Identifying TB hotspots through mobile X-rays in Karachi, Pakistan: spatial analysis of data from an active case-finding program

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Abstract

Introduction

Tuberculosis (TB) is the leading cause of avoidable deaths from an infectious disease globally and a large of number of people who develop TB each year remain undiagnosed. Active case-finding has been recommended by the World Health Organization to bridge the case-detection gap for TB in high burden countries. However, concerns remain regarding their yield and cost-effectiveness.

Methods

Data from mobile chest X-ray (CXR) supported active case-finding community camps conducted in Karachi, Pakistan from July 2017- March 2020 was retrospectively analyzed. After a CXR screening supported by computer-aided detection, those with presumptive TB were counselled to submit a sputum sample for Xpert MTB/RIF testing. Frequency analysis was carried out at the camp-level and outcomes of interest for the spatial analyses were mycobacterium TB positivity (MTB+) and X-ray abnormality ratios. The Moran's I statistic was used to test for spatial autocorrelation for MTB+ and abnormal X-rays within Union Councils (UCs) in Karachi. Local Indicators of Spatial Autocorrelation analyses were performed for UCs within Karachi. Point-pattern analyses were carried out utilizing GPS coordinates recorded at the camp sites and were analyzed for spatial autocorrelation using Getis Ord Star tests.

Results

A total of 1,161 (78.1%) camps yielded no MTB+ cases, 246 (16.5%) camps yielded 1 MTB+, 52 (3.5%) camps yielded 2 MTB+ and 27 (1.8%) yielded 3 or more MTB+. A total of 79 (5.3%) camps accounted for 193 (44.0%) of MTB+ cases detected. Statistically significant clustering for MTB positivity (Moran's I: 0.09) and abnormal chest X-rays (Moran's I: 0.36) ratios was identified within UCs in Karachi. Clustering of UCs with high MTB positivity were identified in Karachi West district. Clusters of camp locations with high MTB+ ratios were identified in Karachi South and Karachi West districts and in several locations in the north and eastern peripheries of the city.

Conclusion

Statistically significant spatial variation was identified in yield of bacteriologically positive TB cases and in abnormal CXR through active case-finding in Karachi. Cost-effectiveness of active case-finding programs can be improved by identifying and focusing interventions in hotspots and avoiding locations with no known TB cases reported through routine surveillance.

Contributions To Literature

• Literature shows that distribution of TB cases may not be geographically uniform. However, past studies from LMICs have evaluated "passive" case-finding data at district or state levels that does not meaningfully identify areas of high disease transmission.

• Out study is the first to identify geographic variation in TB risk utilizing “active” case-finding data at the neighborhood-level in one of the world’s largest cities.

• Several TB hot and cold spots were identified, supporting the need for increased precision in mapping to find high TB transmission areas in mega-cities.

• Low-cost data collection methods for conducting spatial analysis using mobile-phones has been described.

Background

Tuberculosis (TB) is the leading cause of avoidable deaths from an infectious disease globally. In 2019, an estimated 10 million people developed TB and 1.5 million died from the disease (1). A main reason for the high mortality is that a large of number of people who develop TB each year remain undiagnosed. Active case-finding (ACF) has been recommended by the World Health Organization (WHO) to bridge the case-detection gap for TB in high burden countries (2). This approach involves screening for TB among people who may not actively seek healthcare, through additional services, often outside of health facilities.

Pakistan has the world’s fifth highest TB burden and only 58% of the people estimated to have TB detected and notified in 2019 (3). In recent years, efforts have been made to strengthen the capacity for ACF in Pakistan including capital investments for mobile X-rays vans by the National TB Program (NTP) and its partners (4). However, as with all ACF approaches, concerns remain regarding their yield and cost-effectiveness. (5) As with any health-related intervention, TB programs in high burden countries such as Pakistan must rationalize costs given many competing priorities, and therefore tools and approaches to improve the efficiency of ACF interventions are particularly useful (6).

The use of geographic information systems (GIS) with spatial statistics has been applied to analyze spatial patterns of several infectious diseases (7–9). While TB incidence and prevalence estimates are calculated at national or regional levels, TB epidemics may be characterized by patches of concentrated risk at the local level rather than spatially uniform risk. Investigating spatial heterogeneity in TB incidence and concentrating interventions in locations of high risk may improve the cost-effectiveness of ACF (10–11). Modelling studies suggest that targeting ACF only in TB hotspots, has a similar impact on reducing TB incidence as conducting TB control interventions over an entire city (12–14). However, in practice, identifying TB hotspots is challenging in countries such as Pakistan, given the absence of street addresses and electronic registries for TB patients. In addition, data sources often largely reliant on passive case-detection registers that may not accurately reflect areas of high disease transmission by excluding asymptomatic carriers in early or subclinical phases of TB.

In 2017, as part of the “Zero-TB Cities” initiative, a large ACF program was initiated in Karachi, Pakistan supported by mobile vans equipped with digital chest X-rays and diagnostic testing using Xpert MTB/RIF (Xpert) (15). This initiative provided an opportunity to evaluate spatial variation in the yield of TB

detected and identify potential hotspots using a large ACF dataset from a South-Asian megacity. Here we report on the findings from an evaluation of spatial data derived from a large scale ACF program to identify potential TB hotspots from Karachi, Pakistan.

Methods

Study Design and Setting

We analyzed retrospective data from mobile chest X-ray supported active case-finding camps conducted in Karachi, Pakistan as part of an active case-finding intervention for TB, from July 2017- March 2020. Karachi is the most populous city of Pakistan with an estimated population of over 16 million, and a population density of over 24,000 people per square kilometer (16).

Participant Enrollment and Case-Detection Algorithm

Community screening camps were conducted using a fleet of mobile-vans with installed digital radiography equipment for chest x-rays (CXR). A total of 5 teams consisting of a screener, radiographer, mobile-van driver and two supervisors were responsible for implementing the camps. Site selection was primarily led by field-teams based on local knowledge and consultation with district health authorities. Camps were often conducted in collaboration with general physicians (GPs), pharmacies and dispensaries to improve turnout. Community mobilization was conducted through announcements in mosques and restaurants, advocacy with community influencers and distribution of communication materials (flyer and banners). Use of loudspeakers and door-to-door visits by community workers supported mobilization on the day of the camp.

