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RESEARCH ARTICLE

A tuberculosis elimination-focused geospatial approach to optimising access to diagnostic GeneXpert machines in Fiji

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Abstract

Objectives: Fiji could be the first country to eliminate tuberculosis. To inform this strategy, we aimed to identify how many GeneXpert® machines are required to enable over 90% of Fijians to be within one-hour easy access.

Methods: We used Geographic Information System (Quantum GIS; QGIS), OpenStreetMap and population data (Kontur) to map possible facilities in relation to QGIS generated 60-min drive-time isochrones, with correction for missing road data. For outer islands, we calculated a *distance to nearest hub* operation.

Results: The solution comprised 24 GeneXpert® machines, allocating 7 GeneXpert® to Viti Levu, 6 GeneXpert® to Vanua Levu and 11 to other islands. This resulted in 827,810 people, 93.6% of Fiji's population, being within 1 h of a machine. Twenty-one thousand four hundred seventy-nine people on outer islands were an average of 43 km by water from the nearest facility.

Conclusions: We conclude that over 90% of Fijians could be within an hour of a GeneXpert® machine with placement of 24 machines.

KEYWORDS
access, allocation, diagnosis, elimination, GeneXpert, tuberculosis

INTRODUCTION

Tuberculosis is the leading infectious diseases killer of humans, accounting for approximately 1.6 million deaths per year globally. The World Health Organisation (WHO) has stated its aim to end tuberculosis by 2030, but the national health burden due to tuberculosis continues to be high in many lower- and middle-income countries in particular. A key step towards eliminating tuberculosis is making high-quality diagnostic tools readily accessible to the whole population to improve access to timely treatment and reduce transmission of *M. tuberculosis* between individuals.

Fiji is a Pacific Island nation with an approximate population of 900,000, the majority of whom live on two islands: Viti Levu and Vanua Levu. However, approximately 60,000 Fijians live in more than 100 other islands spread across approximately 1.3 million square kilometres of the Pacific Ocean. The estimated incidence of tuberculosis in Fiji is 66 cases per 100,000 population per year [1]. Fiji has a unique opportunity to improve access to tuberculosis diagnosis because of its supply of 54 GeneXpert® machines, most of which were donated to help with their national response to COVID-19. Following a meeting in August 2022, key stakeholders decided that, as part of a tuberculosis elimination strategy, the 'number of GeneXpert machines required to enable all Fijians to be within one-hour easy access to a tuberculosis test should be calculated'.

Based on this decision, the primary objective of this study was to calculate the number of machines required to bring at least 90% of Fiji's population within one-hour easy access of a GeneXpert® and recommend the locations where these machines could be placed. A secondary objective was to measure the distance between the many inhabited islands of Fiji and the nearest GeneXpert®, assuming the machines are allocated to the proposed solution.

Sustainable Development Goals: Reduced Inequalities; Good Health and Well-being

METHODS

Mapping and population data

We used the crowd-sourced mapping platform OpenStreetMap [2] and QGIS v3.28 [3], a free and open-source Geographic Information System. Population data came from Kontur [4], displayed as 9650 identically-sized hexagons across Fiji on OpenStreetMap, each representing a defined number of residents. The thorough, high-resolution data totalled 883,705 people, similar to other Fiji population estimates (884,887—Fiji Census 2017 [5]; 924,610—World Bank 2021 [6]).

Potential facilities

A list was obtained of 28 hospitals and 86 health centres in Fiji. Forty-one health centres were either not found on OpenStreetMap or Google Maps or were situated very near to a hospital and therefore considered redundant for the purposes of this study. We excluded three private hospitals. Therefore, 25 hospitals and 45 health centres were selected for possible GeneXpert® locations and were found across the main and outer islands as follows:

> Main island Viti Levu—4 divisional or specialised hospitals, 12 subdivisional hospitals, 18 health centres.
> Main island Vanua Levu—1 divisional hospital, 2 subdivisional hospitals, 12 health centres.
> Outer islands—6 subdivisional hospitals, 15 health centres.

