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Review

A systematic review of vaccine preventable disease surveillance cost studies

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ABSTRACT

Background: Planning and monitoring vaccine introduction and effectiveness relies on strong vaccine-preventable disease (VPD) surveillance. In low and middle-income countries (LMICs) especially, cost is a commonly reported barrier to VPD surveillance system maintenance and performance; however, it is rarely calculated or assessed. This review describes and compares studies on the availability of cost information for VPD surveillance systems in LMICs to facilitate the design of future cost studies of VPD surveillance.
Methods: *PubMed, Web of Science, and EconLit* were used to identify peer-reviewed articles and *Google* was searched for relevant grey literature. Studies selected described characteristics and results of VPD surveillance systems cost studies performed in LMICs. Studies were categorized according to the type of VPD surveillance system, study aim, the annual cost of the system, and per capita costs.
Results: Eleven studies were identified that assessed the cost of VPD surveillance systems. The studies assessed systems from six low-income countries, two low-middle-income countries, and three middle-income countries. The majority of the studies (n = 7) were conducted in sub-Saharan Africa and fifteen distinct VPD surveillance systems were assessed across the studies. Most studies aimed to estimate incremental costs of additional surveillance components and presented VPD surveillance system costs as mean annual costs per resource category, health structure level, and by VPD surveillance activity. Staff time/personnel cost represents the largest cost driver, ranging from 21% to 61% of total VPD surveillance system costs across nine studies identifying a cost driver.
Conclusions: This review provides a starting point to guide LMICs to invest and advocate for more robust VPD surveillance systems. Critical gaps were identified including limited information on the cost of laboratory surveillance, challenges with costing shared resources, and missing data on capital costs. Appropriate guidance is needed to guide LMICs conducting studies on VPD surveillance system costs.

Contents

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1. Introduction

Cost is a commonly reported barrier to communicable disease surveillance system maintenance and thus, performance. However, it is rarely calculated or assessed, revealing a major gap in knowledge to improve disease surveillance systems, which are chronically underfunded, especially in low-income countries [1]. This knowledge gap is especially consequential for vaccine-preventable disease (VPD) control and elimination and eradication programmes where weak surveillance and monitoring data can lead to flawed planning and decision making for immunisation activities. When assigning limited resources, there is a need for low- and middle-income (LMICs) countries to understand the real costs associated with VPD surveillance.

While WHO recommends that member states *strengthen and sustain surveillance capacity by investing in disease detection and notification systems, routine analysis and data reporting systems* [2], for VPD surveillance systems there is a lack of impact and evaluation evidence to guide investment priorities. Countries face many competing health sector priorities, especially in LMICs where adequate and sustained levels of resources are the biggest constraint toward achievement of health outcomes. Therefore, information about programme costs are desperately needed to inform resource allocation [3,4]. Practical contextual cost-related guidance is required for decision makers to design or adapt VPD surveillance systems that can inform vaccine introduction decisions, monitor impact of immunization, and rapidly identify and respond to outbreaks.

To inform the World Health Organization on standards and best practices to guide future VPD surveillance system cost studies, we undertook a systematic review to assess and characterize existing cost studies of VPD surveillance systems in the literature. The review aimed to answer the following questions:

1. What are the characteristics and findings of cost studies on VPD surveillance systems performed in low and middle income countries?
2. In broader VPD evaluations that were not focused on costs, how were cost data collected and used?
3. What were the gaps in VPD surveillance cost studies?

2. Materials and methods

In this review, VPD surveillance is defined as the routine on-going collection, analysis and dissemination of health data which might include the following functions: detection and notification of health events, collection and consolidation of pertinent data, investigation and confirmation of VPDs, routine analysis and creation of reports, and feedback of information to persons providing data. [5].