All individuals greater than 15 years of age who approached the mobile van during the camp were eligible for screening. All participants were offered screening using a digital CXR supported by computer-aided detection (CAD) software irrespective of symptoms (17). People with presumptive TB were identified based on the results of the CXR and were counselled to submit a sputum sample for Xpert MTB/RIF (Xpert) testing. In certain instances, sputum was also collected from people with normal chest X-rays, if recommended by GPs on clinical examination. Sputum induction was carried out where feasible through ultrasonic nebulization and mucolytic agents. Centralized Xpert testing was conducted in private TB diagnostic and treatment centers called *Sehatmand Zindagi (Healthy Life)* with the use of a sputum transport system. Samples were evaluated for sputum quantity and quality prior to Xpert testing. Samples with food-particles, insufficient sputum or saliva were rejected for testing. Individuals with MTB-positive results on Xpert were initiated on anti-TB treatment (ATT) at the centers and notified to Provincial Tuberculosis Program (PTP), Sindh. Individuals with unavailable or negative Xpert results but with high suspicion of TB after clinical evaluation by medical officers at the centers were started on ATT. All individuals were offered X-ray screening, Xpert testing and TB treatment services free of charge.

Data Collection

A unique identifier (ID) was generated for each camp on a centralized Health Management Information System (HMIS) at the time of camp-planning. A custom-built android application was installed on tablet devices with 4G connectivity and provided to community workers for data-capture. Demographic data including age, gender, contact details and test IDs were recorded. Global Positioning System (GPS) coordinates were recorded at camp sites prior to start of activities. At the conclusion of camps, data was synced with the HMIS and linked to the relevant camp IDs. This allowed for detailed monitoring and analyses at the patient, camp and district-levels.

Statistical Analysis

Frequency analysis was carried out for participant demographics and TB case-detection cascade indicators at the camp-level. Continuous variables were expressed as means (and standard deviations) or medians (and interquartile range). Camps for which no GPS coordinates were available were excluded from the analysis for this study.

Outcomes of interest for the spatial analyses were MTB positivity (MTB+) and X-ray abnormality ratios, calculated as the number of bacteriologically confirmed TB cases and number of abnormal X-rays, per total number of individuals screened, respectively in each camp. Individuals enrolled for ATT based on clinical evaluation (without bacteriologically confirmed TB) were not included in the analysis. This was carried out to remove biases arising from subjective clinical decision-making between medical officers. The outcomes were analyzed for spatial heterogeneity using: 1) aggregated data, and 2) point-pattern analyses. The aggregate level analyses were conducted by assigning each chest camp to a Union Council (UC), the smallest administrative unit in the city. The Moran's I statistic was used to test for spatial autocorrelation for MTB + and abnormal X-rays within UCs in Karachi overall. Local Indicators of Spatial Autocorrelation (LISA) analyses were performed for UCs within Karachi. The LISA analysis was utilized to identify high or low clustering of MTB + and abnormal X-rays between UCs. All LISA analyses were performed using a contiguity of both one neighbor (only the directly bordering union councils were considered neighbors). Point-pattern analyses utilized GPS coordinates recorded at the camp sites and were analyzed for spatial autocorrelation using Getis Ord Star (GI*) tests. The GI* test identifies GPS locations of camps with high or low clustering for MTB + and abnormal X-rays. LISA and GI* tests were performed using a partial dataset (Q3 2018 – Q1 2020) and the entire dataset (Q3 2017 – Q1 2020) to evaluate changes in spatial variation temporally. Frequency analysis was carried out using Stata version 13 (College Station, TX: StataCorp LP). Spatial analyses were conducted using GeoDa and exported to QGIS for mapping and visualization.

Results

A total of 1,543 chest camps, in 151 union councils, were conducted during the study period and included in the analysis. A total of 57 (3.7%) camps did not have GPS coordinates and were excluded from the analysis. A total of 197,693 individuals were screened using CXR among whom 7,907 (4%) were deemed abnormal (Fig. 1). The median age of camp participants was 35 (IQR 13.8) and 78.3% were males (Table 1).

Table 1
Participant demographics and TB case-detection cascade indicators for mobile chest X-ray supported active case-finding camps in Karachi, Pakistan (July 2017- March 2020).

	n/Mean/Median	IQR / SD / %
Age of participants	35	13.8
Proportion males	78.3%	-
Participants per camp	139	(98–175)
Abnormal X-rays per camp	5	(2–7)
Sputum samples collected per camp	6	(3–11)
Xpert MTB/RIF tests per camp	4	(2–6)
MTB + detected per camp	0.29	0.65

The median number of participants per chest camp was 139 (IQR: 98–175). Sputum was collected from 6,769 (85.6% of individuals with an abnormal X-ray) and from an additional 5,401 people (2.8% of those with a normal X-ray). After evaluating sputum quality, a total of 4,162 Xpert tests were conducted among individuals with an abnormal X-ray yielding 374 MTB + cases (9% positivity), whereas 2,409 Xpert tests were conducted among individuals with a normal X-ray yielding, 65 MTB + cases (2.7% positivity). A median of 5 (IQR: 2–7) abnormal chest x-rays and 6 (IQR: 3–11) sputum samples were collected per chest camp. Each camp yielded a mean of 0.29 (+/- 0.65) individuals with MTB + results. A total of 1,161 (78.1%) camps yielded no MTB + cases, 246 (16.5%) camps yielded 1 MTB+, 52 (3.5%) camps yielded 2 MTB + and 27 (1.8%) yielded 3 or more MTB+ (Table 2). A total of 79 (5.3%) camps accounted for 193 (44.0%) of MTB + cases detected.