Determining population access

'One-hour easy access' was defined as 1 h driving a car. We used the QGIS plugin ORSTools to generate car-driving isochrones for each facility on Viti Levu and Vanua Levu. Isochrones depict the area within a given time of a destination, with various options for mode of transport. The 60-min isochrones generated by ORSTools appeared incomplete in certain areas, thought to be due to imperfect road data in the software. To correct this issue, we expanded the 60-min zone to include all points within 10 km of each facility or within 2 km of a 45-min isochrone of the facility.

Field validation of the correction

In order to evaluate the validity of this isochrone correction, our team visited two locations which were included only when the expanded zone was applied. The chosen locations were Naivilaca Village, a rural village 8.4 km away from its nearest Xpert allocated health centre, and Waivatu Settlement, on the northern cusp of the extended zone. Both house less than 200 people. After customary engagement with the local leadership, and their subsequent consent, we looked for any potential geographic barriers to efficiently commuting to a nearby hospital, along with access to transport. Then, starting a stopwatch from the centre of the village/settlement, we returned to our vehicle and drove to the designated health facility. The time to various checkpoints was measured, and the stopwatch was stopped once the TTH carpark was reached.

Developing a solution

We initially trialled allocating GeneXpert® to various combinations of facilities and used multiple tools from the *Processing Toolbox* on QGIS to quantify the population coverage by each. This included: observing the isochrones for each hospital and health centre on Viti Levu and Vanua Levu and calculating the population within the 60-min zone; running a *distance to nearest hub* operation for facilities beyond the two main islands; and calculating the average distance to GeneXpert® for people living on islands without GeneXpert® (isolated islands) using QGIS-generated tables and the formula for a weighted mean [7]: average Distance $= \frac{\sum(\text{Distance} \times \text{Population})}{\sum \text{Population}}$. Some major hospitals were omitted in favour of allocating GeneXpert® to health centres with greater population coverage when considered as part of a whole solution. After reviewing the population coverage attributable to each health facility involved in this trial allocation, a refined combination of facilities was chosen. We calculated the population within (corrected and uncorrected) 60-min zones of these facilities and the average inter-island travel distance required for population without GeneXpert® on their island. Figure 1 depicts the way in which the calculation within 60-min was undertaken using ORSTools and Kontur data.

RESULTS

Four hospitals and three health centres were selected on Viti Levu (Table S1; Figure 2a). Before correction, their isochrones reached 646,155 people, 91.1% of Viti Levu's population and 73.1% of Fiji's total population. After correction, this number increased to 694,825 people, 95.9% of Viti Levu's population and 78.6% of Fiji's total population. The remaining people on Viti Levu are more than one-hour easy access away from these seven facilities.

Zero hospitals and six health centres were selected on Vanua Levu (Table S1; Figure 2b). Before correction, their isochrones reached 92,692 people, 91.4% of Vanua Levu's population. After correction, this number increased to 96,612 people, 95.2% of Vanua Levu's population. The remaining people on Vanua Levu are more than one-hour easy access away from these six facilities.

Six hospitals and five health centres were selected on other islands (Table S1). These islands host a population of 36,373 people, 62.6% of the total 58,122 people outside Viti Levu and Vanua Levu, and 4.1% of Fiji's total population. The remaining 21,749 people are an average of 43 km from

