

Cost of tuberculosis and multidrug resistance tuberculosis diagnostic tests in Tigray health research institute, Mekelle, northern Ethiopia

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Abstract

Background: Tuberculosis is a communicable disease, one of the top ten causes of death and the leading cause of death from a single infectious agent worldwide. Economic analysis to determine the cost-effectiveness, affordability, or budget impact implications of diagnostic tests requires reliable unit cost estimates. Therefore, the present study figured out unit cost of tuberculosis (TB) and multidrug resistance tuberculosis (MDR TB) diagnostic tests by performing detailed cost analysis methods to help decision makers and researchers.

Objective: To estimate the unit cost of tuberculosis and multidrug resistance tuberculosis diagnostic tests.

Method: Cross sectional bottom-up and retrospective top-down approach was carried out from September 8, 2018 to August 22, 2019 from the health care providers' perspective were used in the cost estimation process. Inputs were consumables, capital equipment, personnel, and buildings. Capital items were annualized using the equivalent annual cost estimation formula and a 3 percent discount rate. All unit costs were calculated in a purposely built Excel spreadsheet that was developed for tuberculosis diagnostic test costing. Locally collected costs were in Ethiopian birr and were converted to United States dollars using the March 2020 exchange rate.

Results: This study revealed that the unit costs of tuberculosis and multidrug resistance tuberculosis were 6.16 USD for sputum smear fluorescence microscopy, 6.33 USD for Ziehl-Neelsen light smear microscopy, 19.19 USD for GeneXpert, 28.37 USD for first line probe assay, 21.22 USD for second line probe assay, 25.76 USD for solid culture, 20.51 USD for liquid culture per test. Moreover, from all costs of TB and MDR TB diagnostic tests 44.54 USD, 24.81 USD, 49.34 USD, and 8.85 USD per test were consumables, personnel, capital equipment and building respectively.

Conclusion: In this study, among all tuberculosis and multidrug resistance tuberculosis tests first line probe assay was the most expensive accompanied by culture, GeneXpert, and sputum smear microscope. Additionally capital equipment and consumables hold a large share of unit costs of all tests.

Key words: Cost, tuberculosis, recurrent cost, capital equipment, diagnostic tests, Mekelle

Introduction

Tuberculosis (TB) is an infectious disease caused by the bacillus mycobacterium tuberculosis, which is spread when people who are sick with TB expel bacteria into the air. It is a major cause of ill health, one of the top ten causes of death worldwide, and the leading cause of death from a single infectious agent. Globally in 2021 an estimated of 10.6 million people fell ill, of them 1.6 million were died due to tuberculosis (WHO 2018). Additionally, the burden of drug-resistant TB (DR-TB) is also estimated to have increased between 2020 and 2021, with 450 000 new cases of rifampicin-resistant TB (RR-TB) in 2021 (WHO 2021).

The 2020 Global Tuberculosis (TB) Report noted that 3 million of TB cases were undiagnosed annually and there is an urgent need to strengthen TB program efforts to improve TB case detection of these missing millions through cost effective and systematic screening and diagnosis programs (WHO 2020).

Additionally Gaps in the cascade of tuberculosis diagnosis, including failure to order appropriate diagnostic testing and loss to follow-up while awaiting test results, are major contributors to tuberculosis burden, mortality, and ongoing transmission (MacPherson et al 2014; Getnet et al 2017).

Delayed diagnosis contributes to continued transmission, poor health outcomes, and distress to the patient and family, whereas early diagnosis is expected to lead to early treatment initiation and hence better outcome. Improved diagnostic tools may facilitate early diagnosis and reduce the direct costs of the diagnostic burden on patients and their families (Laokri S DM et al; WHO 2015).

Cost analyses of diagnostic tests and strategies for TB and drug-resistant TB have important economic implications. Economic analyses to determine the cost-effectiveness, affordability, or budget impact implications of diagnostic tests require reliable unit

cost estimates of diagnostic tests and procedures (Pantoja A FC 2013).