Table 2
Yield of TB case-detection from mobile chest X-ray supported active case-finding camps in Karachi, Pakistan (July 2017- March 2020).

	n	%	MTB + Detected	%
Camps with Zero MTB+	1,161	78.1%	0	0%
Camps with 1 MTB+	246	16.5%	246	61.3%
Camps with 2 MTB+	52	3.5%	104	23.7%
Camps with 3 or more MTB+	27	1.8%	89	20.3%
Total Camps	1,486		439	

The Moran's I statistic identified small but statistically significant clustering for MTB positivity within UCs in Karachi overall (Moran's I: 0.09) and moderate, statistically significant clustering for abnormal chest X-

ray (Moran's I: 0.36) ratios (Fig. 2). The LISA analysis identified clustering of UCs with high MTB + ratios (described as High-high) in north-west and south-central Karachi, both using a contiguity of 1 (Fig. 3) and contiguity of 2 (not presented). These UCs were primarily located in Karachi West district (Table 3). Clustering of UCs with high abnormal chest x-ray ratios were identified in Karachi West and Karachi South districts (Table 4). Union Councils with high MTB + and abnormal X-rays surrounded by UCs with low ratios (described as High-Low) were identified in eastern parts of the city (Table 3).

Table 3
Union-Councils with clustering of MTB positivity identified from mobile chest X-ray supported active case-finding camps in Karachi, Pakistan (July 2017- March 2020).

District	Tehsil	Union Council	Type
Malir	Gadap Town	Uc-8 Mango Pir	High-high
Karachi West	Baldia Town	Uc-2 Ittehad Town	
Karachi West	Orangi Town	Uc-7 Chushti Nagar	
Karachi West	Orangi Town	Uc-6 Ghaziabad	
Karachi West	Orangi Town	Uc-8 Bilal Colony	
Karachi West	Orangi Town	Uc-13 Baloch Goth	
Karachi West	Orangi Town	Uc-11 Dad Nagar	
Karachi West	Orangi Town	Uc-12 Mujahidabad	
Karachi West	Orangi Town	Uc-4 Muhammad Nagar	
Karachi West	Orangi Town	Uc-2 Haryana Colony	
Karachi West	Baldia Town	Uc-6 Mohajir Camp	
Karachi West	Kiamari Town	Uc-4 Baba Bhitt	
Karachi South	Jamshed Town	Uc-12 Soldier Bazar	High-low
Karachi East	Gulshan E Iqbal Town	Uc-1 Dehli Mercantile	
Korangi	Shah Faisal Town	Uc-7 Al Falah Society	
Karachi East	Gulshan E Iqbal Town	Uc-8 Jamali Colony	
Karachi Central	Gulberg Town	Uc-6 Yaseenabad	
Karachi Central	Gulberg Town	Uc-2 Karimabad	
Karachi Central	Liaqatabad Town	Uc-11 Abbasi Shaheed	

Table 4
Union-Councils with clustering of abnormal X-rays identified from mobile chest X-ray supported active case-finding camps in Karachi, Pakistan (July 2017- March 2020).

District	Tehsil	Union Council	Type
Karachi West	Kiamari Town	Uc-4 Baba Bhitt	High-high
Karachi West	Kiamari Town	Uc-1 Bhutta Village	
Karachi West	Kiamari Town	Uc-2 Sultanabad	
Karachi South	Saddar Town	Uc-4 City Railway Colony	
Karachi South	Saddar Town	Uc-3 Kharadar	
Karachi South	Layari	Uc-4 Khada Memon	
Karachi South	Layari	Uc-5 Bhagdadi	
Karachi South	Saddar Town	Uc-2 Garden	
Karachi South	Jamshed Town	Uc-9 Jacob Lines	
Karachi West	Site Town	Uc-9 Islamia Colony	High-low
Karachi Central	North Nazimabad Town	Uc-10 Buffar Zone-1	
Malir	Gadap Town	Uc-4 Gujjro	
Malir	Malir Town	Uc-7 Gazi Brohi	
Malir	Bin Qasim Town	Uc-2 Rehri	
Malir	Bin Qasim Town	Uc-7 Ghaghar	

Clustering of UCs with low MTB + and abnormal X-ray ratios (described as Low-low) were identified primarily in Karachi Central district (Fig. 4). The GI* analysis identified clusters of camp locations with high MTB + ratios in Karachi South and Karachi West districts and in several locations in the north and eastern peripheries of the city that are part of District Malir (Supplementary Table 1). Clusters of camp locations with low MTB+ (described as Low-low) were identified in District Central, District East and parts of Korangi district (Fig. 5). Clusters of camp locations with high ratios of abnormal X-rays identified in Karachi South and Malir districts (Supplementary Table 2). However, fewer low abnormal X-ray clusters were identified relative to MTB+ (Fig. 6). No significant differences were observed in the spatial trends for MTB + and abnormal X-rays for the partial (from Q3-2018 onwards) and full datasets (from Q3 2017 onwards), suggesting no temporal variation in the spatial heterogeneity.

Discussion

The premise of the Zero TB Cities Initiative is that concentrating resources in urban centers rather than spreading them over national or regional geographies can “drive sharp reductions in TB death rates and

prevalence" (18). This study provides evidence that even within cities, especially larger ones such as Karachi, the risk of TB is likely not distributed uniformly (Fig. 7). While district-level GIS analyses have been previously carried out in Pakistan, this is the first study to investigate spatial variation in a major metropolitan area with detailed coordinates of ACF efforts (19–20). The strength of this study was the use of a very large dataset from a ACF program to achieve greater precision in the identification of TB hotspots in a city with diverse ethnicities and large variations in socioeconomic indicators. The ACF dataset allowed for inclusion of cases from the community that would otherwise been missed, thereby increasing the accuracy of our findings, relative to data captured from routine surveillance.

Our approach may allow for more actionable information that can be utilized to guide programmatic decision-making, further enhancing the Zero TB City approach. A notable finding was that nearly three-quarters of all camp locations yielded no MTB + cases, whereas only 5% of camp locations accounted for over 40% of all MTB + cases detected. These results strongly suggest a targeted approach to ACF in high-risk areas to improve yields and cost-effectiveness. A number of UCs with clustering of MTB yield were identified, particularly in the western and southern parts of the city. Clusters were also identified through the spatial point-pattern analysis using camp GPS coordinates in the western and southern regions, as well as in the peripheries of the city. These areas correspond to densely populated areas near the port, slum-dwellings in the west and peri-urban communities and villages in the outskirts of the city. It is likely that population density as well as social determinants of TB, such as crowded housing, low-income and poor nutrition contributed to higher TB risk. UCs and camp locations with clustering of low values were identified in central and eastern parts of the city suggesting lower numbers of people with active TB in these areas. These consist of locations around major avenues of the city that include commercial properties and planned middle and upper-middle income residential areas.

