose of this report is to summarize the findings of the Smart Testing strategy implemented in Lahore in May 2020, and to recommend next steps to the Government of Punjab. We summarize below how each of the above TORs have been addressed:

a) Smart sampling and data collection methodologies were designed by the SCALE team and implemented in partnership with P&SHD and the Lahore District Health Authority from 3rd May to 16th May 2020 in the city of Lahore (see section 2 for details). Through such innovations as pooled testing, the cost of testing was lowered by 63.5%.[1]
b) Preliminary analysis as well as guidance to conduct their own analysis was shared with the government in a series of presentations to the following stakeholders noted below:
    i) Secretary P&SHD on 16th May 2020
    ii) Working Group meeting chaired by Minister Finance on 19th May 2020
    iii) Commissioner Lahore on 23rd May 2020
    iv) Working Group meeting chaired by Commissioner Lahore (and also attended by Secretary P&SHD and Secretary SH&ME) on 11th June 2020
    v) Minister Health and the Chief Secretary on 11th June 2020
c) Section 3 provides detailed analysis of the data collected and offers analytical guidance to the Government of Punjab
d) Section 4 provides technical input to government about Covid-19 policy response

2. Smart Sampling & Data Collection: Design & Implementation

A. Smart Sampling Design

The strategy proposed by the SCALE consortium and endorsed by the Working Group entailed a Smart Testing process combined with real-time analysis, to help inform the Punjab

[1] Including field costs, the average cost of a pooled PCR test is 1,334 whereas an individual test costs 3,663. This amounts to a 63.5% cost saving. More details may be found in the ‘Testing Costs and Efficiency’ section of this report.

government's policy response towards countering disease spread as well as minimizing unintended adverse outcomes through a systematic and data-driven approach.

The SCALE Smart Sampling strategy is generally focused on providing representative prevalence data at the level of the smallest feasible geographical unit (S-grid) within a district where Covid-19 specific response measures (such as testing, quarantine and lockdowns) can be effectively enforced. The ideal S-grid is one that is minimally feasible (200+ households), integrates with census information such as population density, distribution of age etc., and can be determined using shape files (geo-referenced boundaries). Appendix 1 lays out the detailed smart sampling strategy.

To implement Smart Sampling it was decided that the city of Lahore would be a good starting case. The Working Group decided to establish census blocks as the S-grid in Lahore. The census blocks selected for inclusion in the smart sample were adjacent to originally infected blocks i.e. blocks that were discovered to be infected before implementation of Smart Sampling. Within each selected S-grid, random GPS points were dropped at a ratio of 1 GPS point per 150 households. The Urban Unit GIS team with support from the SCALE consortium extracted the necessary census blocks using the established criteria.

Once the GPS points in each census block were shared with P&SHD, the District Health Authority's smartphone-equipped field team was trained on administering a patient survey. The survey was designed by the SCALE consortium and the application was developed by the Health Information & Service Delivery Unit (HISDU) within P&SHD. The survey instrument is included in Appendix 2.

In order to reduce the cost of testing, the SCALE team proposed pooled testing. Recent work has argued this can be a very cost-effective means of testing.[2] In this case, a pool of up to ten individuals at each GPS point was selected. The pooling procedure is detailed in Appendix 1. The left-hand rule was used to determine the first household to be tested. Within each household, the person with the highest contacts and mobility was selected for testing and was subsequently administered the patient survey to record patient contact information, symptoms, comorbidities, number of contacts, and names of nearby contacts who they considered to be highly mobile. Through this 'daisy chaining' process, a pool of up to 10 individuals was built from 1 GPS point. The collected samples were tested through the pooled testing procedure.[3] Through this innovative approach, which was first implemented in Punjab as part of this Smart Sampling & Testing exercise, the Punjab government was able to decrease its cost while

[2] Majid F, Omer SB, Khwaja AI. Optimising SARS-CoV-2 pooled testing for low-resource settings. Lancet Microbe. 2020;1(3):e101-e102. doi:10.1016/S2666-5247(20)30056-2

[3] Pooled testing works by combining a set of individual specimens into a common pool. If the pool tests negative, all individuals are diagnosed as negative. If the pool tests positive, the individuals within the pool shall have to be retested, and the samples processed individually to identify positive individuals from the negative individuals.

simultaneously enhancing its testing capacity.[4] We will provide more details on this in section 3 below.

As part of its routine contact tracing arrangements, the contact tracing team of P&SHD made follow-up visits to the residence of positive individuals in order to test the individuals in their households and to seek information of other potential contacts in the past 2 weeks. The team administered a brief patient survey designed and developed by HISDU and separately from the SCALE consortium. The process and protocols followed by the contact tracing team were developed and implemented separately from the SCALE consortium, and as such, we are unable to comment on their efficacy at this point but look forward to providing data analysis as additional data is shared by P&SHD.

B. Implementation Progress to date

Testing using the smart sampling methodology took place in 3 stages: Pilot, Wave 1, and Wave 2. Wave 2 was partially completed while a potential Wave 3 of testing has not commenced.

The Pilot stage was implemented on 3rd and 4th May 2020 in 11 blocks that were adjacent to originally infected blocks. The field team was trained to follow the daisy chain process outlined earlier in this report. If the chain broke at any point either because a test recipient refused to share contact information, the referred person was not available, or because the referred person refused a test, the field team moved to the adjacent house/property and followed the same set of procedures as before.

Wave 1 implementation spanned from 5th May to 9th May 2020 and covered 282 S-grids that were adjacent to originally infected blocks. While largely the same process was followed as in the Pilot stage, anecdotal evidence emerged (through focus groups and discussions with the survey operators from the District Health Authority) of the field team also using their local knowledge and contacts to identify individuals (within the census block) who they deemed to have high mobility.

Wave 2 implementation spanned from 13th May to 16th May 2020 and covered 449 S-grids that were adjacent to originally infected blocks. P&SHD was advised to implement the following three implementation strategies:

- Track A: daisy chaining by contact referrals
- Track B: conducting frontline worker testing (with emphasis on healthcare workers, police, grocery stores)
- Track C: pool testing those individuals identified by the local P&SHD surveyor

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[4] Cherif A, Grobe N, Wang X, Kotanko P. Simulation of Pool Testing to Identify Patients With Coronavirus Disease 2019 Under Conditions of Limited Test Availability. JAMA Network Open. 2020;3(6):e2013075. doi:10.1001/jamanetworkopen.2020.13075

Unfortunately, only Track A has been completed as of yet. With regard to Track A, the field team led by the Punjab Health Facilities Management Company (PHFMC) and the District Health Authority did an extremely impressive job of collecting over 12,000 samples and surveys across 11 days. The difficult logistical nature of the exercise was augmented by the hot May temperatures and the holy month of Ramadan. Despite the challenges, enhancing testing efforts by expanding capacity from 8 teams in the Pilot to over 80 teams in Waves 1 & 2 within a short span of time is a commendable achievement and reflects P&SHD's organizational ability for rapid training and deployment in the wake of this pandemic. All the actors within P&SHD - ranging from the Secretary, Special Secretary, Deputy Secretary (General), lab technicians, software developers at HISDU, and all the way down to the field staff from PHFMC and the Lahore District Health Authority deserve due credit in executing this complex task with tenacity and commitment in spite of the health risks to them. Similarly, the Urban Unit deserves great credit for their support in timely sampling and for generally being responsive.

A total of 645 blocks have been covered under Smart Sampling in Lahore as of date. Out of 12,251 unique samples collected, 97.7% have received results after submission to the laboratory whereas 2.3% of results were not obtained due to sample rejection by the laboratory. The table below breaks down the number of samples by test result:

Table 1 - Sample Results

Result	Count	Percentage
Positive	450	3.67%
Negative	11,516	94.0%
Rejected	285	2.33%
TOTAL	**12,251**	**100%**

C. Operational Challenges and Lessons Learnt

Timeliness

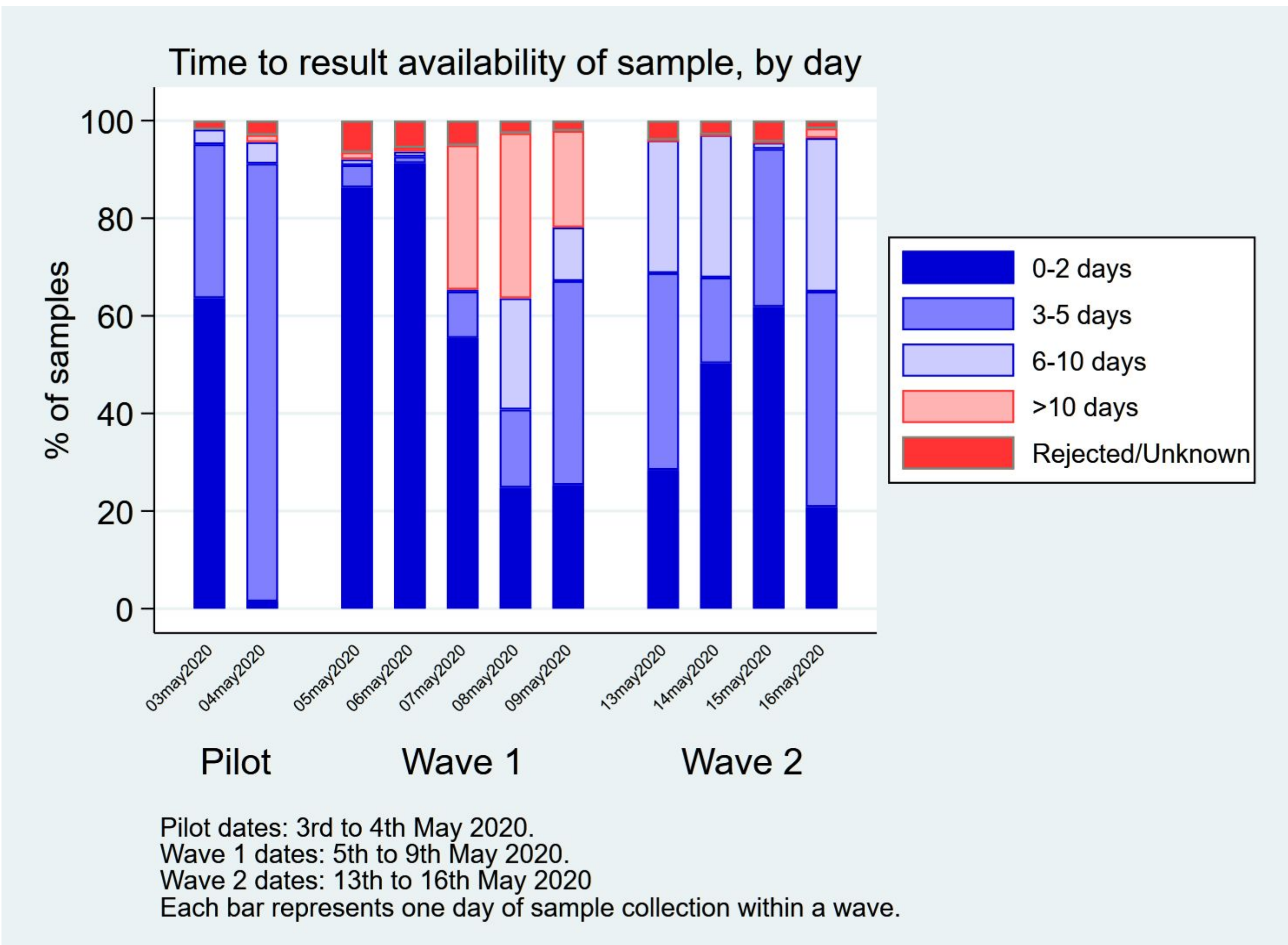
While the field team did a tremendous job in collecting the data, the laboratory side was not as timely. Although the testing finished on 16th May 2020, the final set of results was shared with the SCALE consortium only by 29th June 2020. Moreover, the somewhat episodic and unpredictable provision of data made the analysis more challenging.

Timeliness is also important from a diagnostic perspective since the value of the result diminishes with time. While the risk of under-sampling has been covered extensively in the media and other discourses, the risk of over-sampling also merits attention from policymakers.

To calibrate timeliness of test results, it is important to ensure that the number of samples collected daily in the field is in accordance with daily lab capacity. It may also be useful for the laboratories to create a formal prioritization framework (such as first in first out) under which samples are processed and to build capacity as needed.