2.1. Search strategy

A systematic literature search was conducted according to the Preferred Reporting Items or Systematic Reviews and Meta-Analyses (PRISMA) requirements [6]. *PubMed, Web of Science and EconLit* (EBSCO) databases were systematically searched to identify peer-reviewed articles in English or French published between 1 January 2000 and 30 June 2017. The search was preformed using appropriate text words and thesaurus terms for papers relating to the following topics: costs analysis, vaccine preventable disease, disease surveillance, and programme assessment. Main search terms including specific VPDs searched are listed in Box 1. Searches were also undertaken by hand searching references from identified papers, the authors' own collections, and review articles. *Google* was searched for relevant grey literature. Articles from high-income countries, as defined by the most recent World Bank classifications (2017), were excluded as well as articles pertaining to non-human surveillance systems were excluded. Search strategies for each database are included in Appendix 1.

Box 1 Literature review search terms.

Cost analysis, costing, cost, economic, finance, budget, resource allocation, funding, surveillance, surveillance system, vaccine preventable diseases, vaccine preventable disease surveillance system(s), Integrated Disease Surveillance and Response (IDSR) [6], immunization, immunisation, notifiable disease(s), low income, middle income, evaluation(s), intervention(s), diphtheria, Haemophilus influenzae, hepatitis B, measles, meningitis (meningococcus, meningococcal, Neisseria meningitidis, pneumococcus, pneumococcal, Streptococcus pneumoniae), mumps, pertussis, poliomyelitis, rotavirus, rubella, tetanus and neonatal tetanus, tuberculosis, yellow fever, Japanese encephalitis, typhoid, dengue, cholera, influenza, congenital rubella syndrome, diarrhoea, pneumonia, invasive bacterial VPDs (IB-VPD) [7], national surveillance systems, incidence based surveillance, communicable disease surveillance, and vaccine introduction.

2.2. Study selection and outcomes

Four reviewers worked in pairs to search databases, identify articles based on the search terms, and screen abstracts and articles using the exclusion criteria. Internet searches were performed on *Google* for any relevant unpublished studies. Disagreements were discussed within each pair, and if consensus could not be reached, a reviewer external to the pair was consulted. All duplicate studies were removed. A modified version of the Critical Appraisal Skills Program (CASP) Economic Evaluation Checklist [7] was used to assess the validity of studies, the method used, and the generalizability of results. Data were extracted and stored in an Excel sheet.

3. Results

The search terms identified a total of 1942 records. After screening of abstracts, full texts and removing duplicates, eleven articles were retained (Fig. 1).