Previous studies utilizing passive case-finding data from Brazil, South Africa and Zimbabwe have identified areas of high TB notifications in peri-urban and lower-income areas within cities (21–23). A modelling study from Ho Chi Minh City found that four-fifths of index cases had no other reported TB cases within a 50m radius (11). These studies and our findings suggest that a useful strategy for improving cost-effectiveness of ACF may also be an avoidance of "cold-spots" or areas where previously no TB cases are reported. This information can be easily extracted from routine TB registers and involvement of local health authorities. An ACF program can therefore be targeted only in areas from where cases have previously been reported from passive case-finding while avoiding new localities that may diminish overall yields.

Further research will be required to investigate the causes for spatial heterogeneity in TB cases. This can include social determinants such as population density, poverty, household family size and type of housing (24). Health systems determinants will also need to be investigated such as number of medical facilities and number of TB testing and treatment centers. Investigating and addressing these factors would require a multi-disciplinary approach and collaboration with researchers involved in urban planning, housing and development as well as coordination with local city officials. Known clinical determinants of TB disease including nutritional deficiencies, smoking history, diabetes and HIV should

also be examined for spatial heterogeneity (25–26). Such analyses can be overlaid with this analysis and modeled as predictors for spatial variation in TB detection.

Our approach can be easily replicated by other programs through the use of simple android mobile-phone applications and collection of GPS coordinates in the field. Free of cost tools such as Google Maps can be utilized to visualize color-coded clusters of camps yielding TB cases if propriety software is not available. Software code for mobile-applications utilized in this study is publicly available to support such data collection for field-teams in other settings. Revisions to the national active case-finding guidelines are also being prepared in collaboration with partners and the NTP to support the wider adoption of these methods. A similar analysis is being carried out for other cities in Pakistan where CHS operates.

There are a number of limitations in our analysis. The location of camp site was taken as a proxy for residence of the participants and this limits the internal validity of the study. While camps were carried out in communities and partnering provider clinics, it is possible that some participants were visiting the area and did not reside near the camp site or in the same UC. A random sampling of households at the UC-level will provide a better estimate of TB prevalence, however, prevalence surveys require even more significant resources than ACF. Given the size of Karachi's population and diversity of its neighborhoods, our results support investment in a city-level prevalence survey to help identify areas for targeted ACF activities. From a programmatic perspective, however, such selection bias may be less relevant. Identified hot-spots could be marketplaces or clinics near "true" TB hot-spots and this may be sufficiently useful information for program teams if the camps consistently provide high-yields. A very limited number of camps were conducted in military cantonments that include several high-income residential areas. These areas were therefore not adequately assessed for spatial variation in TB risk.

Challenges in participant recruitment included lower representation of females. Due to cultural reasons, women may have been hesitant to take part in screening camps in public locations. Older age groups and those with disabilities may have also not taken part in screening. It is possible that such people with TB were residing near camp sites and were missed, affecting the number of hotspots identified. These constraints were however, applicable to all camps and would therefore have limited the bias towards individual clusters. Sputum expectoration and quality also proved challenging in the field and this may have also reduced the number of hotspots identified in the MTB positivity analysis. Limited sputum quantity, salivary samples, food particles and betel nut contaminants were frequent problems identified at the laboratory. People with abnormal X-rays were encouraged to visit the nearest SZ centers to deposit morning samples and provided phone-call reminders. Analyses for abnormal X-rays were included to adjust for missing testing data and these produced similar results to MTB positivity, again suggesting limited bias towards identified clusters. Additional limitations include the sensitivity of the CAD software for screening for TB and of Xpert as a diagnostic test, particularly for pauci-bacillary disease. It is likely that a number of individuals that were started treatment on clinical basis may have early-stage disease and would have converted to bacteriological positivity in the future. This may have accounted for the

large proportion of camps with no positive results and limited the number of hotspots identified. Future studies may consider a low cutoff for the CAD scoring and use of Xpert Ultra to improve sensitivity.

Conclusion

Statistically significant spatial variation was identified in yield of bacteriologically positive TB cases and in abnormal CXR through active case-finding in Karachi. This suggests that TB transmission in the city is clustered in certain areas that can be targeted for screening. This approach can improve the cost-effectiveness of active case-finding programs and be easily replicated in other settings. Further research is required to investigate spatial variation in TB risk in other cities and to identify their underlying causes.

Declarations

Eithical approval

An ethical approval was deemed unnecessary for this study by the Ethics Review Committee at KIT Royal Tropical Institute, Netherlands. An informed consent was verbally obtained from the participants in relation to treatment only. The research poses no more than minimal risks to participants and does not give any rise to the disclosure of the participant's identity. In addition, the analysis has an important public health function.

Consent for publication

Not applicable.

Availability of data and materials

The dataset used for analysis during the current study is available from the corresponding author on reasonable request.

Conflict of interest:

The authors have no conflicts of interest to declare.

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Authors contribution:

S.M.A.Z., S.S.H., C.M. and J.C. were involved in conception of the study, finalizing the study design. W.Z.J and S.S.H conducted the literature review and K.S.A performed data collection and cleaning. C.M. and N.V.D.B were involved in data analysis and data interpretation. S.S.H and W.Z.J drafted the manuscript.

S.M.A.Z., J.C., S.K and A.K reviewed the drafts critically and finalized the manuscript. All authors reviewed and approved the final version to be published.