Tuberculosis (TB) continues to be a major public health problem in Ethiopia. Among the top thirty high TB and multidrug-resistant TB burden countries, ranked twelfth and twenty-fourth respectively (EMoH 2022). Diagnosis of tuberculosis requires considerable and sustained financial resources for delivering and maintaining the standard services and this has resulted in considerable resource investment and budgetary implications for the government (ENHA 2017).

Furthermore, the Ethiopian National Tuberculosis Programme 2022 findings revealed that some of the obstacles to reducing the morbidity and mortality of TB and MDR TB included a lack of initial presumptive TB screening, limited access to TB diagnostics, and a lack of funding for TB. Increasing the use of rapid molecular diagnostics for routine screening and implementing newer diagnostic technologies were the strategies to address the aforementioned diagnostic gaps (EMoH 2022).

Therefore, to scaling-up rapid molecular diagnostics and to adopt new diagnostic technologies evidences on cost and cost effectiveness of existing tuberculosis diagnostic tests are essential. Hence, this study is part of large scale research project on development and cost effectiveness of novel paper based TB and MDR TB diagnostic test. The main purpose the study was to provide baseline unit cost estimates of existing TB and MDR TB diagnostic tests in order to cascade further cost effectiveness evaluation of the novel paper based diagnostic test relative to existing TB and MDR TB diagnosis.

Additionally, Findings of this study can provide guidance for National Tuberculosis Program managers to scale-up rapid molecular diagnostics for routine screening and adopting newer technologies, and may assist researchers to conduct further cost-effectiveness analysis. And also, output of this research can help local managers for budgeting, price setting and evaluation of resource use.

Materials and Methods

Study area and period: The study was done at Tigray Health Research Institute which is a regional reference laboratory, located in Mekelle, Ethiopia. The regional laboratory was established in 1985 E.C to strengthen the laboratory services in Tigray. According to health management information system of the institute a total of 1320 sputum smear microscope, 346 GeneXperts, 15 first LPAs, 55 second LPAs, and 1320 cultures were done during the study period. The data collection period was from September 8, 2018 to August 22, 2019.

Study perspective and design: This study was assessed from health care provider perspective with cross sectional study design. In this paper both bottom-up and retrospective top-down costing data collection approaches were used.

Costing assessment

Inputs: The study analyzed the cost of smear Ziehl-Neelsen (ZN) staining, smear fluorescence microscopy (FM) staining, Gene Xpert, first-line probe assays, second-line probe assays, and liquid and solid cultures. Inputs categories were consumables, capital medical laboratory items, personnel, and buildings.

Costs: Costs are categorized into specific variable, shared variable, and shared fixed costs. Specific variables refer to recurrent costs that vary per test and include consumables and personnel (WHO 2017; Sohn H J et al 2009). Shared variable costs refer to the costs of items that are commonly used by all tests and vary per time and/or per consumption, including cleaning agents, kits, non-disposable nitrile gloves, cotton, towels, gowns, small equipment, other protection materials, etc (WHO 2017; Sohn H J et al 2009). In this study, shared variable cost is estimated and presented based on the sum of the initial price of specific single items required for a given test and in the absence of data on the number of items consumed per test total expenditures made in a given year were used. Whereas shared fixed costs are costs that do not vary with the volume of diagnostic tests performed in a given period of time. Shared fixed costs include capital equipment like a microscope, analytical balance, autoclave, printer, centrifuge, refrigerator, laboratory chair, biosafety cabinet, compressor, PH meter, Minishaker/Vortex, precision incubator, bursen burner, etc (WHO 2017; Sohn H J et al 2009). In this study, unit cost (total cost per test) is the sum of specific variable costs and shared fixed costs; however, shared variable costs were not included in the unit cost analysis since recorded data was unavailable.

Inclusion and exclusion criteria: We included direct tuberculosis and multidrug resistance tuberculosis tests (staffing, laboratory equipment, reagents, building plus laboratory based overheads (office utilities, cleaning and sterilization). We exclude institute level over heads, research cost, training cost, transportation, maintenance cost due to lack of specific data.