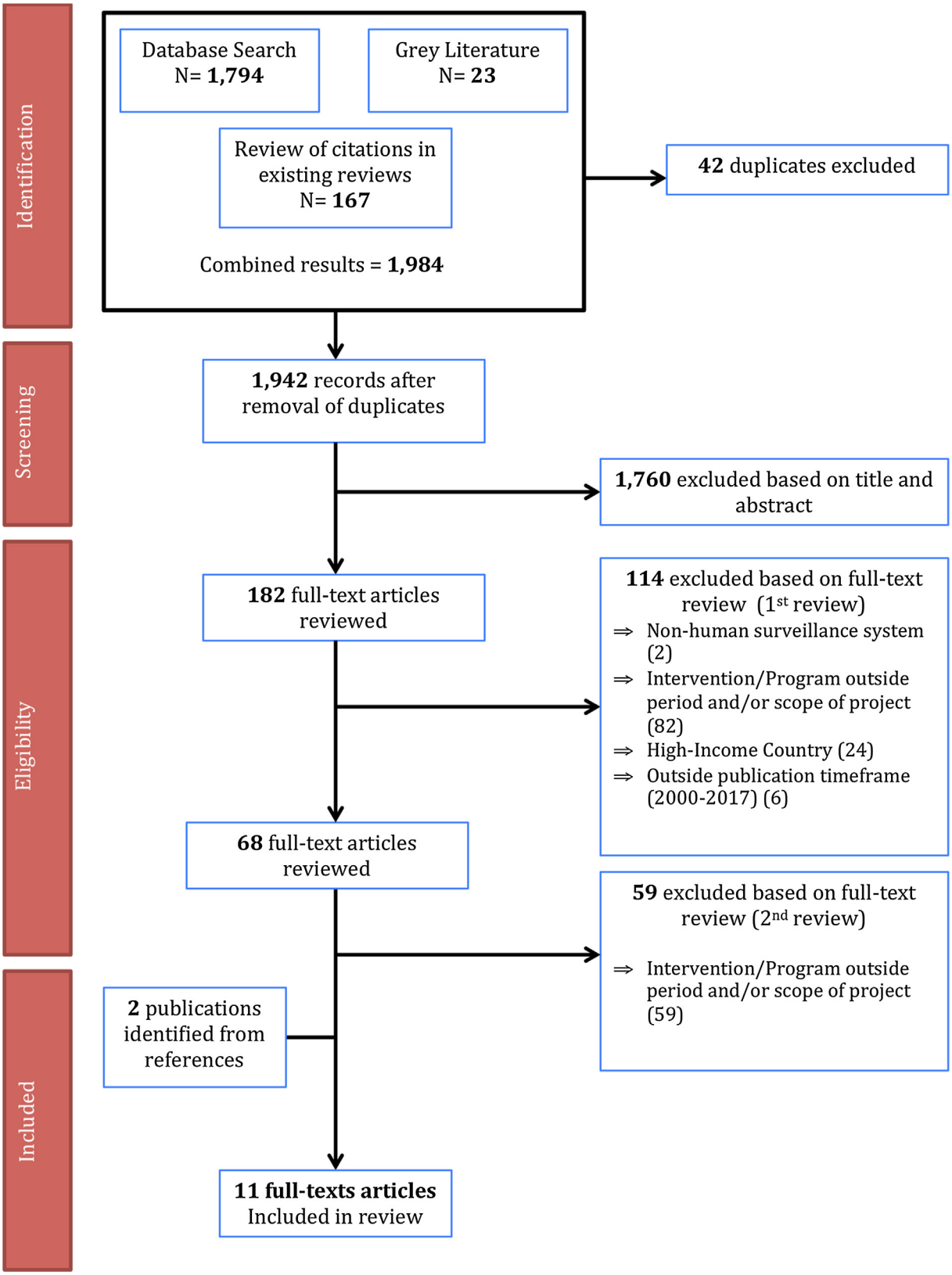

Fig. 1. PRISMA Flow chart for selection of included studies.

3.1. Overview of selected studies

A summary table of the included studies is presented in Table 1. Ten of the 11 studies were published in peer-reviewed journals and one, a Ph.D. thesis [8], was identified from grey literature. Six (55%) of the studies [9–14] addressed the first question on characteristics and findings of VPD surveillance system cost studies, one (9%) study exclusively answered the second question on collection and use of cost data in VPD surveillance evaluations [15], and four studies (36%) [8,16–18] addressed both questions.

Table 1
Overview of studies included in the review.