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Figures

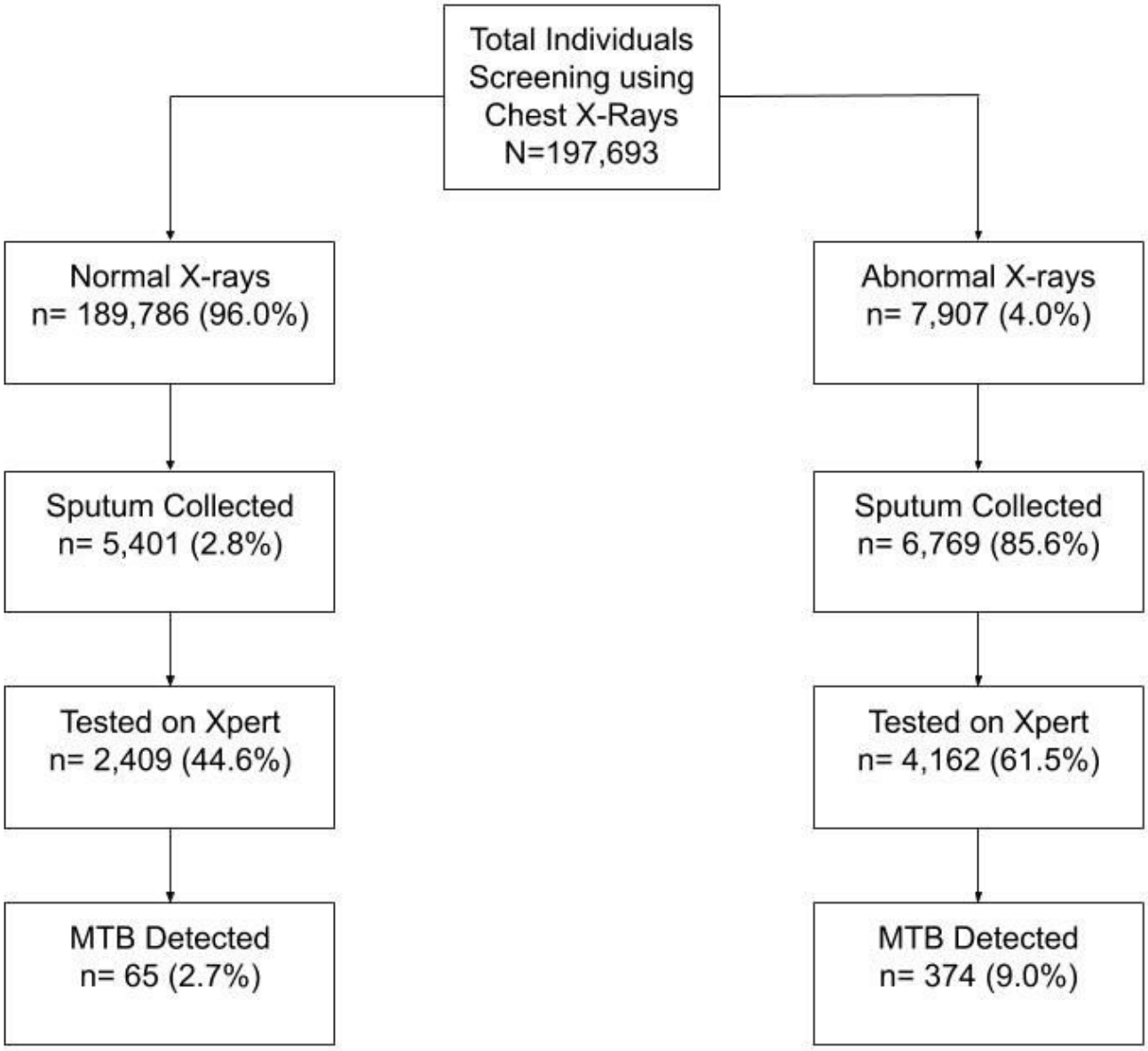

Figure 1

Overview of TB case-detection cascade for mobile chest X-ray supported active case-finding camps in Karachi, Pakistan (July 2017- March 2020).