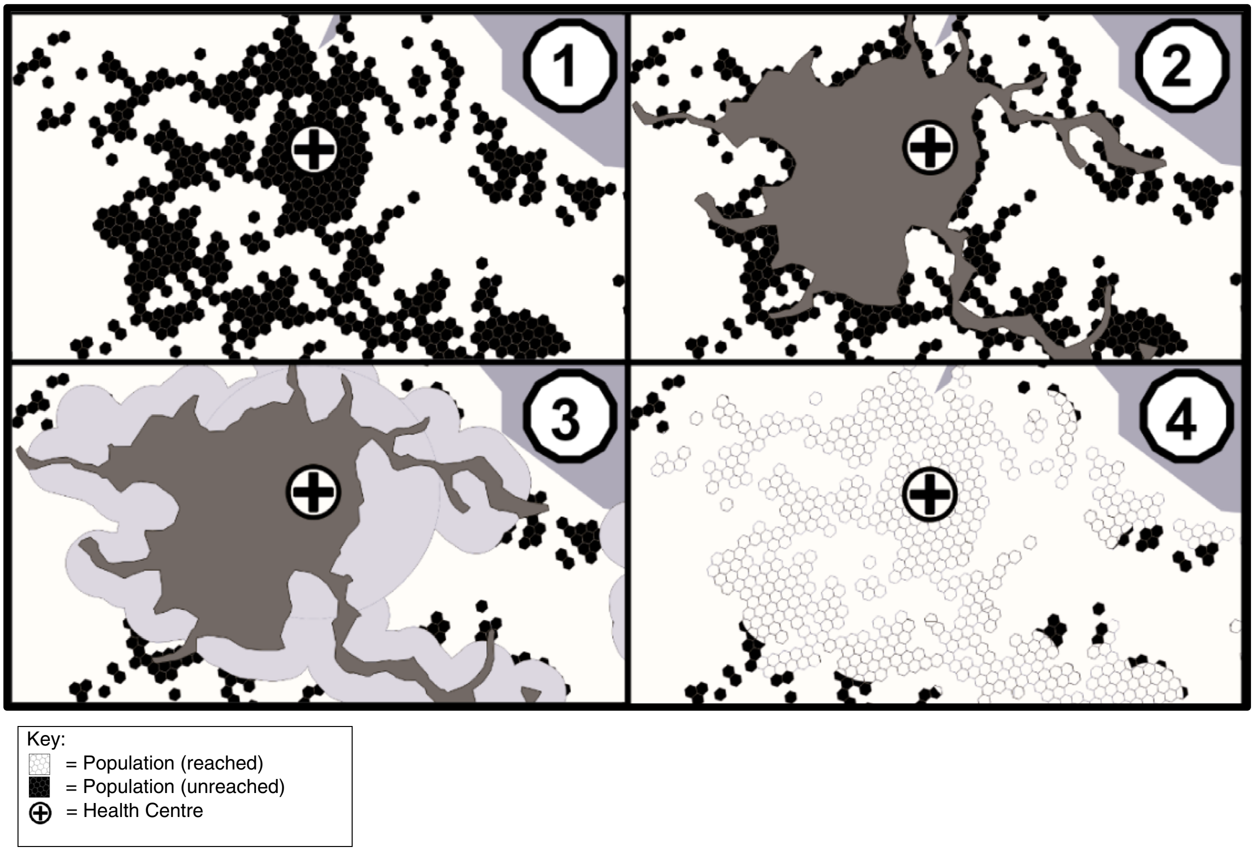

FIGURE 1 Determining population within 60 min. In (1), a health centre and the Kontur population are plotted in a small area of Viti Levu. In (2), the ORSTools 60-min isochrone (dark grey) for this health centre is displayed. (3) Displays the zone included after correction (light grey). (4) Simplifies the display to show the reached population in white and the unreached population in black.

the nearest GeneXpert®, dispersed across 109 isolated islands (Figure 3). Generally, islands with the highest populations, and those with multiple islands nearby (Malolo, Nacula), were allocated GeneXpert® (Table 2). However, there were some notable exceptions to this rule. Qamea, despite being larger in population than some islands allocated GeneXpert®, is just offshore to Taveuni, so it was inefficient to allocate another machine there. On the other hand, Rotuma, being so distant from all other potential GeneXpert® facilities, was allocated a machine despite its relatively low population.

With 7 facilities on Viti Levu, 6 on Vanua Levu and 11 on other islands, the solution includes 24 GeneXpert® facilities (Table S1; Figure 2a,b). Including all islands, the population within 1 h of GeneXpert® before correction totals 775,220 people, 87.7% of the total population (Table 1). After correction, the population within 1 h increases to 827,810 people, 93.6% of the total population (Table 1). In a sensitivity analysis (data not shown), allocation of GeneXpert® to 49 facilities was required to increase population coverage by 3.4% to 97%.

With respect to the field validation of the isochrome correction, for Naivilaca Village there were potential delays identified related to being in a flood-prone area. The total time to the nearest health facility allocated an Xpert machine was 1 h and 3 min by car. The total time to the nearest health facility not allocated an Xpert machine in the analysis, was 23 min. For the Waivatu settlement, the total time to the nearest health facility allocated an Xpert machine was 1 h and 23 min by car. The total time to the nearest health facility not allocated an Xpert machine in the analysis, was 30 mins' drive.