Data source and collection methods: Semi-structure questionnaire and checklists were used as data collection methods. Data sources were record review (for consumables, initial price of capital equipment, personnel), health management information systems

(for number of tests done, amount of consumables consumed), medical laboratory experts (identification and listing of all inputs/items in TB and MDR TB diagnosis, timing of test procedures, measurement of laboratory space, in quantifying amount of consumables used).

Data quality control, management and analysis: To assure quality of data training was given to data collectors; collected data was checked for accuracy, completeness, clarity and consistence daily. All unit costs were calculated in a purpose-built Excel spreadsheet that was developed for TB diagnostic test costing. Locally collected costs were in Ethiopian birr (ETB) and are converted to US dollars (USD) using the exchange rate for March, 2020 G.C (1 USD = 33.98 ETB) (US 2020).

Input cost estimation: Consumables: Unit costs of specific variable costs were calculated per test based on standards required for each test using the data from the Global Drug Facility (GDF) tuberculosis diagnosis ordering list (GDF 2018). The total cost was presented per test and/or per year. Total cost per test is the sum of all unit costs for specific recurrent costs. The total cost per year is estimated based on multiplying the total unit cost per test by the number of patients seen or the number of tests performed in the previous year.

Capital items: Capital costs include annualized discounted depreciation of capital equipment using the straight-line depreciation approach; we assumed that the services from the capital items were divided equally over the useful life of the capital items (Walker D KL 2002). Total fixed costs for capital equipment were based on the sum of the initial prices of the items from the GDF tuberculosis diagnosis ordering list and an annualized total cost (total cost per year) based on the equivalent annual cost (EAC) estimation formula and a 3 percent discount rate. EAC is equal to the net present value (NPV) divided by the present value annuity factor, $A(t, r)$, while taking into account the price of capital equipment (r) and the number of years in question (t) (Walker D KL 2002 & Kenton W 2019). The annuity factor was calculated as follows (Equation 2).

$$\text{Annuity Factor} = \frac{1 - 1/(1+r)^t}{r} \dots \text{Equation 2}$$

Where: r = Price of capital equipment
 t = Number of periods (life span)

According to studies, the life span or use of capital medical equipment ranged from three to ten years (Halbwachs H 2000), and a few medical equipment items that were not included in the literature were assumed to have a five-year life span (Creese A PD

2000). Unit cost capital equipment for a given test was calculated using a top-down costing approach by allocating the annual cost of the item to the number of tests done in that year. Finally, an annualized cost was allocated per test based on the number of samples done that year.

Personnel: Personnel costs indicate that the cost of staff time for laboratory technicians and coordinators, estimated by on the average hourly time required to perform the specific test and gross monthly salary (260.35 USD), is associated with that setup (Creese A PD 2000) (see equation 2 below).

Personnel cost of a given test

$$= \frac{\text{Average time to perform the test} \times 260.35 \text{ USD}}{\text{Number of working hours in month}}$$

Building/space: The cost of building was assessed indirectly through average rent of similar house in Mekelle city, since the building was built ten years back of the study, and was difficult to find cost data on each specific input from contractor and also building was built for other departments too. The average rents in Mekelle city were about 88.23 USD per room per month. A room is 36 square meters. Unit costs were estimated by dividing the total cost of building a specific test by the total number of tests done in that year. The number of tests done in that year was obtained from health laboratory management information system data.

Ethics approval and consent: The study was approved by the ethical review board of the college of health sciences at Mekelle University. Permission letters were obtained from the Tigray research health institute and the tuberculosis diagnosis coordinator.

Results

Input description: A total of 1320 sputum smear microscope, 346 GeneXperts, 15 first LPAs, 55 second LPAs, and 1320 cultures were done during the study period. The average monthly salary was 260.35 USD (8852 ETB). The average time required to perform a given test ranged from two hours (sputum smear microscope) to 68 days (solid culture). Measured laboratory space areas ranged from 1/6 of a room (sputum smear microscope) to three rooms (LPA tests).