In each of the testing phases, there was a small percentage of samples that were either rejected by the laboratory or had a result date that was before sample collection date. Therefore, these results may be suspect and greater investigation is required for these cases. As the figure below shows, the proportion of samples with timely results was greater in the pilot and Wave 2 compared to Wave 1.

Figure 1 - Time to Result Availability



Refusal rates

The process of Smart Sampling involves selecting random GPS points in blocks from where the field teams begin their process of procuring samples for pooled testing. Since it is important to obtain proper consent, refusal by citizens to do so may pose a challenge in terms of interpreting the results, especially if refusal is tied to the likelihood of prevalence and/or specific demographic characteristics.

While in the earlier rounds of surveying refusal rates were not formally recorded, anecdotally there was concern from the field team that people were somewhat reluctant to provide samples due to concerns that they may be moved to quarantine facilities (if tested positive) as well as a general stigma attached with contracting Covid-19. To counter this public perception, it was suggested that the government may undertake an extensive public awareness campaign to sensitize the public of the importance of testing and preventative precautionary measures. Engaging individuals of public repute across both traditional platforms (television, radio, newspapers etc.) and novel social media platforms can help broaden the reach of the message and also help enhance credibility of testing at a time when public trust is low.

While in Wave 3 the plan was to explicitly start documenting refusal rates and reasons for refusal (and we hope to do so if/when wave 3 starts), the earlier surveys can provide a sense of this. We can check whether field teams managed to get their first samples from the selected GPS point. We calculate that about 84% of the samples taken were within 500 meters of the dropped point, and 64% of the samples taken were within 250 meters of the dropped point. This indicates that the field teams were largely able to obtain their first sample in the vicinity of the dropped point.

Other logistical issues

It is not surprising to observe the rollout of large scale field exercises such as this one being subject to logistical constraints and operational difficulties, especially at the beginning. Augmenting the challenge further was the difficulty in securing community buy-in, which manifested itself in outright citizen refusal to be tested, refusal to answer questions entirely or potential misreporting of answers. Anecdotal evidence obtained through focus group sessions with members of the field team attributes the stigma associated with testing and/or disease and the fear of being forced into quarantine in isolation centers as potential drivers of community antagonism. Despite these difficult circumstances, we have worked with the P&SHD, District Health Authority and the field teams directly to improve the implementation process and to streamline the various components involved in Smart Testing. Some other issues that were faced early on in the process and eventually resolved are highlighted below.

While testing itself was certainly the most important component of this field exercise, the importance of the survey data cannot be minimized. Administering a survey that involves asking sensitive questions regarding an individual's health, contact information, CNIC details, etc., is a difficult task in and of itself but the difficulty is compounded when trust may already be low. Refusal of respondents to answer questions or to answer incorrectly can seriously affect data quality. Therefore, it is critical for data quality purposes that those who administer the surveys must have the appropriate experience and skill set in administering similar surveys. In addition to thorough survey-specific training, constant feedback sessions with the field teams are important to establish a feedback loop and to incorporate information from the field into the implementation protocols.

While Computer Assisted Personal Interview (CAPI) surveys are superior to paper-based data collection methods, they can be prone to errors if they are not tested adequately before the main rollout. To test for any potential deficiencies in the survey instrument and data collection protocol prior to Wave 1, a Pilot stage was conducted for 2 days. Through this Pilot stage, we were able to flag errors on the backend application infrastructure. Since the application could only be activated in the target census block, the bugs in the application prevented the enumerator from activating the app, and forced the enumerators to fill out the survey on paper in the field and to enter the data manually on the computer once they returned to P&SHD premises. While this certainly doubled the effort on the part of the enumerators and was ineffective, flagging and fixing this problem before the larger rollout saved considerable time and effort for HISDU and the field team. It is therefore crucial that the application be stress tested before field deployment to ensure that errors in the application do not augment the effort in the field since that would have a direct impact not only on the quality and quantity of the surveys administered in a day but also on the motivation of personnel and program cost.

In addition, a software bug in the application developed by HISDU led to incorrect generation of unique pool identifiers. This meant that although a set of samples may have been collected as part of one pool, incorrect pool IDs in the data led the data user and the lab technician to consider them as multiple pools of varying sizes. For example, if 10 samples were collected from one GPS point and formed one pool, incorrect pool IDs could give the appearance of three distinct pools of 4-3-3 (or even ten distinct pools of 1 sample each). This would reduce the efficacy of pooling, blur the differences between individual testing and pooled testing, and prevent the government from achieving optimal cost savings that pooled testing allowed. To mitigate such future problems, efficient coordination is required between HISDU, the field team, and the lab *ex-ante,* i.e,. before any rollout and while the application is being developed.

In addition, there are many crucial operational details that remain unavailable and therefore reduce the breadth of insights that can be provided. For example, the blocks chosen for Smart Sampling were those that were adjacent to those that already had incidence of infection. However, until recently we did not know what the infection rates were in adjacent blocks (or have their maps) and, therefore, we are currently unable to say much about how infection travels between blocks. This will be subsequently addressed in later updates to this report. So far, work in other places around the world has shown that there is a very strong spatial component to the virus' spread: getting an idea of where prevalence is high is crucial to policies such as enforcement of 'smart' lockdowns.

Similarly, we also possess only limited information on contact tracing to get an idea of how prevalent localized spread was. Data currently available to us has 23.4% (439 from 1872) of results still showing as 'Awaited', thereby implying that we cannot draw conclusive results regarding local spread. We also do not know the response rate,s i.e., how many of the individuals approached for sample collection actually provided one.

These data, among other pieces of information, would have enabled a far better policy response to be mounted. For example, availability of recent testing data would have allowed us to evaluate (i) how effective the initial lockdown was, and (ii) how costly the lockdown easing and lifting was in terms of virus spread and burden on the health system. Further, availability of mortality data from confirmed positive cases would have allowed us to analyze overall mortality rates combined with those differentiated by demographic data. Newer policy proposals being discussed such as age-differentiated lockdowns and policies could be enriched with these data.

3. Results from Analysis of Smart Sampling Data

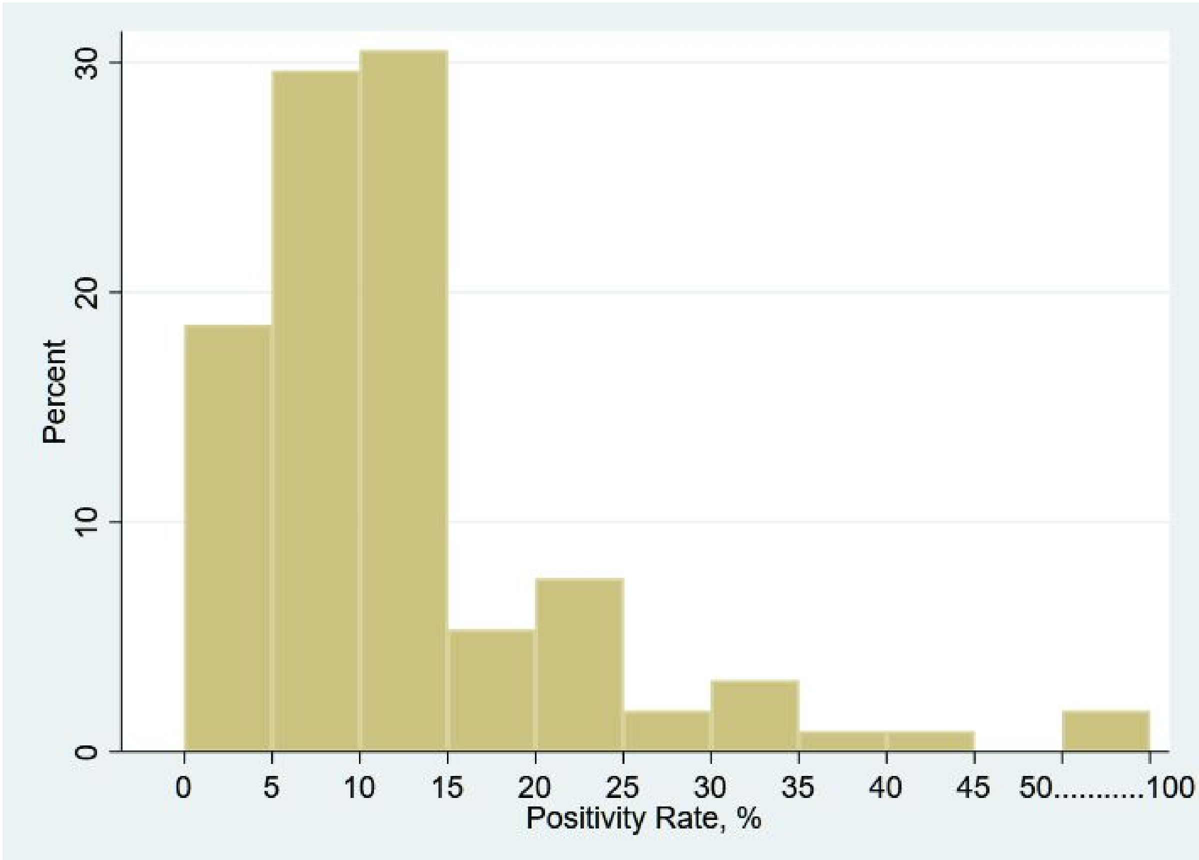
A. Overall Prevalence & Spatial Variation

The overall Covid-19 prevalence rate in the sample is 3.76% with roughly similar splits between gender - as 4.43% of females and 3.66% of males tested positive, a statistically significant difference at the 10% level.

The blocks in which testing took place were spread all over Lahore. Because our sampling strategy randomly surveyed blocks around infected blocks, this provides some sense of spatial distribution of prevalence. Our results suggest that there was quite a bit of variation in Covid-19 prevalence rates even within a given city/neighbourhood.

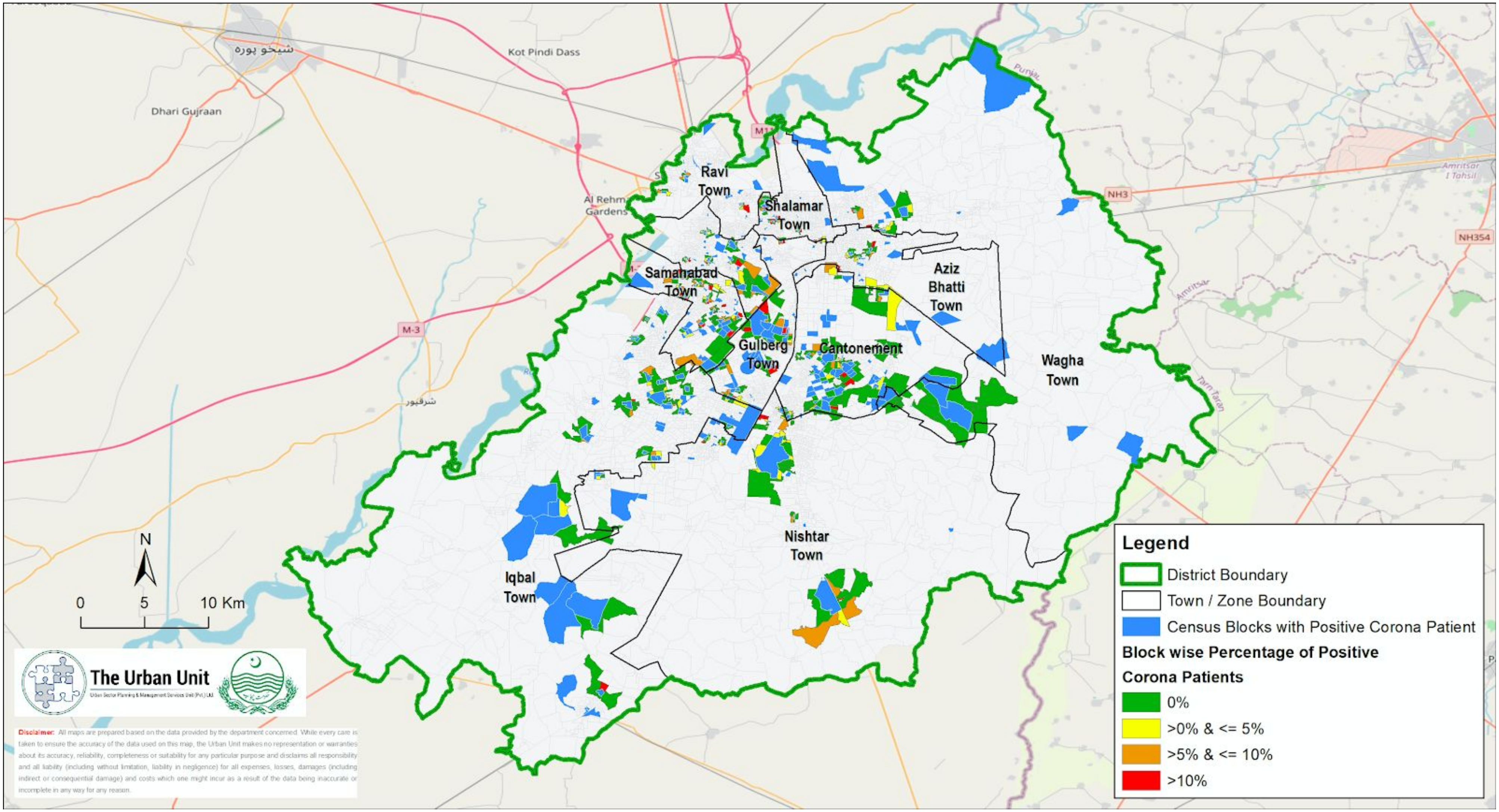
First, at the level of blocks we find that the spread of Covid-19 was localized in most cases with 419 out of 645 blocks testing negative for all those sampled. Among the blocks that did contain at least one positive individual (226 blocks), the distribution of positivity rates looked as follows:

Figure 2 - Block Level Prevalence Rates (excluding zero prevalence blocks)



The maps below illustrate this variation spatially and again makes the point that there is a lot of variation in prevalence rates.