DISCUSSION

In this study, we have estimated that 827,810 people, 93.6% of Fiji's total population, are within 1 h of 24 facilities. This is comprised 694,825 people from Viti Levu (78.6% of total), 96,612 from Vanua Levu (10.9% of total) and 36,373 from other islands (4.1% of total). Of the 56,621 people estimated to be beyond one hour's reach of the selected facilities, 34,872 are on the main islands and 21,479 are on other islands. With the suggested 24 machines, 21,749 people would inhabit isolated islands without a machine and be an average distance of 43 km from the nearest GeneXpert® facility.

GIS platforms have been used for global tuberculosis research before. Mahara et al. [8] combined GIS and statistics to examine the relationship between socio-economic factors and tuberculosis incidence in Beijing, China, whereas Beiranvand et al. [9] used GIS to identify trends in tuberculosis incidence between wet and dry climates across a

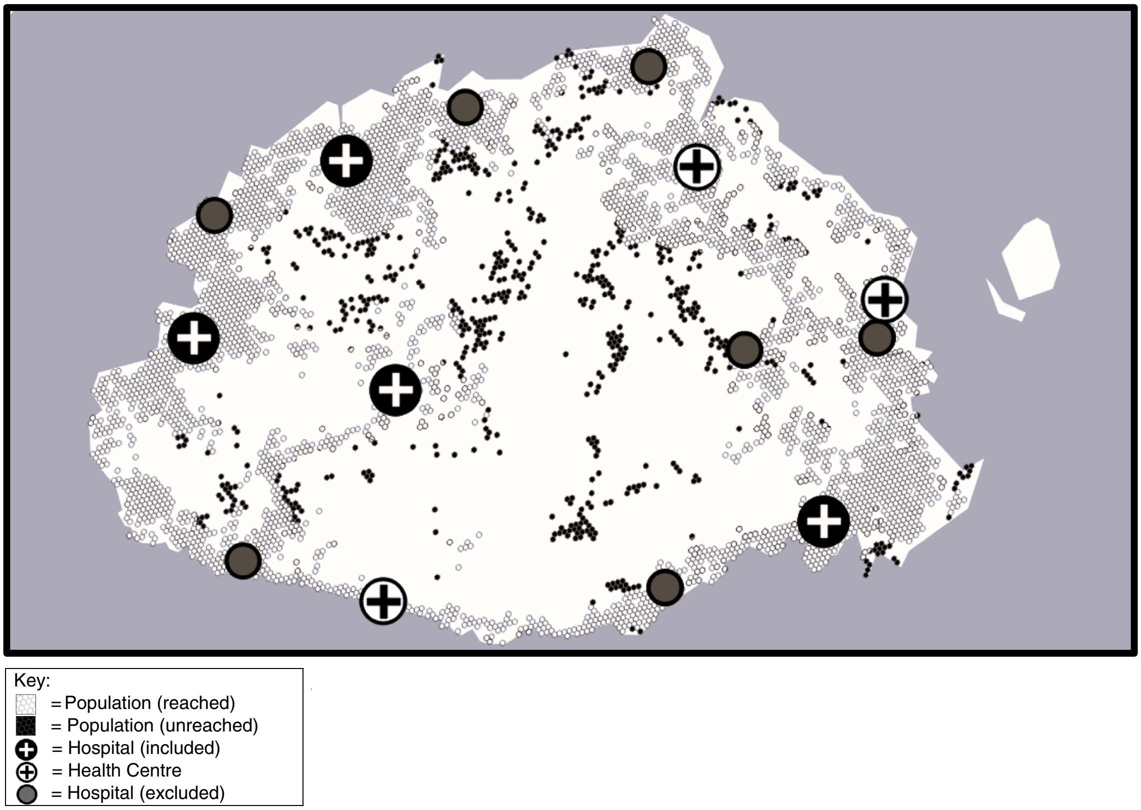

FIGURE 2 (a) Population coverage, Viti Levu. Displayed is the island of Viti Levu with our allocation of GeneXpert (GX) to seven facilities (four hospitals and three health centres). 694,825 people live within the white hexagons and 30,016 people live within the black hexagons. Shaded grey are hospitals excluded from this solution which may be considered as additional locations to prioritise for GX. (b) Population coverage, Vanua Levu. Displayed is the island of Vanua Levu with our allocation of GeneXpert (GX) to six facilities (all health centres). 96,612 people live within the white hexagons and 4856 people live within the black hexagons. Shaded grey are hospitals excluded from this solution which may be considered as additional locations to prioritise for GX.