Cost of sputum smear microscope (fluorescence microscopy staining): In this study unit cost (cost per test) of sputum smear microscope FM staining was 6.16 USD of these specific variable costs accounted 3.22 USD and shared fixed costs accounted 2.94 USD. Personnel and capital costs holds large share variable and fixed costs respectively (Figure 1).

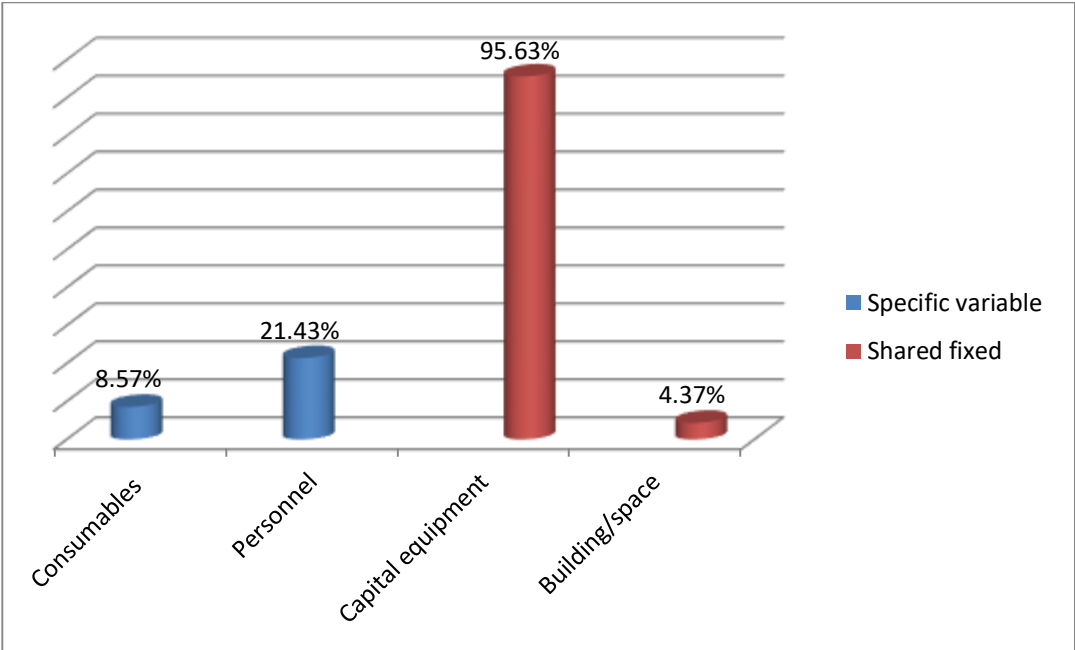


Figure 1: Cost sputum smear fluorescence microscopy (FM) staining, Tigray research health institute, 2018/19

Cost of sputum smear microscope (Ziehl-Neelsen staining): Unit costs of sputum smear microscope Ziehl-Neelsen staining were 6.33 USD, of these specific variable cost were 3.36 USD per test and shared fixed costs were 2.97 USD per test (Figure 2).