First author, Year (reference)	Title	Setting/income classifications	Sample Size	Vaccine preventable disease(s)	Study design*	Study aim**
Tebbens, 2006 [10]	The costs of Future Polio Risk Management Policies	All countries with polio eradication programs/Middle & low income	Includes data from 61 low income countries and 24 low –middle income countries	Poliomyelitis	PO, BU + TD	CS
Mueller, 2010 [16]	Costs of early detection systems for epidemic malaria in highland areas of Kenya and Uganda	Kenya (low-middle income) & Uganda (Low income)	20 sentinel health facilities in four pilot districts	Malaria	PO, BU	CS
Somda, 2009 [17]	Cost analysis of an integrated disease surveillance and response system: case of Burkina Faso, Eritrea, and Mali.	Eritrea, Burkina Faso, Mali/Low income	Eritrea: MoH, one provincial one district office Burkina Faso: four regions, 14 districts and 20 primary health care centres; Mali: three regions, three districts, three primary health care centres	Measles, N. meningitidis, S. pneumoniae, and Haemophilus influenzae type B (Hib), Tetanus, Poliomyelitis, Tuberculosis	RE, BU	SE, C
Baly, 2012 [9]	Costs of dengue prevention and incremental cost of dengue outbreak control in Guantanamo, Cuba	Cuba/Middle-income	Five health areas, polyclinics and a provincial pediatric hospital. 100 family doctors	Dengue	RE, BU + TD	CS
Lukwago, 2013 [15]	The implementation of Integrated Disease Surveillance and Response in Uganda: a review of progress and challenges between 2001 and 2007	Uganda/Low income	20 districts, 40 health sub-districts, 217 health units (both government and private, at different levels)	Poliomyelitis, Cholera, N. meningitidis, S. pneumoniae, and Hib, Measles, Neonatal tetanus, Typhoid	RE, TD	SE, C
Castañeda-Orjuela, 2013 [14]	Using standardized tools to improve immunization costing data for program planning: The cost of the Colombian Expanded Program on Immunization	Columbia/Middle income	One central administrative unit; six municipalities; three departments; 112 health facilities	Rotavirus, Hepatitis B, Measles, S. pneumoniae, Hib, Mumps, Pertussis, Poliomyelitis, Rubella, Tetanus, Diptheria, Tuberculosis, Yellow Fever	RE, BU	CS
Toscano, 2013 [11]	Cost analysis of an integrated vaccine-preventable disease surveillance system in Costa Rica	Costa Rica/Middle income	Five participating institutions (incl. laboratories)	Measles, Influenza, Rotavirus N. meningitidis, S. pneumoniae, and Hib, Poliomyelitis	RE, BU	CS
Le Gargasson, 2015 [18]	Costs of routine immunization and the introduction of new and underutilized vaccines in Ghana	Ghana/low-middle income	Six districts, 50 primary healthcare facilities	Tuberculosis, Diphtheria, Tetanus, Pertussis, Hepatitis B, Hib, Poliomyelitis, Measles, Yellow fever, S. pneumoniae, Rotavirus	RE, BU	CS, VI
Erondu, 2016 [8]	Evaluating communicable disease surveillance in resource-poor settings: A new approach applied to meningitis surveillance in Chad	Chad/Low income	Four regions, seven districts, 21 district hospitals, six district laboratories, one regional hospital laboratory, one national laboratory of reference, 13 surveillance offices from the MoH, four partner organizations	N. meningitidis, S. pneumoniae, and Hib	RE, BU	SE, C
[6] Irurzun-Lopez, 2016 [12]	The actual and potential costs of meningitis surveillance in the African meningitis belt: Results from Chad and Niger	Chad & Niger/Low income	Niger: Seven regions, 10 districts, 33 clinics, eight district hospitals, two regional hospitals, two national hospitals, eight district laboratories, two regional hospital laboratories, two national hospital laboratories, one national laboratory of reference, 22 surveillance offices from the MoH, two partner organizations Chad: Four regions, seven districts, 21 district hospitals, six district laboratories, one regional hospital laboratory, one national laboratory of reference, 13 surveillance offices from the MoH, four partner organizations	N. meningitidis, S. pneumoniae, and Hib	RE, BU	SE, C
Kaburi, 2017 [13]	Evaluation of the enhanced meningitis surveillance system, Yendi municipality, northern Ghana, 2010–2015	Ghana/low-middle income	Four sub-municipal health centres, one municipal hospital, and one municipal health directorate; 15 sub-municipal officers responsible for meningitis surveillance	N. meningitidis, S. pneumoniae, and Hib	RE, BU	SE, C

* Study design: BU = Bottom up costing approach; PO = Prospective; RE = Retrospective; TD = Top down costing approach.
** Study aim: CS = Cost Study; SE = Surveillance Evaluation with Cost section; VI = Vaccine Introduction.