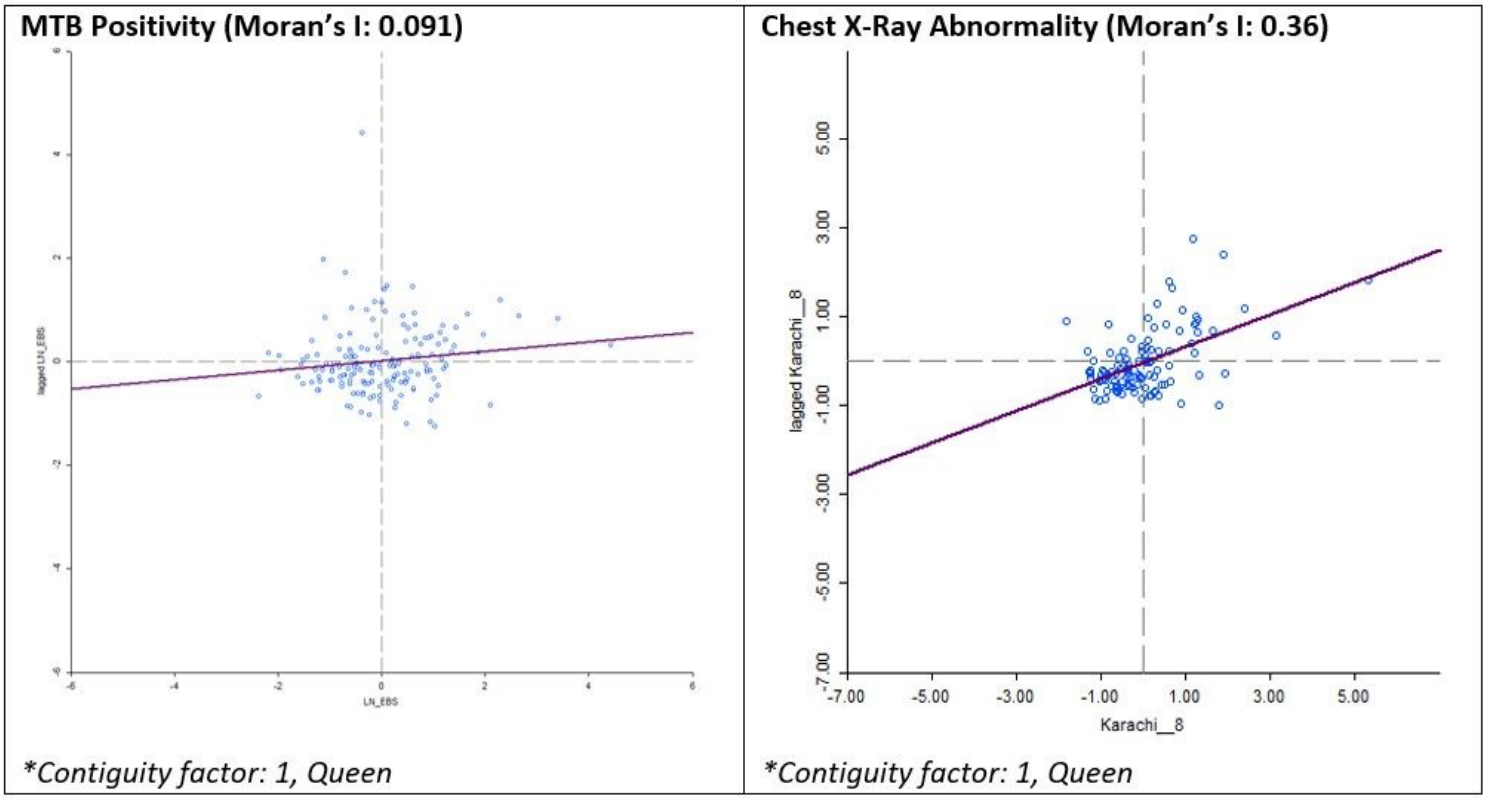

Figure 2

Moran's I statistic for MTB positivity and X-ray abnormality ratios from mobile chest X-ray supported active case-finding camps in Karachi, Pakistan (July 2017- March 2020)

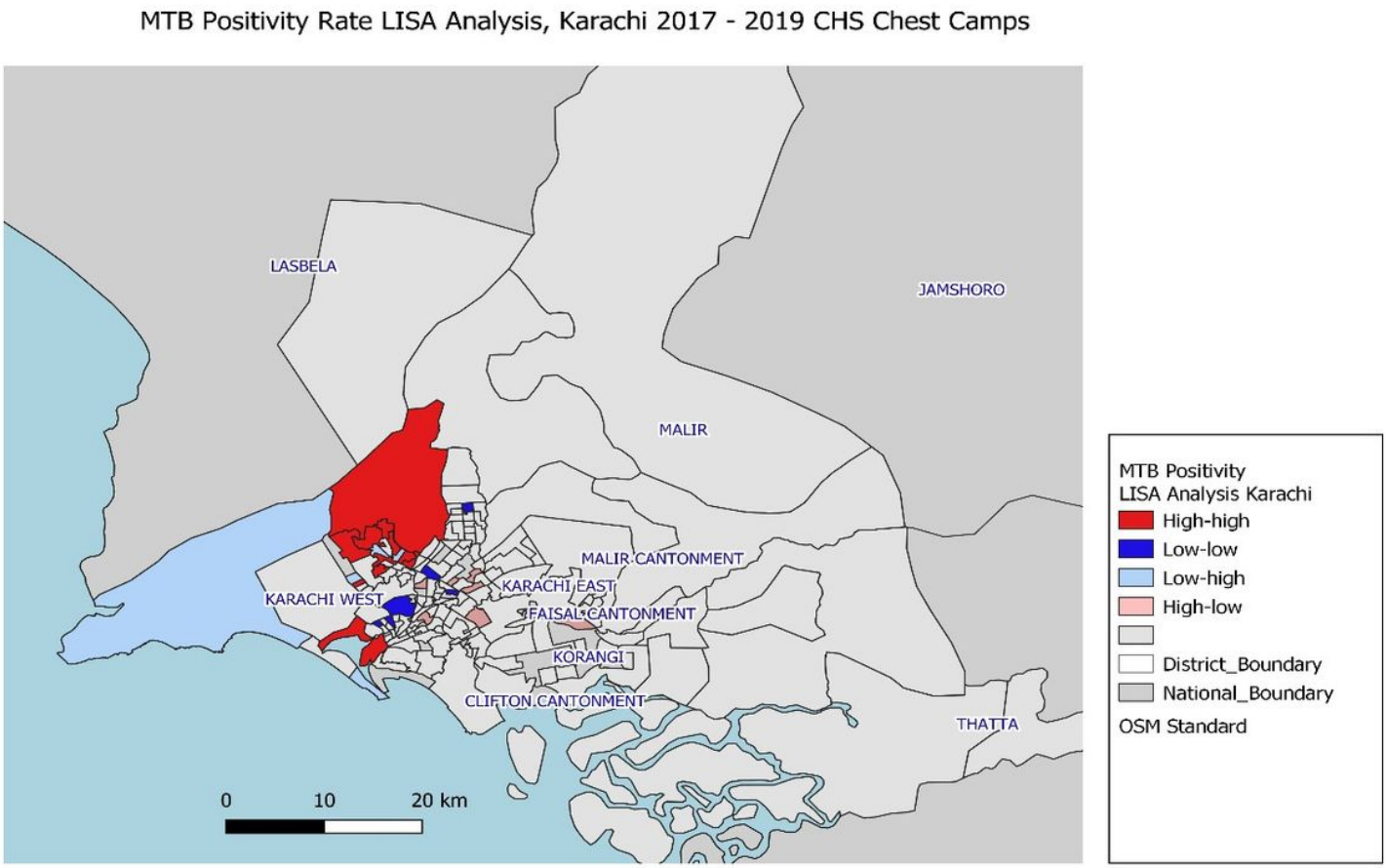

Figure 3

Local Indicators of Spatial Association (LISA) analysis for MTB positivity ratios from mobile chest X-ray supported active case-finding camps in Karachi, Pakistan (July 2017- March 2020). A High-high result indicates clustering of Union Councils (UCs) with high MTB positivity. A High-low result indicates a UC with high MTB positivity surrounded by UCs with low positivity. A Low-low result indicates clustering of UCs with low MTB positivity. A Low-high result indicates a UC with low MTB positivity surrounded by UCs with high positivity.