Figure 5 - Map of Lahore showing Originally Infected Blocks (in blue) along with Adjacent Blocks where Smart Testing was implemented (in green/yellow/orange/red)



What is interesting to also note is that there was a lot of very localized variation in prevalence as well. Even adjacent blocks can have fairly different levels of infection suggesting that Covid-19 spread may be a fairly localized phenomenon (especially when lockdown policies are in effect). The figures below provide zoomed-in versions of a few different areas of the overall prevalence map and illustrate this even very localized differences in Covid-19 prevalence rates.

Figure 6 - Map of Gulberg Town showing Originally Infected Blocks (in blue) along with Adjacent Blocks where Smart Testing was implemented (in green/yellow/orange/red)

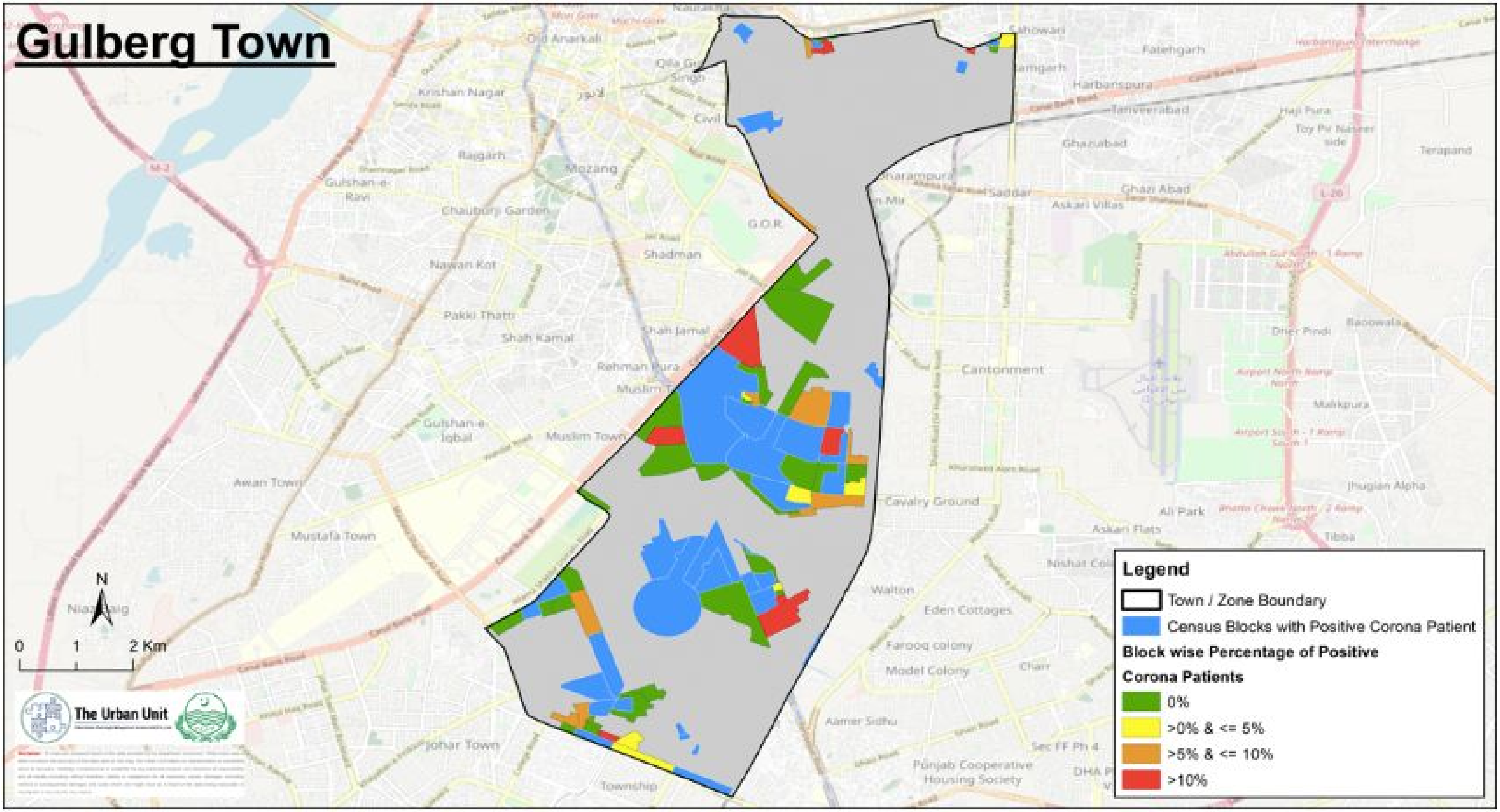
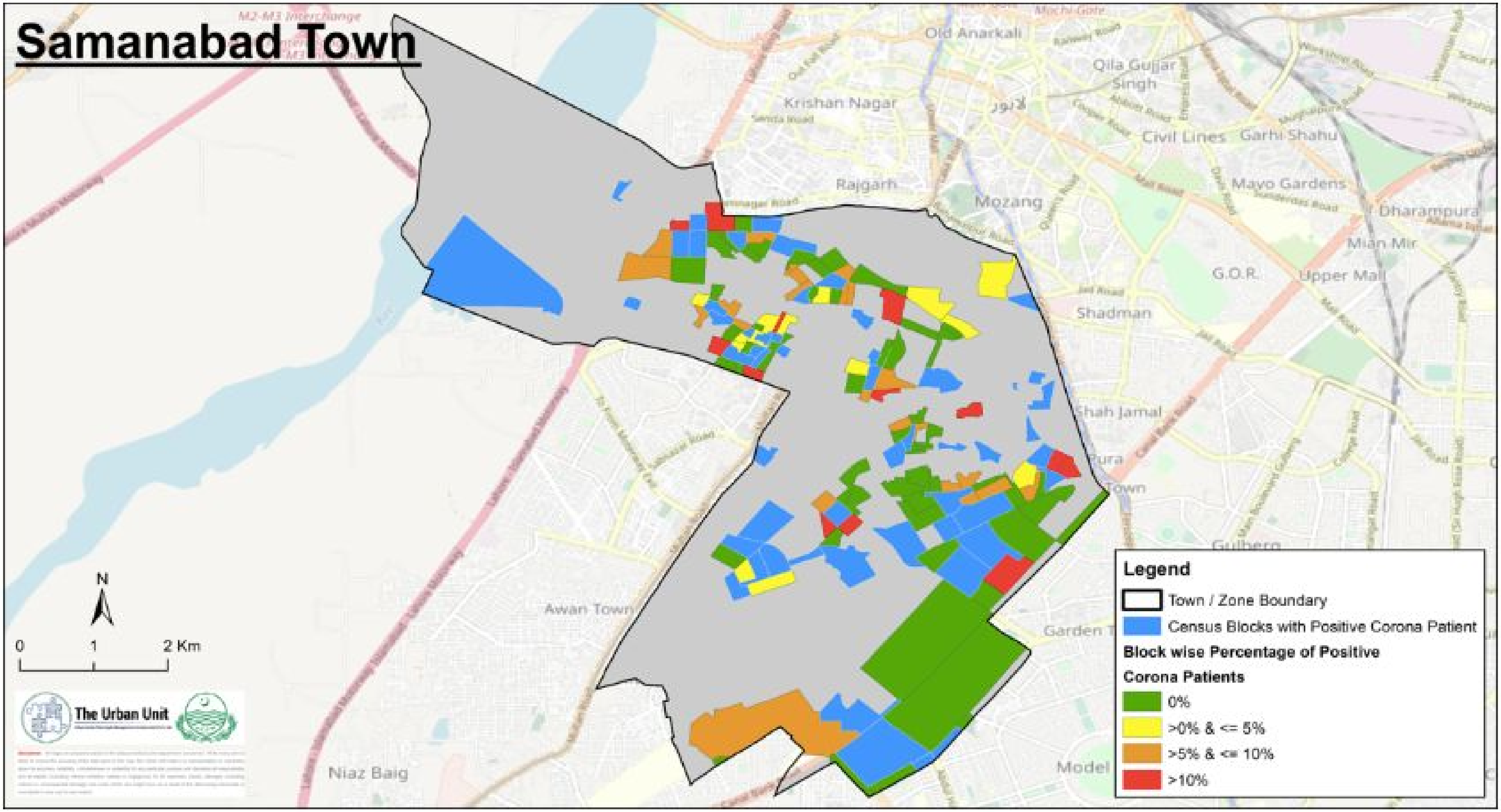


Figure 7 - Map of Samanabad Town showing Originally Infected Blocks (in blue) along with Adjacent Blocks where Smart Testing was implemented (in green/yellow/orange/red)

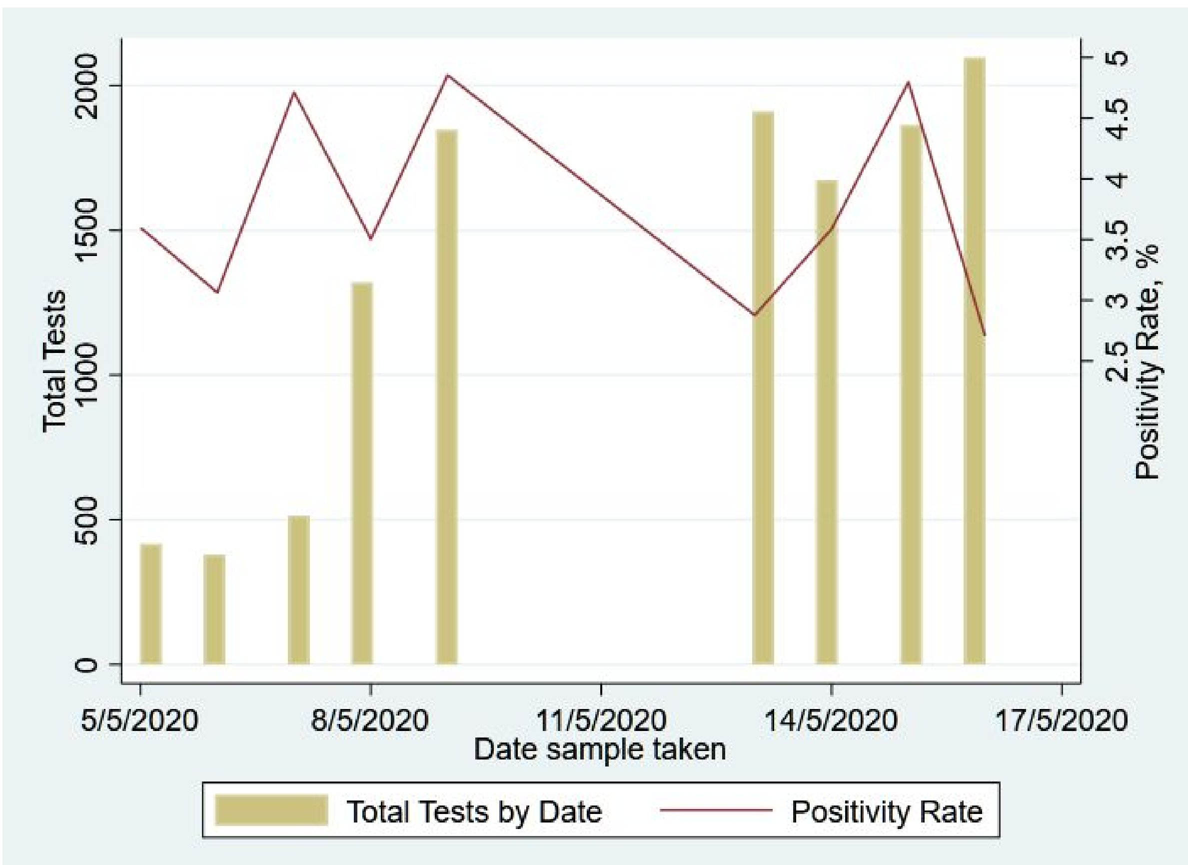


B. Prevalence Rates over time

An important statistic that informs how to deal with Covid and the extent and effectiveness of lockdowns is how prevalence rates change over time. Without taking any precautionary measures one would expect the number of infected to increase exponentially over time. While we do not have repeat samples for the same area, given that the blocks were selected randomly and tested in no specific order, looking at prevalence rates across the different days of collection provides a rough sense of how they were changing over time.