Two studies included surveillance as a cost component, but did not provide specific surveillance estimates; in both cases both cases the authors estimated the cost of the Expanded Programme on Immunization (EPI) [14,18]. All studies provided information for the third question on gaps in VPD surveillance cost studies.

Seven (64%) studies were conducted in sub-Saharan Africa, one in South America, two in North America, and one study assessed data from countries across multiple continents. Six studies represented low-income countries (LICs), three represented middle-income countries (MICs), and two included settings in lower-middle income classifications. One study included information from low, low-middle, and middle-income countries [8]. Overall, surveillance for 19 VPDs was captured by the review. A summary table of the included studies is presented in Table 1.

3.1.1. Characteristics of VPD surveillance cost studies

3.1.1.1. Stated study objectives (in papers reviewed). Seven of the identified studies evaluated the incremental costs of additional surveillance components [5,6,9,11–13]. Researchers collected costs during opportunities to assess newly adopted surveillance strategies [11,15,17] a new outbreak control program [9], or an electronic data-collection system [16]. Two studies evaluated surveillance systems in the context of evaluating the cost of core immunization programme functions [16,18]. Although ten studies aimed to provide a cost per capita or cost-outcome description of the surveillance system, only one study assessed cost-effectiveness of a surveillance system [16].

3.1.1.2. Cost perspective. A cost perspective is a decision of which entities' incurred costs will guide the identification of resource inputs that will be included in the study. The most comprehensive societal perspective, which includes costs incurred by all parties, was used in three studies [9,14,19]. A healthcare payer perspective study, often associated with the government and partners, was used in a Costa Rican study and considered costs incurred by the National Reference Laboratory, the Pan American Health Organization Costa Rica office, US Centres for Disease Control and Prevention (CDC), and a sentinel hospital [11]. A Colombian study [14] applied a combined health service and government perspective to estimate costs associated with treatment, surveillance and an outbreak investigation in one hospital and health department.

3.1.1.3. Time horizon. The cost study analytic horizon, or the period of time for which the costs are measured in the analysis, was generally set to capture two reference points. For example, studies evaluating new systems tended to define such reference points as "preparatory phase" and "implementation/routine operation phase." IDSR system costs varied over the preparatory phase (coinciding with start-up costs) compared with the implementation phase (coinciding with the costs of routine operations). For example, Toscana et al. defined preparatory phase costs as "one-time" costs incurred while implementation phase costs were defined as "annual costs required for ongoing" surveillance activities [11]. Time horizon varied widely (ranging from one to 20 years) across studies and was defined according to the study objectives.

3.1.1.4. Number of surveillance systems assessed. The number of surveillance systems described by the 11 cost studies ranged from one to three; six studies evaluated one system [7–9,12,14,15]; three studies evaluated two systems [5,10,13], Somda et al. evaluated three systems [6], and one study did not specify the number of systems evaluated over the 20-year period [11].

3.1.1.5. Resource valuation. Resource valuation is usually based on the desire to evaluate the full cost of a health program (i.e., the economic cost). To accomplish this, researchers often make the distinction between economic and financial costs. Economic costs are the financial costs (i.e., expenses incurred) plus the opportunity cost of resources used. For example, Erondu N estimated both economic and financial costs for the Chad meningitis surveillance system where economic costs included a valuation of all inputs needed for the surveillance as well as donated items and volunteer time. In this study, financial costs only included financial expenses for surveillance activities [8]. Additionally, Five studies estimated opportunity costs [9,10,12,16,18]. Opportunity costs are the cost of an alternative that must be forgone in order to pursue a certain action such as staff time and the valuation of other owned or donated resources (e.g. vehicles, buildings, volunteer time, etc.) used to accomplish surveillance functions that could otherwise have been devoted to other activities [20].