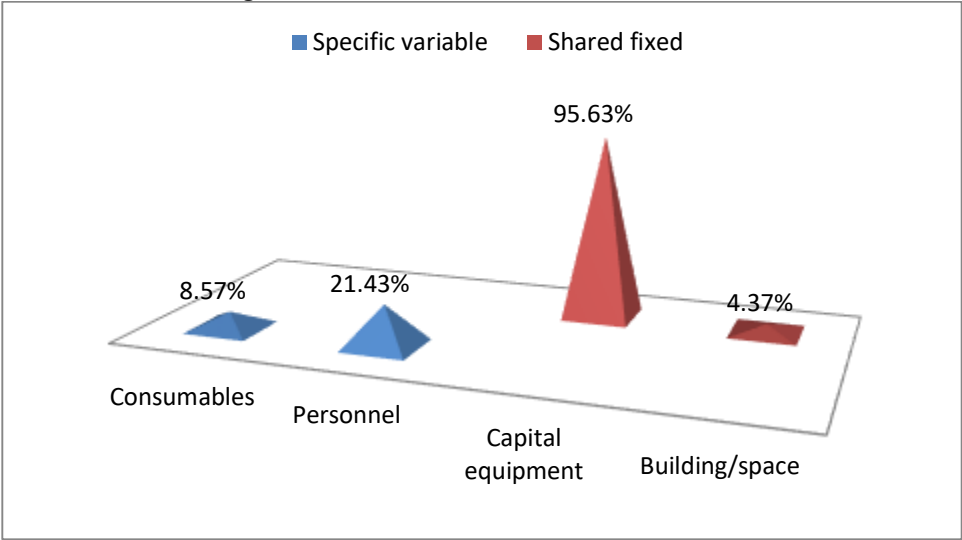


Figure 2: Cost category of sputum smear microscope Ziehl-Neelsen (ZN) staining, Tigray research health institute, 2018/19

Cost of GeneXpert: Total costs for GeneXpert were 19.19 USD per test. Specific variable costs accounted for 10.78 USD per test, of which 10.06 USD (93.3%) were consumables and 0.72 USD (6.7%) were personnel. Shared fixed costs were 8.41 USD per test, or 2917.52 USD per year, of which 7.9 USD (93.93%) per test were for capital equipment and 0.51 USD (6.06%) per test were for building space. Specific variable costs accounted for 1,538.53 USD (Table 1).

Table 1: Cost category of GeneXpert of Tigray research health institute, 2018/19

Consumables	Cost per test in USD
Sputum containers	0.08

Specific items	variable		
		Xpert MTB/RIF kit of 50 tests	9.98
		Total	10.06 USD
		Personnel	0.72 USD
Total			10.78 USD
Shared fixed items	Capital equipment	Annualized cost in per year (USD)	Cost per test (USD)
	GeneXpert IV-4 modules with desktop computer	2179.48	6.29
	Laboratory refrigerator 140 L	185	0.53
	Battery pack for UPS 3000 VA	376.57	1.08
	Total	2741.05	7.9
	Building space	176.47	0.51
Total		2917.52	8.41
Other (shared variable items)	Items	Cost in USD	
	Xpert MTB/RIF kit of 50 tests	499.00	
	GeneXpert Calibration kit for GXIV-4	450.00	
	Marker pen	1.51	
	Alarm clock	4.12	
	Indoor and outdoor thermometer	12.25	
	Isopropanol	15.01	
	Discard bin 2 L	42.42	
	Transparent polypropylene bags	175.96	
	Sterilization indicator tape for hot air oven - dry	13.32	
	First aid kit for laboratories	126.61	
	Disposable nitrile gloves	15.92	
	Cotton laboratory coat size M	19.07	
	Laboratory coat	19.07	
	Absorbent laboratory paper	29.60	
	Plastic bags 30 L	79.10	
	Chlorine disinfectant	30.25	
	Spray dispenser 1 L	5.32	
Total		1,538.53 USD	

Cost of first and second Line probe assay: The unit cost for first LPA was 28.37 USD, and the unit cost for second LPA was 21.22 USD per test, of which cost-specific variable costs accounted for 13.47 USD and 13.33 USD per test for the first and second LPA, respectively. Shared fixed costs of the first LPA were 14.9 USD per test or 9103.15 USD per year, of which 11.12 USD (74.64%) per test or 5926.75 USD per year were equipment costs, whereas 3.78 USD (25.36%) per test or 3176.4 USD per year were building space costs. Shared fixed costs of the second LPA were 7.89 USD per test and or 8612.45 USD per year, including 4.11 USD (52.10%) per test or 5436.05 USD per year for capital equipment and 3.78 USD (47.9%) per test or 3176.4 USD per year for building space cost. The

shared variable cost is 2688.09 USD for both the first and second LPA.

Cost of solid culture: Total costs of solid culture were 25.76 USD per test; among this specific variable were 14.87 USD per test, of which 7.77 USD were consumables and 7.10 USD were personnel costs. Shared fixed costs were 10.89 USD per test or 14,378.15 USD per year, including 10.62 USD (97.53%) per test or 14025.21 USD per year for equipment and 0.26 USD (2.47%) per test or 352.94 USD per year for building space. Whereas specific variable costs accounted for 1,538.53 USD per year (Table 2).