The figure below shows this evolution from 5th May to 17th May 2020. What is interesting is that the positivity rate mostly remained between 2.5% and 5% during this period with no evidence of a clear upwards trend let alone an exponential growth.

Figure 8 - Positivity rate across Wave 1 and Wave 2

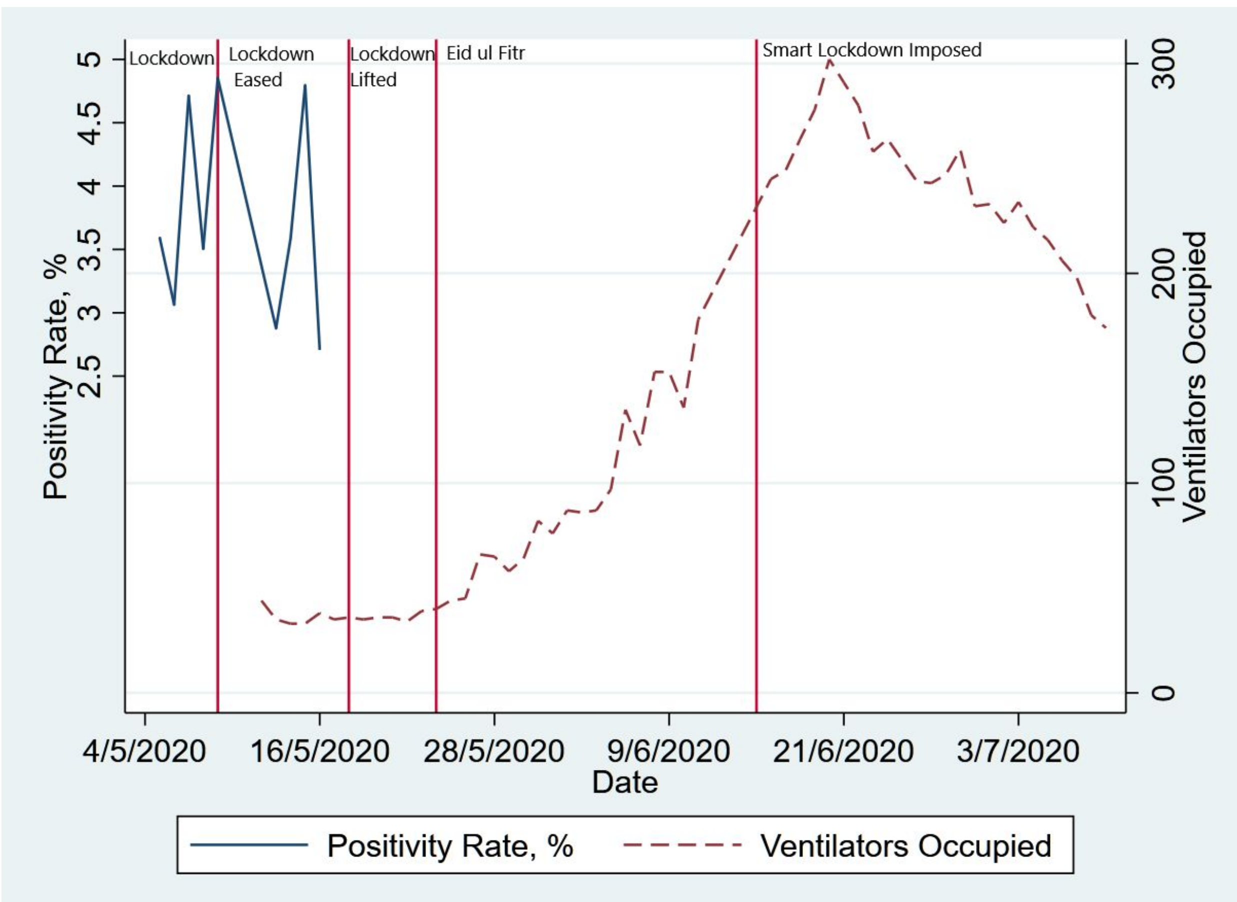


These results, while suggestive, do indicate that the lockdown period prior to Eid seems to have been somewhat effective in the sense that blocks that got surveyed later did not show significantly higher prevalence rates.

However, a more accurate picture of the efficacy of the lockdown measures would have been to have collected repeat samples and to continue testing, especially after Eid when the lockdown was eased and, more recently, when a partial lockdown was re-enacted. Unfortunately, despite strong advice given by the SCALE team, this data has not been generated and therefore we are unable to accurately assess how well the lockdowns have worked.

One piece of evidence that suggests that initial (pre-Eid) lockdown was likely to have been effective in mitigating Covid-19 spread, and that the opening up of the lockdown during Eid worsened the spread, comes from looking at ventilator usage data (in Lahore) based on statistics provided by SH&ME. We repeat the prevalence data in the previous figure but now overlay it with time-series data on ventilator usage. Note that while the positivity rate from PCR tests (blue line) provides a closer to real-time measure of Covid-19 prevalence, the number of ventilators used provides an alternative prevalence measure though with greater lag (since those infected may take longer to develop severe enough symptoms that require ventilators).

Figure 9 - Positivity rate and Ventilator Usage during different policy periods



Nevertheless, comparing these two graphs and using ventilator data to “fill in” the lack of smart PCR testing after mid-May suggests that the initial lockdown may indeed have been effective. First, note that prior to lifting the lockdown both the PCR test based prevalence data and ventilator usage shows that there wasn’t much change in Covid-19 prevalence. However, we can see that a week after lockdown was lifted, ventilator usage started increasing and continued to increase substantially suggesting that the initial lockdown indeed had been effective and the subsequent opening caused prevalence rates to increase. Further, after the imposition of smart lockdown in mid-June the ventilator usage declined in line with expectations.

Unfortunately, to really confirm this one would have needed to continue testing. The (absence of such data in the) graph above underscores the importance of testing regularly. Not only would this provide a sense of how effective lockdown strategies are and how costly opening up could be, it also allows us to provide leading indicators on hospital burden as the PCR testing numbers likely show changes before symptoms become severe enough to require hospitalization.

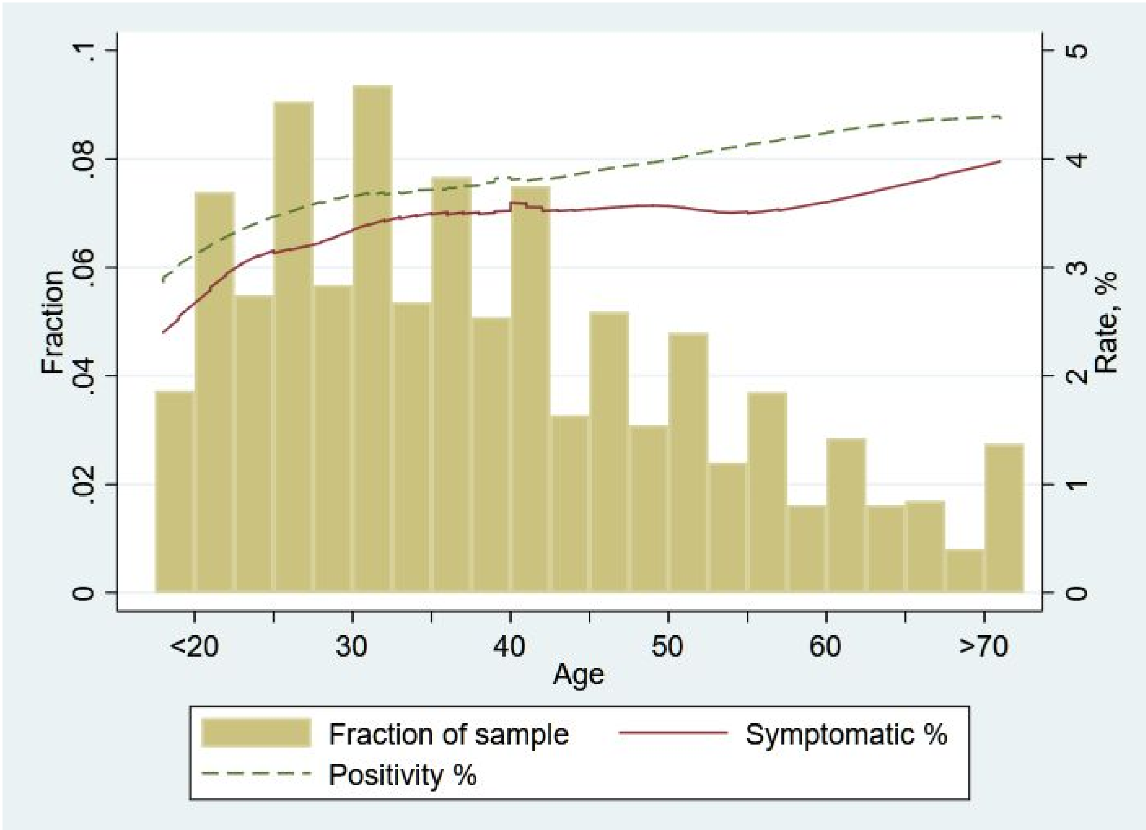
C. Prevalence Rates by Demographic Characteristics

Age: The median age among all tested was 36 years and therefore the sample skewed younger. In the figure below, the dashed green line represents the ("smoothed out") relationship between the positivity rate and respondent age.[5] The bar chart represents the fraction of our sample of a given age. Since we have few folk above 70 or below 20, in future graphs we will collapse these categories.

The main trend to note in the graph is that the rate of Covid-19 positivity increased with age of the individual tested. It is lower for younger age groups and increased at a high rate till age 30, after which it increased but at a lower rate. Among those above 50 years of age (comprising 20% of the sample), the positivity rate exceeded 4% throughout.

[5] We plot the lowess (Locally Weighted Scatterplot Smoothing) curve that shows the smoothed-out relationship between positivity against age.