FIGURE 3 GX facilities and isolated islands (distance to nearest hub). Displayed is a map of Fiji representing the 24 facilities allocated GeneXpert (GX) in our solution and 109 isolated islands. Each line represents the distance between an isolated island (triangle) and the nearest GX facility (black circle). Excluding the main islands, the population inhabiting the islands with a GX facility totals 36,373 people. The 21,749 people on the isolated islands are an average of 43 km from the nearest GX facility.

province of southern Iran. Moonan et al. [10] used GIS and molecular analysis techniques to track the transmission of specific strains of tuberculosis in Texas, and Tanser & Wilkinson [11] used GIS to suggest locations which could become tuberculosis supervision centres to improve community access to tuberculosis care. Our study, to our understanding, is one of the first to use GIS to assess the potential for a country to make GeneXpert® testing widely accessible as part of a tuberculosis elimination strategy. GIS has been used to address other public health issues in the Pacific. Shafiq et al. [12] explored access to radiotherapy throughout Pacific Island countries, using GIS to calculate the distance to the closest radiotherapy facility. They projected that therapeutic targets could only be reached by increasing the number of megavoltage machines from 3 to 29.

This study has several strengths. First, the population data we used was of 400 m resolution, with 9650 polygons that each represent between 1 and 6754 people, enabling greater precision than could have been achieved with other datasets, such as the 2017 Fiji Census data (1602 polygons). Indeed over 100 inhabited islands could be identified in addition to the two main populated islands, enabling widespread access to be quantified. Kontur's data is also well developed, combining multiple datasets to produce accurate population estimates. Second, ORSTools enabled use of drive-time as a surrogate variable for easy access on the main islands, which is more informative and realistic than measuring straight-line distance to a given facility. Third, we adjusted our methods to partially account for the limitations in the ORSTools software, adding a new isochrone-extending rule to correct for populations that appeared to belong inside certain 60-min zones, but who had been excluded. As discussed earlier, some of the regions included by this correction are actually slightly more than one-hour easy access from prospective GeneXpert® hubs. Further research could include more extensive investigations into the barriers to healthcare access identified at these sites, as they are likely to affect many Fijians nationwide. Fourth, this study is part of an ambitious wider goal of tuberculosis elimination in Fiji. Given the sparsity of GeneXpert® in many countries, even with a high tuberculosis burden, decentralising GeneXpert® in Fiji to this extent would set a new standard for timely diagnosis for tuberculosis control.

This study has several limitations. First, the road data in ORSTools appeared to be incomplete, even when exploring walking and cycling track options. Hence, it seems likely that ORSTools simply did not recognise the roads or tracks in these areas. The correction employed may not fully mitigate

TABLE 1 Population coverage calculations.

	Population within 1 h (%)		Population beyond 1 h (%)		
	Corrected	**Uncorrected**	**Corrected**	**Uncorrected**	**Total**
Viti Levu	694,825 (95.9%)	646,155 (91.1%)	30,016 (4.1%)	78,686 (10.9%)	724,841
Vanua Levu	96,612 (95.2%)	92,692 (91.4%)	4856 (4.8%)	8776 (8.6%)	101,468
Other Islands[a]	36,373 (62.6%)	36,373 (62.6%)	21,749 (37.8%)	21,749 (37.8%)	58,122[b]
Total	827,810 (93.6%)	775,220 (87.7%)	56,621 (6.4%)	109,211 (12.3%)	884,431[b]

[a]It was assumed that the population of other islands with a GeneXpert facility was all within 1 h due to the smaller land mass of these islands.
[b]A small duplication error arose in the 'other islands' calculation, and subsequently in the total population.