3.1.1.6. Classification of costs. Capital (i.e., one-time investments) and recurrent (i.e., ongoing or operational) costs must both be collected in VPD surveillance system cost assessments. Capital costs reported in the literature sample commonly included vehicles (e.g., needed for surveillance supervision), laboratory equipment, computers and other office equipment. All the studies, with one exception included both capital and recurrent costs. Costs associated with building infrastructure were often omitted due to lack of information on market value and replacement cost [8,9,13,15,16]. Recurrent costs typically included personnel, supplies and materials and could be extensive. In some cases, recurrent costs were differentiated between setup/start-up costs and running costs [15,17,18] Yet, among these only Le Gargasson et al. compared proportion of total cost between start-up (i.e. 14.8%) and ongoing phases (i.e. 85.2%) [18]. Five studies also classified costs by surveillance activity (e.g. training) or function (e.g. detect, report) [8,12,15–17].

3.1.1.7. Shared resources. The challenge of attributing costs of a specific disease surveillance program with shared resources is particularly common in surveillance systems since resources and activities can often be shared across disease programs. Such costs include utilities, maintenance, administration, personnel, transport, and buildings. In practice, cost studies dealt with this by asking surveillance and/or clinical staff the proportional time allocated to related disease surveillance activities [8,9,12,14,16]. In some cases, this method was coupled with observation sessions or existing estimates retrieved from the literature [8,17]. However, in several studies, a systematic method for identifying shared costs was not articulated [10,13,15].

3.1.1.8. Estimating resource use/costing approach. Bottom-up costing (also called the ingredients approach or micro-costing) is an exercise that seeks to measure costs as accurately as possible. Top down costing usually reflects budgets or planned allocations rather than actual expenditures. Five studies exclusively used bottom-up costing approach, two studies applied top-down costing exclusively, and four studies applied a combination of both approaches (Table 4). Mueller and colleagues assessed costs by means of the ingredients approach and then categorized these into recurrent and capital costs to determine the incremental costs needed to set up and run an early detection system (EDS) on top of a functioning health care system [16]. They reviewed expenditures for purchases and financial transactions and interviewed staff to estimate time spent on EDS-specific tasks and captured costs at every level of the health system. In other studies, costs were analysed using a top-down approach without the inclusion of unit prices. Lukwago et al. collected aggregate data at the national level due to national operated vertical programs (i.e., lack of decentralization). Consequently, the analysis produced mean annual costs associated with key resources involved in IDSR implementation

[15]. A different method was used by Somda et al. [17], who collected aggregate pharmacy, clinical, and medical data using a structured questionnaire based on the SurvCost tool—a tool designed to measure costs of IDSR systems [21].

3.1.1.9. Annual depreciation. Depreciation cost is a component of capital costs that measures the decrease in value of an asset over a certain period of time. The studies reflected that annual depreciation rates may vary from 3% [17] to 5% [16] to 6% [9]. The horizon for depreciation can be described broadly, such as "normal length of life," or more specifically, such as "over a 10-year useful life time horizon for normal capital costs" [15]. Throughout the studies useful-life horizon was used to assess annual depreciation of buildings, laboratory equipment, office equipment, and vehicles [11,17].

3.1.1.10. Differences in currencies. All studies collected cost data in local currency and subsequently adjusted to US dollar equivalents using US dollars to the local currency exchange rate. This conversion reflects the market price in the year corresponding with the time frame for data collection. Only Somda et al. and Tebbens et al. used purchasing power parity (PPP) to convert national currencies into international dollars [10,17]. PPP is used to correct currency conversion problems due to fixed conversion rates that may not reflect actual relative costs [17].

3.1.1.11. Sensitivity analysis and validation. In all cost analyses, there is a degree of uncertainty regarding the inputs and consequences; a sensitivity analysis is a critical appraisal method that assists in judging the robustness of conclusions. While probabilistic sensitivity analysis (i.e., varying multiple inputs and model structure) is encouraged as a gold standard for evaluating the robustness of the conclusions, only three studies included it in their analysis [8,10,16]. Cost studies in general often employ deterministic sensitivity analysis (i.e., univariate and scenario analysis) varying one input at a time to evaluate uncertainty. For instance, Mueller and colleagues performed a sensitivity analysis to estimate potential variation in the costs of the additional components, such as external technical assistance and increases in salaries. This study also included variations in the exchange rate and discount rate (i.e., estimated figures with applied discount rate options of 5% to 3% to 7%) [16].