Figure 10 - Age profile, symptomacity and positivity rate of sample



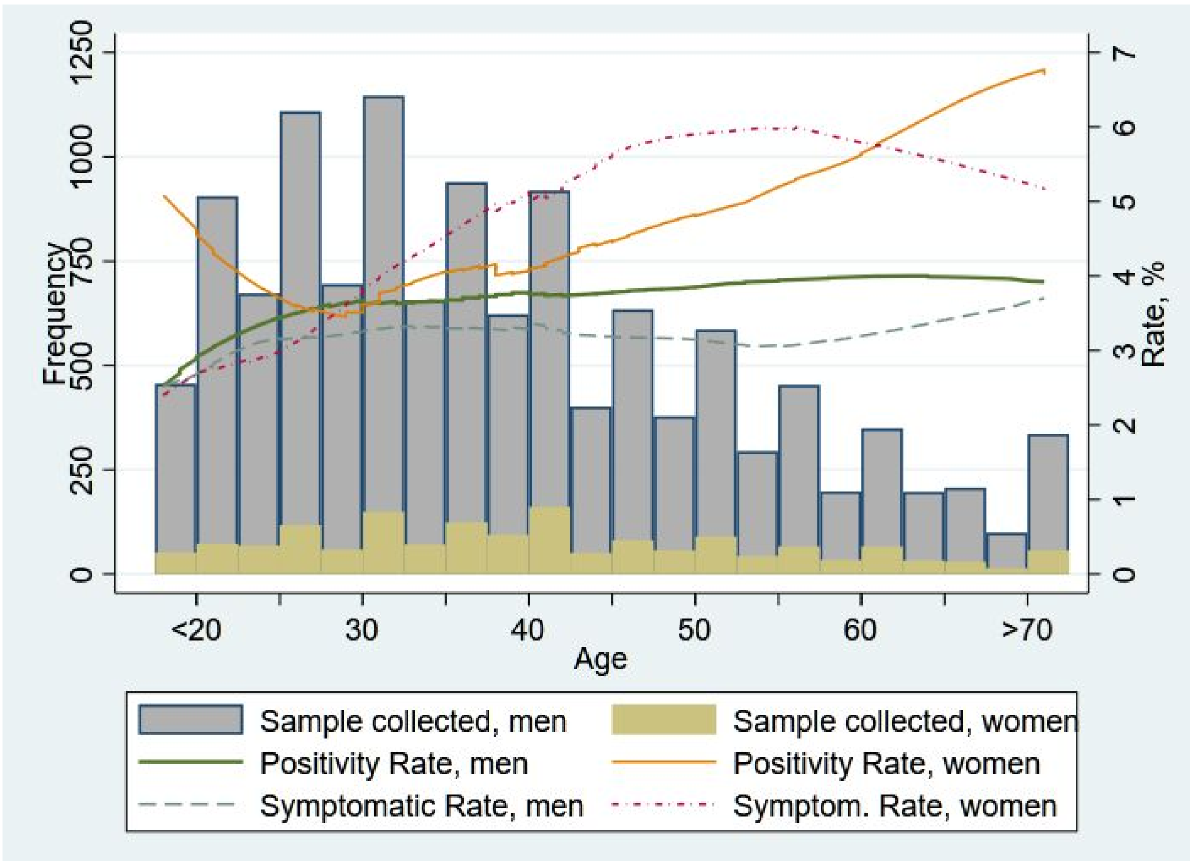
We should note that, as shown in the solid red line in the figure, part of this relationship is likely due to the higher fraction of symptomatic people we see at higher age groups. We should caution that since we do not know refusal rates at different age groups we do not know if this is a feature of the underlying population (i.e. older people are more likely to be symptomatic/infected) or is it that older people who are symptomatic are more likely to consent to being tested. As we had suggested in future rounds of testing, once refusals and reasons for refusals can be collected we could have a better sense of this. Regardless, these results do suggest extra caution for the elderly - not only do we know from other countries experiences that their morbidity outcomes may be worse, but at least based on the data we have it seems they may be more likely to be infected as well.

Gender: Likely due to social norms and the fact that we had suggested that priority be given to testing individuals within the household who had higher contacts/exposure, more men were tested (10,410 valid samples) as compared to women (1,556 valid samples). We had previously noted that the positivity rate seemed significantly higher for women (4.43%) compared to men (3.66%).

Figure 11 below examines this further by examining whether Covid prevalence varies differentially by age for men and women. Interestingly, we see a marked difference here: For men their positivity rate is rising till age 30 but then remains around 4% at all ages beyond. Women, on the other hand, after a small initial drop, show a clear and sustained rise in positivity rates with age, starting from around 4% even at ages lesser than 20 and then increasing to about 7% at beyond 70 years of age.

Without knowing if there is differential selection in who agrees to be tested it is hard for us to determine what causes this large age effect for women but not for men. While there is some selection here (see Fig 4 below which shows that there is a great fraction of symptomatic women as age increases) it is also not clear that this by itself can drive the large increases women see in being PCR positive as their age increases.

Figure 11 - Age profile, positivity and symptomatic rate by sex



Other Attributes: Another risk factor associated with contracting the virus was whether a person had to leave their residence for work. During the sample collection period, the lockdown was eased in Lahore and therefore people might have been able to commute to their workplaces. Those who were employed constituted 85.6% of the sample and showed a generally higher positivity rate as compared to those unemployed across all age groups. Overall positivity rate for those employed stood at 3.8% versus 3.2% for the unemployed, a statistically significant difference at the 10% level. Our data is too limited to draw inferences on whether different occupations have differential risks but this is something that could be worth examining in future testing.

In the early days of virus spread (February-March 2020), all the cases in Pakistan almost exclusively came from those who had either traveled internationally or their domestic contacts. In our sample, there were 532 cases of travel (4.3%) and among these only 10 had traveled internationally. In our data while 4.5% of those who traveled tested positive compared to 3.7% of those who did not, these differences are not statistically significant.

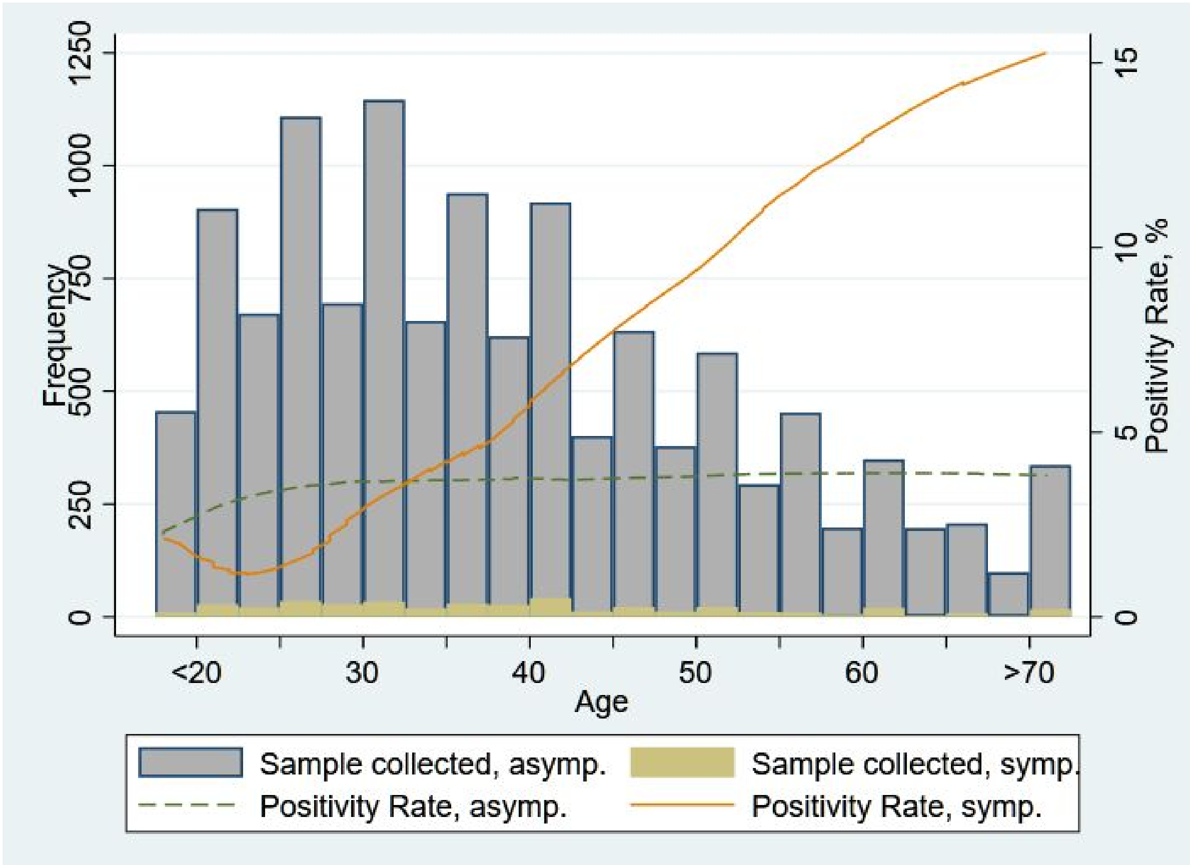
D. Prevalence Rates for symptomatic and those with pre-existing conditions

Given PCR testing is costly, one hope is that symptom based phone surveys may be an effective way of determining Covid-19 prevalence. We therefore examine how effective such methods may be.

In our overall sample, 3.4% of individuals report themselves as having relevant symptoms.. While the symptomatic rate is not that far off from the overall rate of Covid-19 prevalence rate and, as we had noted before, symptomatic rate increases with age along similar lines to Covid-19 positivity, the relationship between being Covid-19 positive in a PCR test and reporting symptoms is not as strong as one would have hoped for: While symptomatic individuals were more likely to have tested positive in PCR testing (5.7%), this is only slightly greater than the PCR-based Covid-19 prevalence rates in asymptomatic individuals (3.7%). While the difference is statistically significant, with close to 95% of those detected as Covid-19 positive in the PCR tests being asymptomatic, it does not seem symptom based surveys will be an effective way to identify the majority of infected individuals.

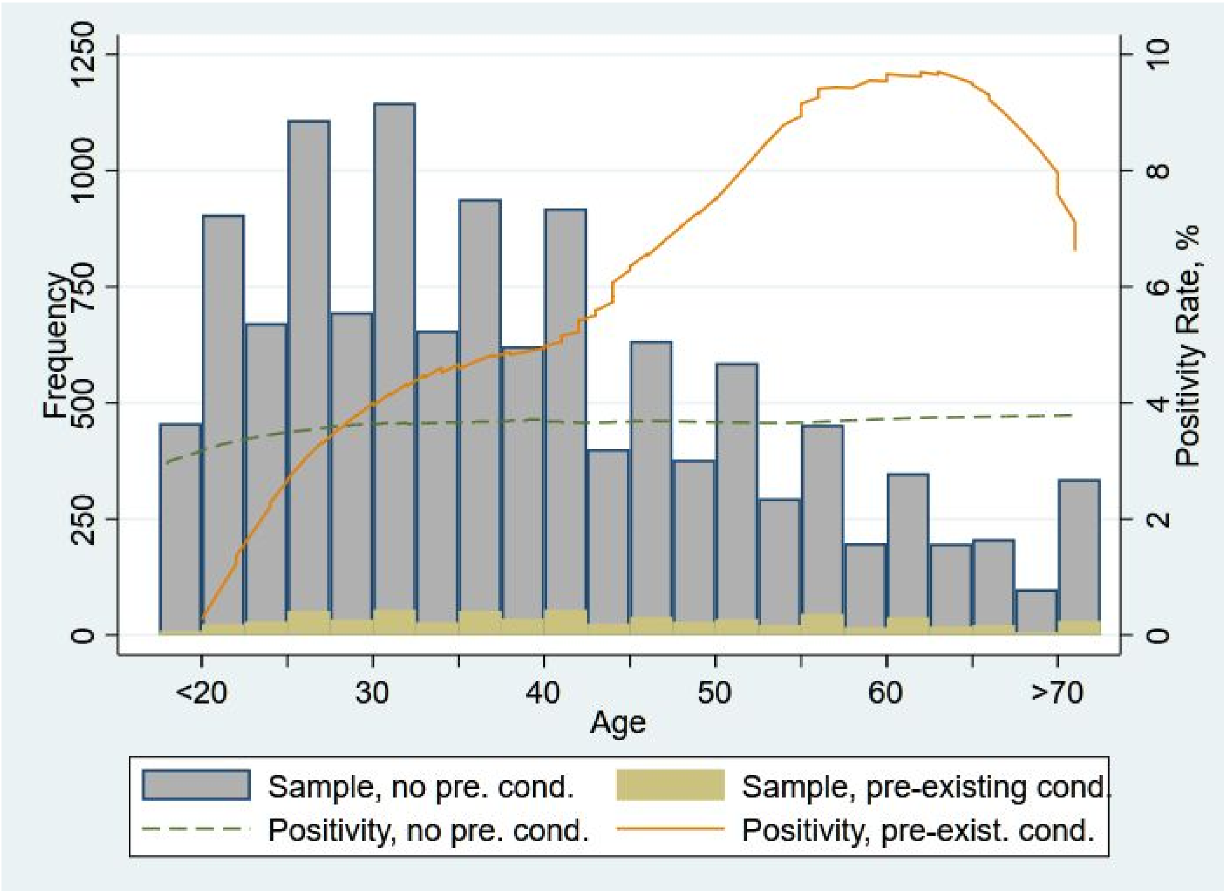
Further analysis reveals that for asymptomatic individuals, there is little pattern with age - while there is some initial increase with age, past late 20s the positivity rate remains stable at around 4%. In contrast, for those reporting symptoms, there is (after a small initial dip) a very strong positive relationship between positivity and age with older people exhibiting substantially higher positivity rates. For individuals reporting symptoms, those greater than 50 years of age have a prevalence rate of around 13%, which is significantly higher compared to those less than 50 (3.8%). This suggests that while symptom based identification may be generally less useful, it is more indicative of Covid-19 prevalence for older individuals i.e. those above 50 years old are more than three times more likely to show Covid-19 positivity if they are symptomatic than if they are not. Though even in this older population around 91% of those detected as positive in PCR-testing report no symptoms.