this. The use of ORSTools may include inaccurate speed limit or road quality data, leading to overestimations or underestimations of actual travel time. Second, the Kontur population data have some limitations that may suggest population underestimation: out of 9650 hexagons in Fiji, more than 20% represent less than five people, although these hexagons cover less than 1% of the whole population; there are also some roads on OpenStreetMap which have no Kontur population along them. Third, a minor limitation is that some error seems to have been introduced in calculations of outer island populations—the final population sums in Table 1 were around 800 people too high, likely due to accidentally counting some small islands twice. Fourth, a small minority of health facilities on the supplied spreadsheet from the government were not confirmed as being operational. A detailed field evaluation would be required to assess how up to date this list of active health facilities is, and was beyond the scope of this exercise. Fifth, our method for selecting facilities required judgement calls after review of multiple sources of information, to identify which isochrones covered the most hexagons. This exposed the study to the possibility of human error. Sixth, although we provided a weighted average distance between isolated islands and GeneXpert®, we could not assess which islands were within 1 h of GeneXpert® due to lack of Fijian interisland travel expertise. Finally, the field validation of the correction showed that the assumption made may not be accurate for all localities on the edges of our included region, especially those at the 'edges'—some of those counted as within one-hour easy access in our results are in fact marginally further from the nearest proposed GeneXpert® facility. There are also multiple potential barriers to healthcare access settlements: transport availability, network connection reliability, weather vulnerability and road condition, to name a few. As such, our pragmatic definition of 1-h driving a car does not necessarily constitute 'easy access' for all Fijians.

One feature of this project that requires specific attention is the nature of Fiji as a multi-island nation. Eleven machines were allocated to islands outside of Viti Levu and Vanua Levu, based on three main factors: the presence of an eligible facility, the population inhabiting the island and the proximity to other inhabited islands (see Table 2; Figure 3). The third of these factors played a major role in allocating machines to smaller islands.

Further research could include estimating demand to match GeneXpert® capacity at each site. Current epidemiology suggests that tuberculosis incidence is relatively uniform throughout Fiji, so our initial recommendation would be to prioritise densely populated areas such as Suva to receive the few 16-module GeneXpert® machines rather than the standard 4-module machines. Future epidemiological research should trigger re-evaluation of priority for these machines. Observational studies and surveillance activities would be helpful post-implementation to assess the success of widespread GeneXpert® distribution and operational factors. Furthermore, a plethora of non-geographical access barriers and enablers could be evaluated and incorporated in integrated solutions, such as waiting time at the facility, social factors, cost, perception of illness, perception of healthcare and other factors [13].

Our solution, which primarily focused on geographical access for widespread access, did not allocate a GeneXpert® to three divisional (and 11 subdivisional) hospitals. Some of these hospitals frequently care for tuberculosis patients and should certainly be considered as possible recipients for GeneXpert® for timely care of hospitalised individuals. Such allocations might be best considered additional to the solution suggested in this study to maintain population access above 90%.

Of course, well-located GeneXpert® is only one essential part of a multifaceted approach that is needed [14]. Successful implementation requires selected facilities to undergo a standardised assessment regarding security, personnel and administration systems, and confirmation that the facility has a stable supply of electricity or appropriate backup (e.g., generator). We have prepared a Health Facility Assessment Tool titled *GeneXpert® Facility Operational Requirements*, to meet this need. Facilities also need to invest time and resources into planning, maintenance and monitoring of GeneXpert® use. Beyond the individual facilities, centralised support, funding and planning is necessary. This includes: fixing or replacing malfunctioning GeneXpert® modules;

TABLE 2 GeneXpert allocation by island population.