Table 2: Cost category of solid culture diagnostic test of Tigray Health Research Institute, 2018/19

Specific items	variable	Consumables	Cost per test in USD
		Phenol crystals	0.048495
		Basic fuchsin	0.16552

	Methylene blue	0.007187306
	Hydrochloric acid	0.0323526
	Immersion oil	0.0924
	Sputum containers	0.1666
	Microscope slides	0.0104
	Sodium hydroxide	0.004946898
	Tri-Sodium citrate dihydrate	0.005014057
	N-acetyl-L-cysteine	0.0333825
	Glycerol 99	0.000855957
	Potassium dihydrogen phosphate	0.007402523
	Magnesium sulphate-heptahydrate	7.1421
	L-Asparagine-monohydrate	0.003818616
	Tri-Magnesium di-citrate nonahydrate	0.001033234
	Malachite green oxalate	0.0011524
	Di-Sodium hydrogen phosphate, anhydrous	0.012464966
	Disposable inoculation loops 10 µl	0.03256
	Total cost	7.76 USD
	Personnel	7.10USD
Total		14.87 USD
Shared fixed cost	Capital equipment	Annuitized cost in USD per year
	Bright field microscope - ZN	139.56
	Analytical balance	289
	Weighing boats	19.15
	Bunsen burner	10.077
	Precision incubator	674.5
	BD BBL Lowenstein-Jensen Medium, slants	20.93
	Magnifying hand lens for laboratory	19.7
	Refrigerated bench top centrifuge	965.7
	4 – Place rotor for refrigerated bench top centrifuge	205.04
	4 – Rotor buckets for refrigerated bench top centrifuge	124.16
	4 – Lids for rotor buckets for refrigerated bench top centrifuge	37.15
	Automated culture media dispenser	676.1
	Inspissator for TB culture medium preparation	1146.744
	Laboratory refrigerator 140 L	185.122
	pH meter	51.459
	Hot plate stirrer	187.5
	Laboratory drying rack for glassware	18
	Calibrated thermometer	76.29
	Autoclave basic unit for Media Kitchen	1744.8
	Exhaust air filtration system for Autoclave	464.1
	Autoclave stainless steel buckets	66.77
	Autoclave stainless steel baskets	242.66
	Printer for Autoclave	192.4
	Compressor for Autoclave 106116	161.38
	Waste container for liquids 4 L	20.54
	Biosafety Cabinet - 2 filters, 5 feet	3817.9
	Base Support for BSC - 5 feet	225.9
	Thimble for Class IIA, hood for BSC	442.04
	Formaldehyde/neutralization fumigation top plate	266.02
	HVP fumigation plate	216.73
	Double Exhaust filter	462.6
	Exhaust HEPA Air Filter	147.3
	Main HEPA Filter for air down flow	294.63
	UPS 3000 VA	376.57
	Minishaker / Vortex	36.687
	Total	14025.21 USD
	Building space	352.94 USD
Total		14,378.15 USD
Other	Shared variable items	1267.79 USD

Table 3: Cost category of liquid culture diagnostic test of Tigray Health Research Institute, 2018/19