Figure 12 - Age profile and positivity rate by symptomacity



In addition, it is also instructive to examine whether individuals with pre-existing conditions show differential rates of positivity. In our sample, 707 (5.8%) people reported having any pre-existing conditions such as diabetes, hypertension, breathing issues, etc. Given what we know about underlying prevalence, we suspect there may be some under-reporting here. Nevertheless, we find that the overall positivity rate of those with pre-existing conditions was 5.8% compared to 3.6% with no pre-existing conditions and this difference is statistically significant. Among those with no conditions, the positivity rate rises in earlier ages and then remains around 4% into higher age brackets. However, those with pre-existing conditions exhibit an increasing positivity rate with age, peaking at around 10% among the elderly. Curiously and somewhat puzzlingly, this drops at above 60 year olds though that may be driven by differential reporting and smaller samples.

Figure 13 - Age profile and positivity rate by pre-existing conditions



E. What Predicts Covid-19 prevalence? A Multivariate Regression Analysis

While there is limited data available, we can still shed some light on what factors may be predictive of Covid-19 prevalence rates. In order to do so, we conduct a multivariate regression analysis utilizing some of the individual attributes mentioned above, as well as some group attributes (like the level of infection in your vicinity) and the population attributes (such as density) in your neighbourhood.

The Table below shows the result of this analysis. Column (1) first only includes variables that are not directly related to Covid-19 (i.e. whether someone is symptomatic and the positivity rate in a person's vicinity) since that is a prediction model that can be used without any testing or special surveying for Covid-19. Column (2) then adds additional factors that are related to Covid-19 specifically - namely whether an individual reports symptoms and the percentage of infected individuals nearby.

Column (1) shows that once we include all these factors together, the two factors that increase an individual's chances of being Covid-19 positive are (i) whether they have pre-existing conditions and (iii) the population density in their surrounding areas. Having a pre-existing condition increases the probability that one is Covid-19 positive by 2.2 percentage points (a 58.5% increase over the average positivity rate of 3.76% in our sample) while an increase of 100,000 people per sq-km (around 0.4 standard deviations increase in population density in our sample) increases the likelihood of infection by 0.3 percentage points for every 100,000 greater density.

Column (2) includes the additional factors that capture whether someone is symptomatic and the percentage of people who are infected in their vicinity. We find that a person is more likely to be infected if individuals near them are infected. People in a person's testing "pool" are those individuals who are essentially their neighbours or live close enough that there were part of the same pool of tests. Here we find a 1 percentage point increase in positivity rate in people who were in a person's testing pool increases the probability they are positive by 0.6 percentage points. Another way of saying this is if everyone in an individual's testing pool was positive then their probability of being Covid-19 positive would increase by 60 percentage points! Interestingly, there is an (additional) effect of 0.2 percentage points increase in being Covid-19 positive if there is a 1 percentage point increase in the percentage of people who are Covid-19 positive and live within a 1km radius of the (but not in their pool). However, there is no additional effect of the percentage of people that are between 1km to 2km, and 2km to 3km of where the person lives. These results suggest that the likelihood of infection increases the greater the percentage of people around an individual are infected but that this effect decays as the distance increases so that people more than 2 kms away don't matter as much, i.e., the infectivity likelihood is very localized. Interestingly, once we include these measures of local infection rates population density no longer matters. This suggests that higher density places are worse off only to the extent that a more dense place means a greater chance that someone is infected nearby.

Regression analysis

VARIABLES	(1) Probability of Individual testing Positive	(2) Probability of Individual testing Positive
Age	9.56e-05	5.67e-05
	(0.000124)	(0.000118)
Male	-0.00596	-0.00373
	(0.00520)	(0.00495)
Symptomatic		0.00570
		(0.00965)
Any Preexisting Condition	0.0216***	0.0164**
	(0.00757)	(0.00748)
Traveled Domestically	0.0109	0.00550
	(0.00888)	(0.00850)
Traveled Internationally	-0.0381	-0.0152
	(0.0673)	(0.0638)
Average Household Size	-0.000138	-0.000144
	(0.00113)	(0.00108)
Population Density (x00,000 per sq km)	0.00306***	0.000341
	(0.000689)	(0.000687)
Positivity Rate in Pool, %		0.00594***
		(0.000184)
Positivity Rate (1km radius), %		0.00229***
		(0.000647)
Positivity Rate (2km radius), %		-0.000697
		(0.00153)
Positivity Rate (3km radius), %		0.00113
		(0.00155)
Constant	0.0302***	0.00522
	(0.00986)	(0.00955)
Observations	11,873	11,815
R-squared	0.003	0.106

Standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Note: Positivity rates in the pool and 1km, 2km, 3km radii are calculated using 'leave-one-out' method by not including the individual in the calculation. This is done to avoid spurious results where one's own positivity also contributes to the calculated positivity rate.

F. Testing Costs and Efficiency

One of the concerns regarding testing may be the financial cost associated with it. While these costs may well be worth it given the value testing and prevalence detection has in reducing future spread, part of the value-additions of our smart sampling and testing strategy has been a large reduction in these costs and an increase in the efficiency of testing.

Based on data received from P&SHD the typical cost of testing is Rs 3,500 per test. Once we factor in the personnel costs of actually collecting test samples this goes up to Rs 3,663 per test.

In our case, we were able to adopt a pooled testing approach by creating pools of ten individuals. Therefore, while each individual person in the pool would have a sample taken, there would only be one test run for the combined sample. If the test was negative no further testing would be done. However, if the test was positive, then each of the ten individuals in that pool would be tested. Given that the majority of pools were negative (79%), this meant that far fewer overall tests needed to be conducted. As a result of this we were able to effectively reduce the cost to Rs 1,170 per test, or Rs 1,334 per test once we factor in costs of collecting the samples.

This is a remarkable and noteworthy saving, as pooled testing effectively reduces the overall cost of testing by a factor of three (i.e. a 63.5% to 66.5% drop in costs). Another way to think about this is that just this change alone allows us to sample three times as many individuals in the same budget. While this is already a significant saving, these costs could be further reduced if larger samples were pooled.

The testing strategy that was adopted also allows us to make considerable headway on two key fronts, which are not only important for Pakistan but also for understanding transmission globally. First, in countries like Pakistan, the number of Covid-19 cases is rising rapidly with increasing evidence of community transmission. Once community transmission is underway, the epidemic is harder to contain through contact tracing alone; some level of community surveillance is required. Second, there is growing evidence, consistent with our data that a large fraction of people infected with Covid-19 are asymptomatic, and although there is a dearth of studies from Pakistan, it appears that many of these patients are truly asymptomatic, rather than pre-symptomatic. The question we are then in a unique position to ask is: How does community transmission and the presence of asymptomatic individuals affect the community surveillance strategy for Pakistan?

We are concerned here both about effective epidemic control and the costs of testing. For effective epidemic control, identifying individuals early in their infectious stage can help break transmission chains. But if many infective patients are asymptomatic, screening on symptoms alone is insufficient. It can also be very costly. To see why, consider how much it costs to detect a single positive patient. With community surveillance, this includes both the costs of screening and the cost of testing. If a large fraction of patients are asymptomatic, screening on symptoms may be less effective even compared to simple random sampling.

In our testing data, we can calibrate these costs exactly. In doing so, we find that even without pooling, a strategy of smart testing like the one we used is more than 50% cheaper in the cost per positive case detected than a policy of first screening for symptomatic individuals and then testing (only) them. One we factor in pooled testing, these savings are as high as 75%.

Taken together, these results highlight how large a saving can be generated by adopting a process of smart sampling and testing.

Conclusions from Implementation and Analysis

While Punjab's Smart Sampling and Testing process only remained in place for a few weeks (early to mid-May), it helped build significant and impressive capacity in the P&SHD team to run smart and cost-effective sampling, testing and data collection activities that remain as critical to informing the Covid-19 policy response as ever.

The analysis above has already revealed several useful and important findings that can directly inform the Covid-19 response for the months to come.

First, it has demonstrated that Smart Sampling combined with pooled testing is not only feasible but can be carried out regularly and at-scale across the province to determine how Covid-19 prevalence is changing over time, even at the level of sub-neighbourhoods within cities. This is a critical tool in helping us understand the effectiveness of various kinds of lockdown policies, as well as how soon and costly an opening up can be. Already our analysis suggests that the initial lockdown was likely quite effective and the past few weeks have suggested that such policies may continue to be an effective tool for containment. Importantly, by tying the extent of future lockdowns to such data the Government of Punjab can ensure effective implementation of the much needed *evidence-based* smart lockdown and containment policy.

Second, our results have shown that we can readily combine the testing process with a rapid and real-time data collection exercise. While we used the system to focus on data that helped us better understand the demographics and patterns of the disease, we can easily amend this and add data on other non Covid-19 related health outcomes as well as economic impact outcomes (such as food security, poverty, employment, income etc.) that will help provide a sense of how costly the lockdowns are to the economic welfare of citizens. By obtaining this additional data, we will be able to arrive at a better policy decision that balances the costs and benefits of each lockdown/opening up strategy. These data will remain just as important even as the Covid-19 prevalence diminishes since they would then help inform and better target the process of rebuilding and restoring affected families and the overall economy.

Third, our analysis already reveals several interesting findings that have several policy implications at least for urban areas like Lahore:

(i) Our results suggest a clear and much needed focus on the elderly. We know from global experience that the elderly face worse health outcomes. Our results provide additional reasons to focus on the elderly as we find that not only are they more likely to be symptomatic, they also have somewhat higher Covid-19 positive rates. In fact the elderly are much more likely to be Covid-19 positive if they are symptomatic. From a policy perspective this suggests we need to target our messages to the elderly and those who interact with them to ensure that they are better quarantined/protected and their symptoms are more closely monitored.

(ii) Our results suggest women may if anything show higher positivity rates. Given the lower mobility women usually face due to social constraints, this finding is surprising but underscores the importance of greater testing and support for women. To the extent that women may have more activities/exposure *within* the household and they are also key to helping improve the household safety environment, within household safety and infection mitigation messaging needs to be developed and emphasized.

(iii) The very high fraction of positive Covid-19 cases reporting as asymptomatic suggests that messaging needs to make clear that just because you show no symptoms does not mean you should not be taking protective measures since you may inadvertently spread the disease. Therefore, wearing masks should be stressed equally for those who are experiencing no symptoms whatsoever. Moreover, this also cautions against using symptomatic data in general as a way of determining prevalence rates of targeting policy and messaging. Essentially, our results suggest that it is safe to assume anyone - regardless of symptoms - may be infected and therefore all need to be careful. Appealing and effective public messaging - targeted to all age groups and especially the young - needs to be developed.

(iv) Our results suggest that people are more likely to be infected if they have an infected person in their vicinity, pre-existing conditions, and if they live in a densely populated area. This information not only should help target where lockdowns will be more effective but it also needs to be shared more widely with the public, including but not limited to publicly sharing prevalence rates (while protecting individual privacy) at the smallest possible geographical unit, so individuals understand the risk they face if they are in dense areas with infection present and can take extra precautionary measures.

Finally, our analysis also reveals that there is substantial and very localized variation in Covid-19 prevalence rates. This emphasizes the need to not only measure prevalence at the smallest possible feasible geographical units, but it also means that lockdown policies will be more effective and overall less costly to the economy if they can be implemented at such localized levels. Even as we start containing Covid-19 prevalence in the urban areas, it is likely that we will get new spread in previously unaffected areas or a resurgence in previously affected areas especially as economic activity starts reopening as the summer draws to a close. Allowing for such time- and regionally- varying lockdowns is consistent with the most recent strategy adopted in Pakistan but it is critical that this be informed by the prevalence measures and analysis similar to the one Punjab has initiated through its Smart Sampling and Testing strategy.