	Island name	Population on island	Population on islands within 10 km	Combined population	Machines allocated
Main Islands	**Viti Levu**	**724,841**	**0**	**724,841**	**7**
	Vanua Levu	**101,468**	**273**	**101,741**	**6**
Other Eligible Islands	**Kadavu**	**8962**	**0**	**8962**	**1**
	Taveuni	**8905**	**0**	**8905**	**1**
	Ovalau	**7394**	**0**	**7394**	**1**
	Koro	**2327**	**0**	**2327**	**1**
	Nacula	**818**	**1405**	**2223**	**1**
	Gau	**2136**	**0**	**2136**	**1**
	Vanua Balavu	**1652**	**82**	**1734**	**1**
	Naviti	**1435**	**15**	**1450**	**1**
	Malolo	**691**	**626**	**1317**	**1**
	Lakeba	**1310**	**0**	**1310**	**1**
	Rotuma	**875**	**0**	**875**	**1**
	Qamea	1431	346	1777	0
	Vatulele	1081	0	1081	0
	Beqa	923	0	923	0
	Cicia	860	0	860	0
	Ono-i-Lau	465	0	465	0
	Matuku	400	0	400	0
	Moala	344	0	344	0
	Rabi	329	0	329	0
	Kabara	294	0	294	0
Ineligible Islands	Yasawa	867	No health centre or hospital present on these islands		
	Ono	810			
	Waya	803			
	Moturiki	794			
	Wakaya	709			
	Malolo Lailai	580			
	Nairai	560			
	Makongai	560			
	Tavua	541			

Note: This table displays the most populous islands of Fiji and how many machines were allocated to each. Rows with bold font indicate islands that were allocated one or more GeneXpert® machines. Islands were considered *eligible* to receive GeneXpert® if they had a health centre or hospital. The *Combined Population* column results from adding the population located on a given island to the population on all islands located within 10 km of the relevant GeneXpert® facility (especially relevant to Nacula and Malolo islands).

education and training for staff to use GeneXpert® correctly; public education about tuberculosis diagnosis; transportation of sputum samples to GeneXpert® facilities; prompt referral to treatment for diagnosed tuberculosis cases; and supply, distribution and storage of GeneXpert® cartridges. Cartridge supply shortages posed significant challenges throughout the COVID-19 pandemic, being mitigated in some places by pooling of samples [15]. A manual to guide streamlined GeneXpert® implementation has been provided by WHO [16]. It outlines the operational prerequisites and key actions necessary for successful GeneXpert® implementation, including policy, financing, logistics and monitoring.

Further improving GeneXpert® access for rural communities may involve consideration of nursing stations to host GeneXpert® after the initial solution is rolled out. Allocating some GeneXpert® to mobile screening units may also improve access, either in replacement of certain facilities or supplementary to the solution. On the main islands, options could include a truck with GeneXpert® onboard, as has been implemented in similar contexts overseas [17, 18]. A ferry-based laboratory may be an option to improve GeneXpert® access for isolated islands. Moreover, given the potential for GeneXpert® to test for other diseases (HIV, COVID-19), planning should ensure that the repurposing of GeneXpert® for tuberculosis diagnosis throughout Fiji is done in a way that only enhances the control of other diseases. Girdwood et al. [19] provide a good example of the integration of tuberculosis diagnosis with HIV diagnosis in Zambia, demonstrating the cost-effectiveness and many benefits of such an approach. Links between GeneXpert® facilities and drug-susceptibility testing in laboratories is also important in monitoring for rates of drug-resistant TB; although these are currently estimated to be very low in Fiji, surveillance programmes often underestimate the rates of drug-resistant tuberculosis [20].

We have shown that over 90% of Fijians could be within an easy one-hour drive of a GeneXpert® machine with strategic placement of 24 machines across the country. The final number and locations will need to be subject to data from health facility assessment, matching GeneXpert® capacity with need in each location, and decisions as to whether there should be mandatory GeneXpert® placement in certain facilities. The application of readily available tools to decision-making around GeneXpert® location to maximise population access, should be of relevance to other settings and diseases.