Specific variable items	Consumables	Cost in USD per test
	Phenol crystals	0.048495
	Basic fuchsin	0.16552
	Methylene blue	0.007187306
	Hydrochloric acid	0.0323526
	Immersion oil	0.0924
	Sputum containers	0.1666
	Microscope slides	0.0104
	Sodium hydroxide	0.004946898
	Tri-Sodium citrate dihydrate	0.005014057
	N-acetyl-L-cysteine	0.0333825
	Potassium dihydrogen phosphate	0.007402523
	Di-Sodium hydrogen phosphate, anhydrous	0.012464966
	Disposable inoculation loops 10 µl	0.03256
	BBL MGIT tubes for use in BACTEC MGIT 960 (7ml)	1.95
	BACTEC MGIT 960 Supplement Kit (PANTA and OADC combined)	0.04248
	Total cost	2.61
	Personnel	7.10 USD
Total		9.71 USD
Share cost	fixed	Capital equipment
		Annualized cost per year
		Bright field microscope - ZN
		139.56
		Analytical balance
		289
		Bunsen burner
		10.077
		Precision incubator
		674.5
		Slanted rack for 16 mm tubes
		13.76
		Magnifying hand lens for laboratory
		19.7
		Refrigerated bench top centrifuge
		965.7
		4 - Place rotor for refrigerated bench top centrifuge
		205.04
		4 - Rotor buckets for refrigerated bench top centrifuge
		124.16
		4 - Lids for rotor buckets for refrigerated bench top centrifuge
		37.15
		Automated culture media dispenser
		676.1
		Inspissator for TB culture medium preparation
		1146.744
		Laboratory refrigerator 140 lt
		185.122
		pH meter
		51.459
		Hot plate stirrer
		187.5
		Laboratory drying rack for glassware
		18
		Calibrated thermometer
		76.29
		Autoclave basic unit for Media Kitchen
		1744.8
		Exhaust air filtration system for Autoclave
		464.1
		Autoclave stainless steel buckets
		66.77
		Autoclave stainless steel baskets
		242.66
		Printer for Autoclave
		192.4
		Compressor for Autoclave 106116
		161.38
		Waste container for liquids 4 L
		20.54
		Biosafety Cabinet - 2 filters, 5 feet
		3817.9
		Base Support for BSC - 5 feet
		225.9
		Thimble for Class IIA, hood for BSC
		442.04
		Formaldehyde/neutralization fumigation top plate
		266.02
		HVP fumigation plate
		216.73
		Double Exhaust filter
		462.6
		Exhaust HEPA Air Filter
		147.3
		Main HEPA Filter for air down flow
		294.63
		UPS 3000 VA
		36.687
		Minishaker / Vortex
		36.68
		Total
		13659
		Building space
		352.94
Total		14,011.94 USD
Other	Shared variable costs	10,444.95 USD

Liquid culture: Total costs were 20.31USD per test. Specific variable cost accounts 9.71 USD per test of which 2.61 USD (26.87 %) were consumables and 7.10 USD (73.12%) were personnel. Shared fixed cost was 10.60 USD per test or 14,011.94 USD per year, including 10.34 USD (97.45%) per test or 13659 USD were equipment and 0.26 USD (2.54%) per test or 352.94 USD per year were building space. Whereas specific variable cost accounted 1,538.53 USD per year (Table 3).

Discussion

In this study, the total cost of sputum smear Ziehl-Neelsen staining was higher than that of fluorescence microscopy (6.16 USD). This is due to the difference in the cost of consumables (2.55 USD for FM and 2.64 USD for ZN) and capital equipment (2.81 USD for FM and 2.84 USD for ZN), but personnel and building costs were the same for both ZN and FM staining. Findings of this study were higher than those of a study done in South Africa, which were 3.40 USD for fluorescence smear microscopy and 2.25 USD for Ziehl-Neelson light microscopy; the variation may be due to the difference in time of analysis and number of samples done in the study period (Shah M CV et al 2013).

Furthermore, the unit costs for smear microscopes in this study were higher than in a study conducted in Brazil (6.01 USD) (Lida Jouca de Assis Figueredo et al 2020), conducted in 2015. This difference may have been caused by inflation and a difference in the costing approach, as our study used both bottom-up and retrospective top-down costing, while the study conducted in Brazil used activity-based costing (bottom-up), which may have resulted in a marginal increase in average cost when compared to deductive or top-down costing approaches (Zuzana Spacirova et al 2020).

Moreover, capital equipment cost represent the largest share of total unit cost sputum smear (47.46% for FM and 46.63% for ZN), followed by consumables (42.22% for FN and 43.34 % for ZN), personal costs (12.16% for FM and 11.82% for ZN), and building space cost (2.19% for FN and 2.13% for ZN test). However, findings in this study were slightly different from study done in India, in which fluorescence smear microscopy's unit cost of consumables accounts (0.36 USD, 10%), equipment cost (0.12 USD, 4%), labor (2.18 USD, 64%), overhead cost (0.74 USD, 22%), and Ziehl-Neelsen light smear microscopy consumables (0.34 USD, 15%), equipment cost (0.11 USD, 5%), labor cost per test (1.05 USD ,47%) (Rupert S VA et al 2017), the differences were due to geographical variation of price of non-tradable goods

(labor cost or salaries) and consumables in the two studies.