Policy Recommendations

While our study so far has shed light on such important policy measures, we would be remiss in not pointing out that the full value of the analysis can only be realized if the Punjab Government continues with and scales up the proposed Smart Sampling and Testing strategy. Punjab is extremely well placed to do this since a lot of the basic implementation capacity has been built up due to the courageous enthusiasm and diligent effort shown by P&SHD, Urban Unit and their field teams. As a result, the value-add to policy of further testing and data analytics has dramatically increased due to the costs having gone down and the potential benefits having gone up. The SCALE consortium feels strongly that not continuing and expanding the smart sampling process has already resulted in missed policy opportunities. Even as we are hopeful that the current lockdown measures both during the past few weeks and over Eid-ul-Adha may have been effective in containing disease spread, it is also clear that until a vaccine is successfully produced and deployed - a process which make take several months even under optimistic scenarios - lowering Covid-19 prevalence needs to remain a central focus of policy. We therefore maintain that it is critical to make use of the capacity built over May and continue the analysis and policy insights generated. In light of this, our recommended next steps are outlined below.

1. In the short run, we need to **immediately restart testing and data collection** based on Punjab's Smart Sampling and Testing strategy. We should start by retesting a few of the places tested earlier to get a sense of how prevalence rates have evolved over the past few weeks given that this period included both Eids and the more recent smart/partial lockdowns. While not testing in June and July was a missed opportunity, we believe also utilizing serological testing along with RT-PCR tests can provide a sense of the disease evolution.

2. Combined with this testing we need to **test a range of "front-line" workers**, as suggested in the Wave 2 testing strategies that were never implemented. These should be prioritized first for health-care frontline workers. While there is appropriate emphasis placed on the supply of medical equipment (isolated wards/beds, ventilators etc.), equally if not even more concerning is the fact that healthcare workers may be falling ill, thereby leading to reduced healthcare capacity. It is therefore critical that we do Smart Sampling and Testing of these workers to get a sense of Covid-19 prevalence. In addition to these, we feel there are a range of others who are also front-line workers - such as those working in pharmacies, staff in quarantine facilities, exposed bureaucratic staff, emergency response teams, enforcement officials, supply-chain logistics providers, immigration/border officials, public transport workers, retailers - and need to be tested.

3. We should also **conduct follow-up surveys with all those who are detected positive** both in our sample but more generally in the Punjab so that we can trace out healthcare

needs and long-term morbidity outcomes for the population. The SCALE team is open to helping design the data gathering and analysis protocols.

4. In addition, while some contact tracing data has been recently shared with us and we hope to analyze this once the complete data has been provided, it is imperative that the **contact tracing process be systematically designed and implemented**. This process is critical in preventing spread and is especially feasible when there is a low level of infection. Thus it can be useful for both places where the disease may have just started or where it is now in decline. Moreover, setting up such a system will also help contain spread in places where there is risk of disease resurgence as has been seen in many places globally when they have begun to reopen. The SCALE team is willing and able to help with the analytics for the design and analysis of this critical process as well.

5. Finally, in the medium to longer term, there is a need to **expand the Smart Sampling and Testing - both geographically and in terms of its scope**. Geographically, we need to expand Punjab-wide, starting first with other urban and rural areas with a high degree of likely Covid-19 prevalence and then moving to other areas. In terms of scope, the data gathering exercise needs to be expanded to add not just Covid-19 related health outcomes but also other health outcomes that may be exacerbated due to both Covid-19 presence and perhaps even more importantly, due to the lockdown and related measures that are being implemented to address the pandemic. These surveys should also be combined with measures of socio-economic outcomes such as poverty, income, employment, food security, social issues and conflict that may be induced due to the policy measures being taken to reduce Covid-19 spread. Provided there is substantial and continued policy support and buy-in, the working group could also help with these medium to longer term policy design and analysis needs as well.

APPENDIX 1 - Smart Testing Strategy Document

Yale Institute for Global Health | CERP Centre for Economic Research in Pakistan | LUMS | Center for International Development at Harvard University

Smart Testing Strategy for the SCALE (Smart Containment and Active Learning) Covid Response

This is a living document and will be updated based on learnings. The step-wise strategy for implementation is given below.

Step 1: Define the lowest sampling grids "S" for City/Districts and conduct data diagnosis

- ➔ 'S' should be as small as minimally feasible (200+ households)
- ➔ Shape files (geo-referenced boundaries) will be required for 'S'
- ➔ Ideal 'S' are census block/mauzas as that will allow for overlaying census information (population density, distribution of age etc.)
- ➔ Alternative options: If census blocks/mauzas not available, then the following can also be used:
    - ◆ UCs
    - ◆ Geo-referenced grids
    - ◆ Creating geo-referenced polygons using cell phone towers
- ➔ Conduct a data diagnosis to assess the usability of the data[1] that is being collected and understand its workflow

Inputs	Outputs
1. Shape files of 'S' grids 2. Census data on 'S' grids 3. Geo-locations of isolation centers, quarantine facilities hospitals and labs conducting PCR Tests 4. Data Diagnosis	N/A

Step 2a: Contact Tracing Testing

- ➔ Identifying contacts of known positive cases - there are two ways to obtain this:
    - ◆ First preference: Through Call Detail Records (CDR) and/or Cell Phone Tower Data. The steps involved would be as follows:
        - ● Provide telecom operators with cell phone numbers of infected patients

[1] Health, location, and contact tracing data is personal data. Information collectors should ensure that the data collected is accurate and secure. The integrity of data can be improved by cross-referencing it with reputable databases and by providing access for the consumer to verify it. Information collectors can keep data secure by protecting against both internal and external security threats. They can limit access within their organization to only necessary employees to protect against internal threats, and they can use encryption and other computer-based security systems to stop outside threats.

    - Identify exposed people - identify individuals that were in the same physical location (same tower) during the span of 15 minutes and/or 30 minutes overlapping window in the past 14 days (ideally 3 weeks). If this number is not too large, use it. If it is too large, narrow it down further to exposed *contacts*
    - Define contact list - ask telecom operators to identify all numbers called by the infected person's number for at least 14 days (ideally 3 weeks) prior to the person's infection start date
    - Narrow down list of exposed *people* to exposed *contacts* by excluding everyone from exposed people list who are not in contact list
  - Second preference: Actual contact tracing done through in-person surveys/phone calls/robocalls (will capture contact details and work/home location of contacts)
- Test & administer basic in-field survey (survey captures basic demographics useful in refining disease model) to contacts and geotag where they live/work and assign to appropriate 'S' grid

Inputs	Outputs
1. Individual level data on contact tracing (CDR or captured through surveys/robocalls) 2. Home and work geo-locations of traced contacts	1. Overlaying the data from inputs on appropriate 'S' grids

Step 2b: Exposed Frontline Worker Testing

- Identify all exposed frontline workers. These are workers (medical staff, caretakers, police and government officials, etc.) who are/have been in direct contact with infected people (with 10 minutes or more of exposure)
- Test & administer in-field for contacts and geotag where they (i) work and (ii) live and assign to appropriate 'S' grids

Inputs	Outputs
1. Individual level data on exposed front line workers 2. Home and work geo-location of frontline workers	1. Overlaying the data from inputs on appropriate 'S' grids

Step 3: Testing in 'S' grids

- Prioritize 'S' grids in the following types - start testing in Category 1 first and then move to lower priorities:
  - <u>Category 1</u>

- ‘S’ grids that have no infection detected as yet but are next to a grid which has an infection
    - ‘S’ grids that have a high number of frontline workers working or living in them
    - ‘S’ grids with people who have high mobility/travel/connectivity
  - Category 2:
    - ‘S’ grids that have high population density
    - ‘S’ grids with large fraction of high health risk people (elderly etc)
  - Category 3:
    - Remaining ‘S’ grids (including ones where we already KNOW there is infection - testing in grids we have cases detected is not as informative which is why it is given lower priority - they are top priority for antibody testing though)
- Conduct the following types of prevalence testing:
  - **Screening and Testing:**
    - Ideal - but may be in limited supply; Instead of randomly testing people in ‘S’ grid, test those who are High Infection Susceptibility (i.e. people who have higher likely of infection) since this gives a more efficient way of testing (i.e. will need to use less tests to detect infection). These can be defined as people with (i) high number of physical contacts/interactions and/or (ii) high mobility
      - FOR PCR Testing pool 10 or 20 tests each depending on what you have been instructed to do. Follow Pooled Testing protocol. Make sure everyone is also administered an in-field basic survey
    - **Preferable method is using CDR data**:
      - High physical contacts: The following complementary approaches can be used
        - run algorithm for each phone number by seeing in one week (can use the most recent full week - make sure weekend and weekdays are included) what is the total number of OTHER phone numbers that were in the same physical location as they were in an overlapping 30 minute time window - list (phone no & location) of the top 5% percentile in this measure
        - run algorithms on CDR data to identify high contact nodes who are in contact with more people/links (restrict these to those within the same city and also see which of their edges are more active for further contact tracing)
      - High mobility folk: These are people who move around a lot (so could be more likely to get exposed) - run algorithm to count how many unique towers (i.e. different locations) the person has been at - can refine this over time to maybe weigh locations that are hot spots - provide list (phone & location) of the top 5% percentile in this measure

        - Build profiles of high contact/mobility individuals by combining CDR data with administrative records
    - **If CDR data not available then define High physical contacts/mobility by**:
        - Randomly arriving at the GPS pin location provided in 'S' Grid - Test & Survey member of household who has highest contact/travel in past 14 days (may not be owner but could be domestic help who does regular shopping etc.) AND ask the household head who is a person with high contacts nearby OR who is their friend nearby (people who are identified as friends will likely have higher connectivity) and then go and Test & Survey them

- **Sentinel Surveillance PCR Testing**
    - Identify main 2-3 sewage collection points in 'S' Grid and collect sample by using protocols similar to those for polio environmental surveillance through sewage sampling
        - This is an experimental approach and will require a pilot before being rolled out on a broader scale. Areas where grid maps of sewerage are available would be required
    - Take samples and note the GPS location where the sample was taken

- **Phone-based Syndromic Surveys**
    - Call randomly selected numbers (if possible prioritize numbers that show high mobility or physical contact in past 2-3 weeks) and administer survey of symptoms on the phone (this can also be done through robo-calls)

Inputs	**Outputs**
1. Categorize 'S' Grids a. Identify high mobility and high contact individuals to administer appropriate tests 2. Contact details and biographic data on high mobility/high contact individuals	1. COVID19 detection PCR tests and field survey on people with high mobility and high no of contacts 2. Sentinel Surveillance by testing water samples and recording GPS location where the sample was collected from 3. Syndromic Surveys through Robocalls and Phone CATI 4. Positive cases overlaid on respective 'S' grids 5. Action items for stakeholders to take in respective 'S' grids a. SOPs for dealing with Positive cases (option for isolation at home)

Step 4: Follow-up socio-economic and broader health surveys

- All individuals tested are administered short phone surveys that will capture their socio-economic as well as broader health situation. This will be used to see what other costs they are incurring and what help may be useful to provide to them

Inputs	Outputs
1. Contact details and relevant biographic data of all individuals tested	1. CATI phone surveys to capture socio-economic and broader health concerns 2. Overlay the information on appropriate ‘S’ grids 3. Devising action items for the stakeholders in ‘S’ grids

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Smart Containment with Active Learning (SCALE) is a multidisciplinary policy response to COVID-19 that draws on the expertise of researchers and practitioners in public health, infectious diseases, epidemiology, economics, policy and public management, technology and data science as well as business & non-profit leaders. We have assembled a broad coalition of experts from leading institutions including Centre for Economic Research in Pakistan (CERP), Harvard Center for International Development (CID), Yale Institute for Global Health (YIGH), Lahore University of Management Sciences (LUMS), London School of Economics (LSE) School of Public Policy, and Georgetown University to develop SCALE.

As part of SCALE, we are producing a series of ancillary documents that provide more detail on specific topics. The logos on each ancillary document represent the institutions of the experts who have lent their subject-specific expertise for its production.

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For comments, please reach out to us at: covidrapidresponse@cerp.org.pk.

APPENDIX 2 - SURVEY INSTRUMENT

SCALE Survey Instrument Repository for Testing and Tracing

This repository consists of 7 modules.

TESTING SURVEY: Module 1, 2, 3, & 4 will be asked from the same respondent at the time of taking the sample for PCR test. This will be done for 10 respondents on each GPS point for a particular area (S Grid number)

Module 1 - S grid Identification: This is section is solely for enumerators to fill up is to keep track of areas covered (S grid and GPS points)
Module 2 - Respondent Info and Testing: This section contains basic respondent information and where test sample should be taken
Module 3 - Travel History: This section records basic travel history of the respondent
Module 4 - Clinical History: This section records clinical history of the respondent

FOLLOW-UP SURVEYS: The modules below are 3 different follow-up survey instruments for Pool Testing follow-up (incase the result is positive), a follow-up with individual positive cases & a Contact Tracing questionnaire.