Further information on the sampled study cost features are presented in a Table 4.

3.1.2. Analysis of findings of VPD surveillance costing studies

The findings of the included studies are summarized in the Tables 2 and 4. Across the studies, the analyses of costs varied based on study perspective, resources collected, and use of population estimates. VPD cost studies often present mean annual cost per resource categories and health structure level as well as disaggregated IDSR activities (e.g., detection, report, and analysis), which included detailed costs by year [17]. Generally, estimates per population figure, presented as cost per capita were derived from national data or through a population census undertaken for the study. When presented this way, the five studies that reported per capita found a range of 0.03 per capita [17] to 0.16 per capita [17] for VPD surveillance-related activities [costs converted to 2016 US dollars [22]]. Costs per population were heterogeneously displayed using different population denominators and time intervals, for example the cost of dengue surveillance (non-transmission period) was 3.30 per inhabitant per month in Cuba [9] and 1.03 per capita for the population of under five year olds covered by integrated VPD in Costa Rica [14] [costs converted to 2016 US dollars [22]]. Several studies provided costs per disease case [8,10,12,13], while other studies presented variations in aggregate costs by health system level [8,10,12,14,15,17,18]. Three studies estimated costs by surveillance activities and functions [8,12,15], which aligns to the CDC/WHO conceptual model of surveillance [23].

3.2. Main cost drivers

Study results generally estimated the distribution of costs by program resource. Overwhelmingly, staff time/personnel cost represented the largest cost driver [9,11,16], which ranged from 21% to 61% of total surveillance system costs across studies. Studies often measured personnel cost as a combination of financial (e.g., expenses on per diems) and economic cost (e.g., value of staff time spent on surveillance activities). The value of personnel or staff time, as a major driver of surveillance costs, could be easily underestimated when studies only relied on financial costs. Transportation of data or lab specimen was also a large cost component. In Uganda, researchers realized that 7% of staff time was spent transporting data (e.g., delivering paper forms to the next health system level office) and so they completed a separate analysis to differentiate the opportunity costs of staff time. They found that transportation of data could be reduced by half with the introduction of electronic data transfer systems [16]. When costs were disaggregated by health level, cost drivers often differed. Studies that looked at costs by surveillance function found laboratory investigation as a major cost driver. Irurzun et al. found that laboratory investigation accounted for 40% and 51% of total surveillance system costs in Chad and Niger, respectively [12]. A detailed description of cost drivers by study can be found in Table 4.

3.3. Missing data

Missing data, primarily due to non-existent or inaccessible data, is often an issue when conducting studies in lower-income countries. Although, most studies attempted to cost resources at all relevant health levels, many times there were difficulties accessing data sources. Some studies address the issue of missing information by excluding missing data [8,13,14] or using extrapolated relevant cost data from other countries and studies [10,17].

A notable missing data component was a comprehensive estimate of laboratory surveillance costs. Eight studies included some costs of diagnostic tests or laboratory reagents and materials; of those five included costs of laboratory equipment used, in part for, disease surveillance (Table 3). Building costs and the cost of overhead were other costs that were often omitted due to inaccessible or missing data.

3.4. Laboratory costs

Laboratory costs were mentioned in eight (73%) of the studies but were collected in only 5 (45%) of the studies (Table 3). In general, when laboratory costs were reported the information was often limited and did not provide resource valuation for staff time nor include detailed cost estimates for equipment, materials, and consumables for laboratory testing. Excluding the comprehensive laboratory cost for surveillance demonstrates why laboratory costs analysis leads to an underestimation of the burden of resources used for surveillance activities [24]. In the most comprehensive example of reporting laboratory-related costs, Toscana et al. found that this category of costs represents almost a third of total costs in the integrated VPD system. The same study found that the reference laboratory was the largest cost share entity [11].