Our study revealed that the unit cost of GeneXpert was 19.19 USD per test, of which consumables covered the largest share of the cost (52.42%), followed by capital laboratory equipment (43.82%), personnel (3.75%), and building space (2.66%). In this study, unit cost of GeneXpert was higher than studies done in India (13.58 USD), South Africa (14.93 USD) and Brazil (17.37 USD), this could be due to a change in price of inputs over time and a difference in the volume of output or tests done (Shah M CV et al 2013; Lida Jouca de Assis Figueredo et al 2020; Rupert S VA et al 2017). In our study, the numbers or volume of GeneXpert tests done during study period were lower than in the above-mentioned studies, resulting in a decrease in the average cost.

This study indicated that the cost of the first LPA was higher than the second LPA, since there was difference in input or item required for the two tests, a tabletop PCR workstation with UV light were required to perform first LPA than second LPA. Unit costs of both the first and second LPA are lower than those in the study done in Cambodia (33.88–37.11 USD), and this is due to the fact that the study done in Cambodia incorporated transportation costs and maintenance costs of capital equipment in the unit cost analysis (Pallas SW CM et al 2018).

The unit cost of solid culture was 25.76 USD higher than findings from Moldova (18.80 USD), and a large share of unit cost solid culture was related to capital equipment (41.22%), followed by consumables and personnel costs (LeAnna Cates et al 2020). This study showed that the unit cost of liquid culture was 20.31 USD, which was higher than the study done in India (11.06 USD), this could be due to the reason study done in India incorporated negotiated price reduction system to enhance generalizability of the findings in other setting (Rupert S VA et al 2017).

Additionally, in liquid culture test capital laboratory equipment accounted for 51.3% of the unit cost, followed by personnel (34.61%), consumables (12.9%), and building space (1.28%). However, a study done in South Africa showed that a large share of the cost was related to consumables (66%) and the least related to equipment costs (9%) ; this could be due to the difference in the number of tests done, causing decrements in the average cost due to the effect of economies of scale from capital equipment (Shah M CV et al 2013).

Our study indicated that, comparing unit costs of tuberculosis and multidrug resistance tuberculosis diagnostic tests, line probe assays were the most

expensive, followed by cultures, GeneXpert, and sputum smear microscopes, respectively. These findings were in line with the study done in India and Cambodia (Rupert S VA et al 2017; Pallas SW CM et al 2018).

Strength and limitation of the study

As strength, the study used both a bottom-up and top-down approach in order to minimize missing data and allow differential timing in cost analysis (discounted and annualized) for capital equipment. The main limitations of the study were that some components like shared variable cost, maintenance cost of equipment, and transportation cost were not included in the unit cost analysis due to the absence of specific recorded data though we tried to assess using both approaches.

Conclusion and recommendation

The first-line probe assay test cost was the highest, followed by culture, GeneXpert, and sputum smear microscopy, respectively. In all tuberculosis and multidrug resistance tuberculosis diagnostic tests, costs related to capital equipment and consumables were the highest. Therefore, TB program managers and health care providers have to consider the high cost of first line probe assay when they plan, prescribe and doing it. Additionally, we recommend further cost effectiveness analysis to recognize whether the high cost balance with effectiveness (performance) of the diagnostic test, and also to reveal the most cost effective diagnostic test and ensure efficient allocation of resource in the diagnostic test.

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Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on request.

Competing Interests: We have declared that no competing interests exist.

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study design, data collection and analysis, the decision to publish, or the preparation of the manuscript.

Author Contributions: All authors participated in the design of the study, development of the study proposal, development of the data collection tools, analysis, interpretation, and writing up the results. Finally, all authors read and approved the final manuscript.

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