Module 5 - Pool Testing Followup: If for any specifc pool, the result comes out positive, then follow-up individual test samples will be taken for each individual that was part of that pool
Module 6 - Followup with postive case(s): Here, enumerators will survey people from the pool who tested positive. They will gather information on other people these positive cases have come into contact with
Module 7 - Contact Tracing: Enumerators will reach out to the contacts provided in Module 6 and survey these contacts using questions here. To get additional data points on traced contacts, Module 3 (Travel History) and Module 4 (Clinical History) are also recommended to be administerd

VER 1

SCALE Survey Instrument				
Module 1 - S Cluster Mapping/ Identification				
Input field name	**Question**	**Relevance**	**Option choices**	**Notes**
S 1	S Grid number (Census block number)			This will be manually entered by referring to the S grid numbers (census block numbers) provided by Urban Unit
S 2	Choose one of the following to describe this survey		1. First interview at pin location 2. Tracked contact at PIN location 3. Follow up after someone tested positive	
S 3	Which area is this?	If S 2 = 1		
S 4	Which GPS/ PIN point is this?	If S 2 = 1		This will be manually entered by referring to the GPS point numbers within each S grid provided by Urban Unit
S 5	How many people have you surveyed at this PIN location, including this survey?	If S 2 = 2		

SCALE Survey Instrument				
Module 2 - Respondent Identification and Biographic information				
Input field name	**Question**	**Relevance**	**Option choices**	**Notes**
RI 0	Identify the person in this Household who has the highest number of contact/ physical interaction with other and/ or is the most mobile?			
Note for enumerator: Record the following for the identified person				
ID	ID (Auto-generated)			This is a unique inhouse generated ID by the HISDU team that will be unique for each individual tested/surveyed
RI 1	First Name			
RI 2	Last Name			
RI 3	Gender			
RI 4	DOB			
RI 5	CNIC Type (Self/Guardian)		1. Self 2. Guardian	
RI 6	CNIC			To be entered withouth dashes or spaces
RI 7	Contact number (Mobile)			To be entered withouth dashes or spaces
RI 8	Alternate number			To be entered withouth dashes or spaces
RI 9	District/City			
RI 10	Home Address			
RI 11	Home geolocation			
RI 12	Work Address			
RI 13	Work geolocation			
RI 14	Occupation		1. Health Occupation 2. Self-employed (owns his/her own business) 3. Law Enforcement and armed forces (police, army, etc.) 4. Legal Profession 5. Employed 6. Teacher/ Professor 7. Student 8. Unemployed 9. Other	
RI 15	Name of company/org			
R16	During an average day in the last two weeks, how many people have you spoken to for at least 10 minutes?			Write a number here
R17	Over the last two weeks, have you been to any place with more than 10 people (this could include a market, a wedding, or a masjid).		1. Yes 2. No	
Note for enumerator: After recording the above information, conduct the test for pool sample				

PL 01	Pool or Individual Sample		1. Pool 2. Individual	
PL 02	Pooling ID (Auto-generated)	if PL01=1		Unique ID for pooled test sample generated at the backend
PL 03	Test ID (Auto-generated)	if PL01=2		Unique ID for individual test sample generated at the backend
PL 04	Date of sample			Record date
Note: After taking sample, ask following				
FU 01	Name of your close friend in this neighborhood?			
FU 02	Name of person1 in this neighbhorhood with highest contact points/mobility?			
FU 03	Name of person2 in this neighbhorhood with highest contact points/mobility?			
FU 04	Name of person3 in this neighbhorhood with highest contact points/mobility?			

SCALE Survey Instrument				
Module 3 - Travel History				
Input field name	**Question**	**Relevance**	**Option choices**	**Notes**
ID	ID (Auto-generated)	Pull from central database		This is a unique inhouse generated ID by the HISDU team that will be unique for each individual tested/surveyed
TH 01	Travel History in the last 3 weeks		1.Domestic 2.International 3. No travel	Select multiple
TH 02	Which country did you travel to?		1. United Kingdom (UK) 2. United States of America (USA) 3. China 4. United Arab Emirates (UAE) 5. Thailand 6. Turkey 7. Germany 8. Qatar 9. Oman 10. Bahrain 11. Saudi Arabia 12. Other	
TH 03	Did you self-isolate for 14 days when you returned to Pakistan?	PI 6 = 2	1. Yes 2. No	
TH 03	Point of entry into Pakistan	PI 6 = 2	1. Lahore 2. Islamabad 3. Karachi 4. Sialkot 5. Multan 6. Peshawar 7. Quetta 8. Other	
TH 04	Which areas did you visit during domestic travel? (select all that apply)	PI 6 = 1	1. Islamabad 2. Karachi 3. Quetta 4. Peshawar 5. Sukkur 6. Bahawalpur 7. Lahore 8. Faisalabad 9. Gujranwala 10. Gilgit 11. Other	

SCALE Survey Instrument

Module 4 - Clinical History

Input field name	Question	Relevance	Option choices	Notes
ID	ID (Auto-generated)	Pull from central database		This is a unique inhouse generated ID by the HISDU team that will be unique for each individual tested/surveyed
CH pec	Do you have any pre-exisiting conditions?		1. Diabetes 2. Hyper-tension 3. Obesity 4. Cancer 5. Smoking 6. Cardiovascular disease 7. Chronic lung disease 8. Chronic liver disease 9. Chronic renal disease 10. Malignancy 11. Other	
CH 1	Symptoms		1. Chills 2. Vomiting 3. Nausea 3. Diarrhea 4. Headache 5. Rash 6. Conjunctivitis 7. Muscle Ache 8. Joint Ache 9. Loss of appetite 10. Nose bleed 11. Fatigue 12. Siezures 13. Altered Conciousness 14. Loss of smell 15. Loss of taste 16. Fever 17. Other neurological signs 18. Other symptoms	
CH 2_num	How many?			
CH 3_num	How many confirmed cases have you been in contact with?			

SCALE Survey Instrument				
Module 5 - Pool Testing Followup (Only to be done for a positive pool)				
Input field name	**Question**	**Relevance**	**Option choices**	**Notes**
PL 02	Pooling ID (Auto-generated)	pull from database if PL01=1		
ID	ID (Auto-generated)	Pull from central database		This is a unique inhouse generated ID by the HISDU team that will be unique for each individual tested/surveyed
Note: After pulling this data, take the sample for testing				
Test ID	Test ID			Unique ID generated at the backend (if, in section 2 'Respondent info and testing' Item PL1 was 'Pool") Otherwise if PL1 was 'individual', then pull data)

SCALE Survey Instrument

Module 6 - Follow Up With Confirmed Positive Case

Input field name	Question	Relevance	Option choices	Notes
Sample ID	ID (Auto-generated)	Pull from central database, assigned during pool testing follow up (Stage 5)		This is a unique inhouse generated ID by the HISDU team that will be unique for each individual tested/surveyed
CI 1	How many people have you been in contact with?			Provide hint for enumerator from clinical history questions CH 2_num and Ch 3_num. This is to make sure that the respondent does not understate his number of contacts once he/she knows they are positive
Repeat Group (count = CI 1)				
CI 1_1	First Name of person			
CI 1_1_1	Last Name of person			
CI 1_2	Mobile phone number			
CI 1_3	PTCL phone number			
CI 1_4	City/ Area of infection			
CI 1_5	Work GPS location/ address			
CI 1_6	Home GPS location/ address			
CI 1_7	What was the nature of your contact with this person?		1. Shook hands with him/her 2. Hugged him/her 3. Prolonged interaction (>10 mins) with him/her in an enclosed space (room, mosque, office, etc) 4. Prolonged interaction (>10 mins) in an open space (market, park, etc) 5. Brief Interaction (<10 mins) with him/her in an enclosed space 6. Brief interaction (<10 mins) with him/her in an open space	
End Group				

SCALE Survey Instrument				
Module 7 - Contact Tracing (From Contacts of Confirmed Positive Cases)				
Input field name	**Question**	**Relevance**	**Option choices**	**Notes**
Sample ID	Sample ID	Pull from central database, assigned during pool testing follow up (Stage 5)		This is a unique inhouse generated ID by the HISDU team that will be unique for each individual tested/surveyed
Contacts Information				
RI 1	First Name			You will have some of this information such as First name, last name from the "Followup with postive cases." This can be pulled whereas the rest will be recorded. The idea here is to repeat the excercise with these contacts and maintain a central database of all respondents
RI 2	Last Name			
RI 3	Gender			
RI 4	DOB			
RI 5	CNIC Type (Self/Guardian)			
RI 6	CNIC			
RI 7	Contact number (Mobile)			
RI 8	Alternate number			
RI 9	District/City			
RI 10	Home Address			
RI 11	Home geolocation			
RI 12	Work Address			
RI 13	Work geolocation			
RI 14	Occupation		1. Health Occupation 2. Self-employed (owns his/her own business) 3. Law Enforcement and armed forces (police, army, etc.) 4. Legal Profession 5. Employed 6. Teacher/ Professor 7. Student 8. Unemployed 9. Other	
RI 15	Name of company/ organisation			
CT 1	According to our data [person name] has tested positive for COVID - 19, we know you may have come into contact with the above mentioned person. Please tell us what is your relation to above mentioned person. In what capacity do you know him?		1. Immediate Family Member 2. Relative 3. Neighbour 4. Friend 5. Colleague 6. Other (specify)	
CT 1_desc	If other, please specify			
CT 2	What was the nature of your contact with [peson name] who has tested positive for COVID-19?		1. Close contact (>10 mins) with [person name], who was not wearing face mask 2. Close contact (>10 mins) with [person name], who was wearing a face mask 3. Close contact (<10 mins) with [person name], who was not wearing a face mask 4. Close contact (<10 mins) with [person name], who was wearing a face mask	
CT 4	How many people (other than the person they are being traced from) do you know who have tested positive for COVID-19?	If CH 3 = No		

CT 5	How many people (who you personally know) do you suspect are postive (showing symptoms)?	If CH 3= yes		

CT 6	How many people have you come into contact with since you met [person the are being traced from]?			
Repeat group (count = CT 6)				
CT rg 1	Contact Number			
CT rg 2	Alternate Contact Number			
CT rg 3	Home address			
CT rg 4	Work Address			
CT rg 5	Place of work (company, organisation etc.)			
CT rg 6	Geo Location (longititude)			
CT rg 7	Geo Location (lattidude)			
End Repeat group				
CT 7	What preventive measures have you adopted to mitigate the risk of contracting COVID-19? Select all that apply		1. Use of Face Mask 2. Handwashing with soap for 20sec 3. Use of alcohol based Hand sanitizer 4. Social Distancing 5. None of the above	
CT 8	What are the preventive measures taken by your employer for the safety of the staff at the workplace? Select all that apply		1. Use of disinfectant for cleaning 2. Provided hand sanitizer 3. Raising awareness about preventative measures 4. Provided masks 5. Provided gloves 6. Allowed work from home 7. I am not going to the office/my office is closed	
CT 9	Do you and your colleagues at the workplace follow the preventive measures of personal hygiene and social distancing?		1. Do not follow at all 2. Do not mostly follow 3. Sometimes follow and sometimes don't follow 4. Mostly follow 5. Strongly follow	
CT 10	Do you and your family follow the preventive measures of personal hygiene and social distancing?		1. Do not follow at all 2. Do not mostly follow 3. Sometimes follow and sometimes don't follow 4. Mostly follow 5. Strongly follow	
CT 11	In the last two weeks how many religious (friday prayers, congregation, etc) or social (marriage, party, etc) gatherings have you attended?		1. None 2. 1 - 3 3. 3 - 10 4. More than 10	
CT 12	In the last two weeks how many religious (friday prayers, congregation, etc) or social (marriage, party, etc) gatherings have you attended?		1. Friday Prayers 2. Congregation prayers 3. Other religious gatherings (Naats, Milaad, Funeral, etc) 4. Conferences 5. Marriage Ceremony 6. Social Gathering (party, dinner, etc)	
Repeat roster (all option choices chosen in CT 12)				
CT 13	Area where you attended the event			
CT 14	City where you attended the event			
End Repeat group				