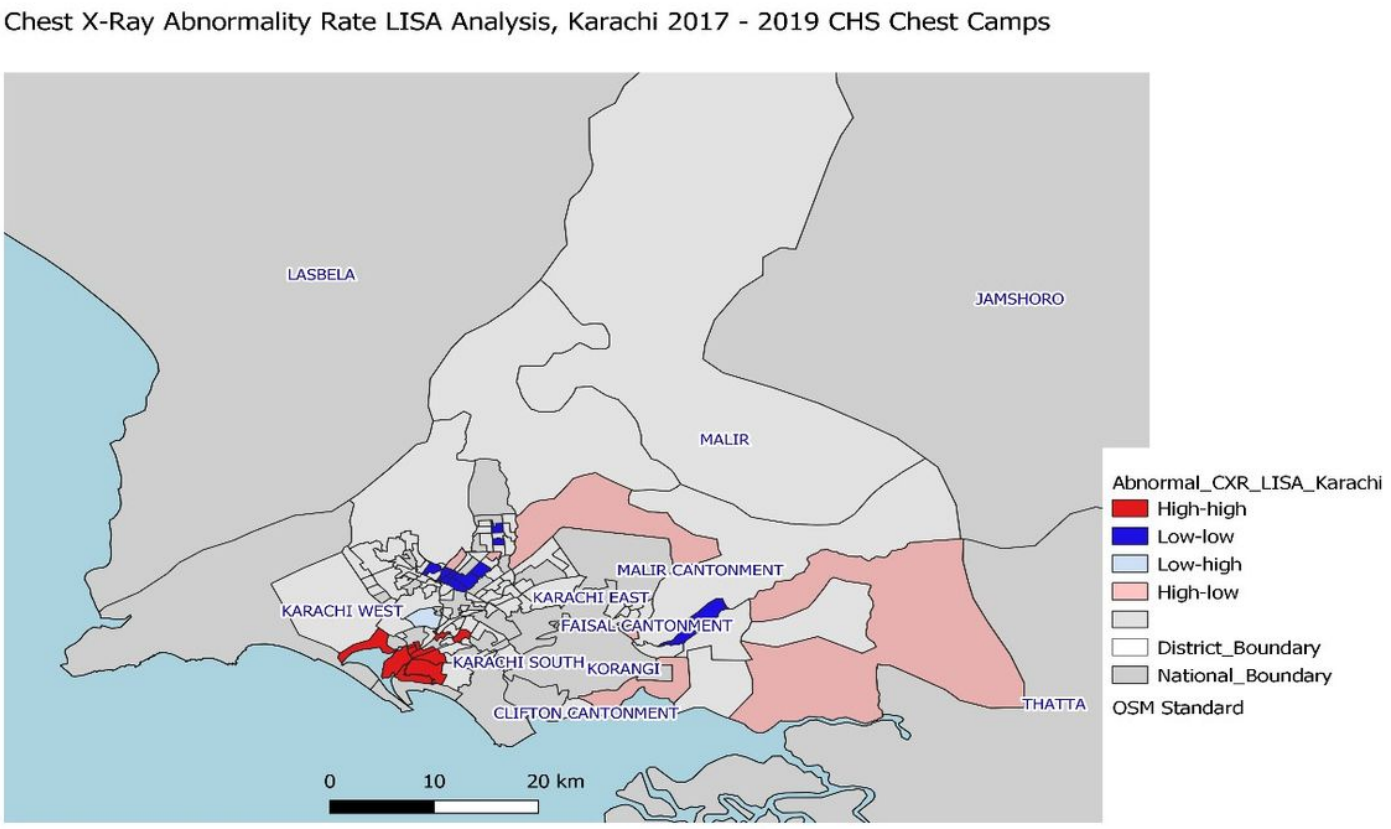

Figure 4

Local Indicators of Spatial Association (LISA) analysis for abnormal X-ray ratios from mobile chest X-ray supported active case-finding camps in Karachi, Pakistan (July 2017- March 2020). A High-high result indicates clustering of Union Councils (UCs) with high abnormal X-ray ratios. A High-low result indicates a UC with high abnormal X-ray ratio surrounded by UCs with low ratios. A Low-low result indicates clustering of UCs with low abnormal X-ray ratios. A Low-high result indicates a UC with low MTB positivity surrounded by UCs with high positivity.