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REFERENCES

1. World Health Organisation. *Tuberculosis profile: Fiji*. [Internet]. 2021 [cited 2023 Feb 18]. Available from: https://worldhealthorg.shinyapps.io/tb_profiles/?_inputs_&entity_type=%22country%22&lan=%22EN%22&iso2=%22FJ%22
2. OpenStreetMap Foundation. *OpenStreetMap*. 2022 [cited 2023 Feb 18]. Available from: https://www.openstreetmap.org/
3. QGIS. *QGIS: A Free and Open Source Geographic Information System*. 2023 [cited 2023 Feb 18]. Available from: https://www.qgis.org/en/site/
4. Kontur. *Kontur Population dataset*. 2023 [cited 2023 Feb 18]. Available from: https://www.kontur.io/portfolio/population-dataset/
5. Fiji Bureau of Statistics. *Fiji Bureau of Statistics Releases 2017 Census Results*. 2018 [cited 2023 Feb 18]. Available from: https://www.fiji.gov.fj/Media-Centre/News/Fiji-Bureau-of-Statistics-Releases-2017-Census-Res
6. The World Bank Group. 2023 [cited 2023 Feb 18]. Available from: https://data.worldbank.org/indicator/SP.POP.TOTL?locations=FJ
7. Glen S. *Weighted mean: formula: how to find weighted mean*. 2023 [cited 2023 Feb 18]. Available from: https://www.statisticshowto.com/probability-and-statistics/statistics-definitions/weighted-mean/
8. Mahara G, Yang K, Chen S, Wang W, Guo X. Socio-economic predictors and distribution of tuberculosis incidence in Beijing, China: a study using a combination of spatial statistics and GIS technology. Med Sci. 2018;6(2):26.
9. Beiranvand R, Karimi A, Delpisheh A, Sayehmiri K, Soleimani S, Ghalavandi S. Correlation assessment of climate and geographic distribution of tuberculosis using geographical information system (GIS). Iran J Public Health. 2016;45(1):86–93.
10. Moonan PK, Bayona M, Quitugua TN, Oppong J, Dunbar D, Jost KC Jr, et al. Using GIS technology to identify areas of tuberculosis transmission and incidence. Int J Health Geogr. 2004;3(1):23.
11. Tanser F, Wilkinson D. Spatial implications of the tuberculosis DOTS strategy in rural South Africa: a novel application of geographical information system and global positioning system technologies. Trop Med Int Health. 1999;4(10):634–8.
12. Shafiq J, Gabriel GS, Barton MB. Radiotherapy service need in the Pacific Island countries. Asia Pac J Clin Oncol. 2021;17(5):e217–25.
13. Rutherford ME, Mulholland K, Hill PC. How access to health care relates to under-five mortality in sub-Saharan Africa: systematic review. Trop Med Int Health. 2010;15(5):508–19.
14. Albert H, Purcell R, Wang YY, Kao K, Mareka M, Katz Z, et al. Designing an optimized diagnostic network to improve access to TB diagnosis and treatment in Lesotho. PLoS One. 2020;15(6):e0233620.
15. Cuevas LE, Santos VS, Lima SVMA, Kontogianni K, Bimba JS, Iem V, et al. Systematic review of pooling sputum as an efficient method for Xpert MTB/RIF tuberculosis testing during the COVID-19 pandemic. Emerg Infect Dis. 2021;27(3):719–27.
16. Mirzayev F, van Gemert W, Gilpin C, Weyer K. WHO guidelines approved by the guidelines review committee. *Xpert MTB/RIF implementation manual: technical and operational 'how-to'; practical considerations* [Internet]. France: World Health Organisation; 2014 [cited 2023 Feb 18].
17. Camelique O, Scholtissen S, Dousset JP, Bonnet M, Bastard M, Hewison C. Mobile community-based active case-finding for tuberculosis among older populations in rural Cambodia. Int J Tuberc Lung Dis. 2019;23(10):1107–14.
18. Morishita F, Garfin AMCG, Lew W, Oh KH, Yadav RP, Reston JC, et al. Bringing state-of-the-art diagnostics to vulnerable populations: the use of a mobile screening unit in active case finding for tuberculosis in Palawan, The Philippines. PLoS One. 2017;12(2):e0171310.
19. Girdwood S, Pandey M, Machila T, Warrier R, Gautam J, Mukumbwa-Mwenechanya M, et al. The integration of tuberculosis and HIV testing on GeneXpert can substantially improve access and same-day diagnosis and benefit tuberculosis programmes: a diagnostic network optimization analysis in Zambia. PLOS Glob Public Health. 2023;3(1):e0001179.
20. Knoblauch AM, Grandjean Lapierre S, Randriamanana D, Raherison MS, Rakotoson A, Raholijaona BS, et al. Multidrug-resistant tuberculosis surveillance and cascade of care in Madagascar: a five-year (2012-2017) retrospective study. BMC Med. 2020;18(1):173.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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