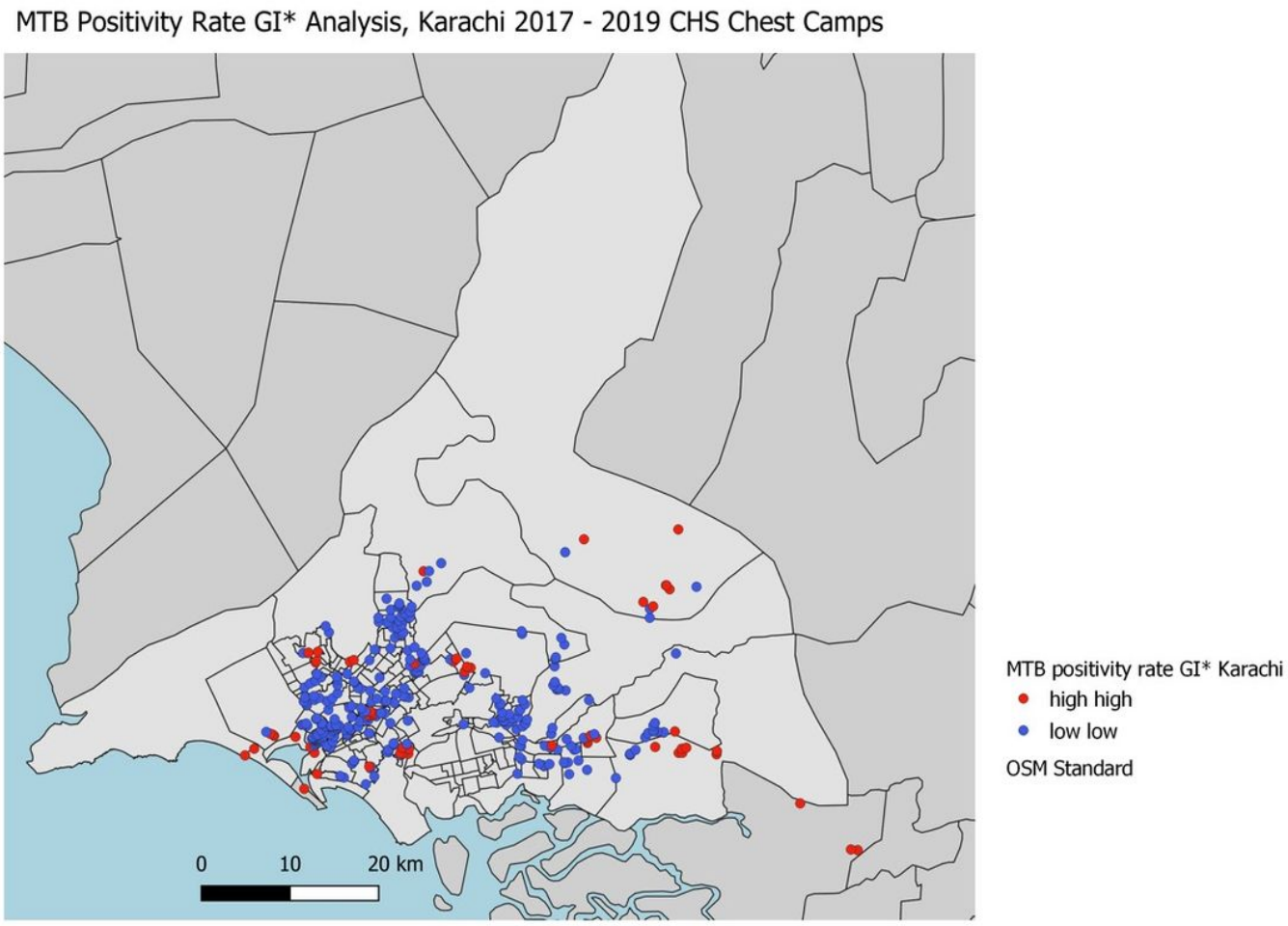

Figure 5

GI* Analysis for MTB positivity ratios from mobile chest X-ray supported active case-finding camps in Karachi, Pakistan (July 2017- March 2020). A High-high result indicates clustering of GPS locations of camps with high MTB positivity. A Low-low result indicates clustering of GPS locations of camps with low MTB positivity.

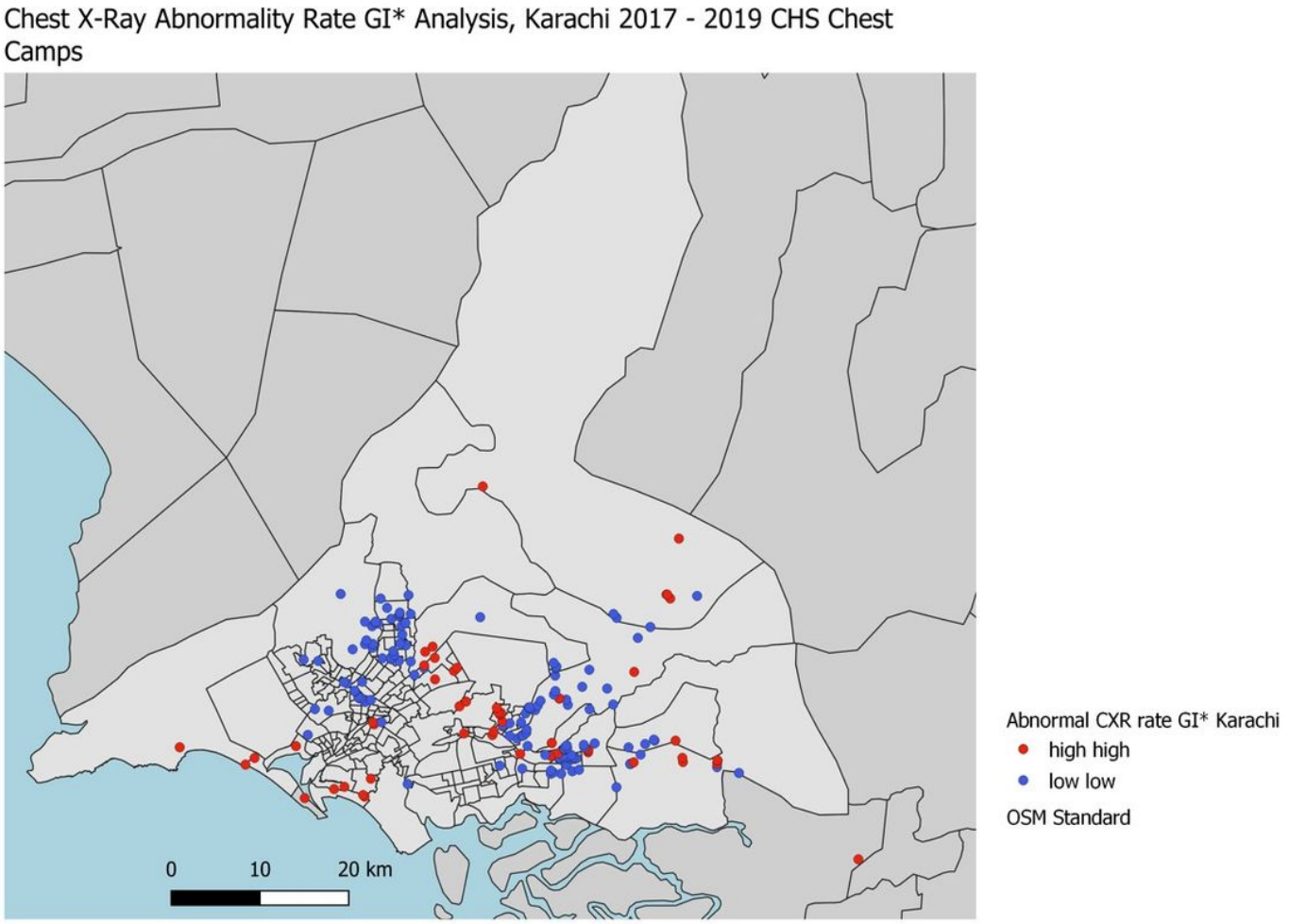

Figure 6

GI* Analysis for abnormal X-rays ratios from mobile chest X-ray supported active case-finding camps in Karachi, Pakistan (July 2017- March 2020). A High-high result indicates clustering of GPS locations of camps with high abnormal X-ray ratios. A Low-low result indicates clustering of GPS locations of camps with low abnormal X-ray ratios.

Figure 7

Karachi's socioeconomic divide is illustrated in the sharpest context from a mountain ridge separating Orangi, an industrial area and with vast, crowded slum dwellings in the west, from North Nazimabad Town, a planned upper-middle class neighborhood on the east. Active case-finding with GPS mapping of camp locations identified a number of TB hotspots towards the west whereas cold-spots were identified east, highlighting the need for neighborhood-level analyses for TB elimination in mega-cities. Image Source: Google Earth.

Supplementary Files

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- Additionalfile.docx
- STROBEchecklistcrosssectional.docx