Table 2
Overview of cost study result.

Study	Type of Surveillance system	Perspective	Currency year	Per capita costs (US$)	Cost per investigated case	Total annual cost of system (US$)	Limitations
Surveillance costing studies							
Baly et al.	Single- Dengue	Societal	2006	N/A	$2.76 (NT)[##]; $6.05 (DT) per inhabitant per month	$673,959 (NT) $1,477,617 (DT)	Did not consider the costs incurred by the MoH and other sectors at supra-provincial level. Did not include buildings due to lack of information on replacement cost. Did not consider the cost-effectiveness of the system
Erondu, N	Single - Meningitis	All-payer/Public health care system	2012	$0.03 per capita	N/A	$393,000	Purposive sampling, poor existing data and lack of data. Did not consider the cost-effectiveness of the system
Irurzun-Lopez, M. et al.	Single - Meningitis	All-payer/Public health care system	2012	Niger: $0.12 Chad: $0.03	N/A	Niger: $1,951,562 Chad: $338,056	Purposive sampling. Omission of district hospitals and overhead costs in Chad. Did not consider the cost-effectiveness of the system
Kaburi. et al	Single - Meningitis	Government	2015	N/A	US$ 52.96 per suspected case investigated	N/A	Included Yendi municipality only; Not a surveillance costing study but an evaluation with a costing component; Excluded 'cost of information' & 'routine [staff] travel', Did not consider the cost-effectiveness of the system
Lukwago, L et al.	Integrated disease surveillance and response	All payer	Not specified	$0.02	N/A	$538,428 (average annual cost)	Did not consider the cost-effectiveness of the system
Mueller, Dirk H et al.	Single – Malaria	Provider/Public health care system	2006	$0.03 – 0.05	N/A	Kenya: $15,512/ district Uganda: $14,439/ district	Did not include the costs of external technical assistance; Did not include financial motivational incentives even though the staff said remuneration (extra) was important;
Somda, ZC et al.	Integrated disease surveillance and response	Government funded health care system perspective/All payer	2002	Eritrea: $0.16 Burkina Faso: $0.04 Mali: $0.02	N/A	Eritrea: $476,208 Burkina Faso: $690,957 Mali: $270,360	Potential inaccuracies when apportioning total cumulative surveillance activities cost. Did not consider the cost-effectiveness of the system
Tebbens, RD et al.	Single – Polio	Societal	2002	N/A	AFP cost per case per child <15 of age Best estimate: Low Income countries 0.067 Range: 0.03–0.10 Best estimate: Lower-Middle-Income countries 0.087 Range: 0.03–0.12	AFP surveillance global total cost $145 Million[#]	Only assumed case-based surveillance in polio control cost analysis.
Toscano, C. M. et al.	Integrated- vaccine preventable diseases	Health system/All payer	2010	$0.918 for population covered by iVPD[**]	N/A	US $422,149	Did not estimate baseline costs of existing VPD surveillance before implementation of iVPD surveillance; Study assessed a pilot study in a sentinel hospital. Did not consider the cost-effectiveness of the system.
Costing studies with surveillance-related components							
Castañeda-Orjuela, C. et al	Integrated – Expanded Programme on Immunization	Public health care system	2009	$2.40 (includes price of vaccine)	N/A	$107.8 Million	Estimated costs for all EPI. Surveillance was a line item but no costs were captured. Missing building costs could have underestimated the total cost Did not consider the cost-effectiveness of the system
Le Gargasson et al.	Integrated- Expanded Programme on Immunization	Government	2011	$2.1[*]	N/A	$53.5 Million	Not a surveillance costing study but an EPI costing study. Did not consider the cost-effectiveness of the system

[*] Cost of entire routine immunization program, which includes surveillance costs as well as other components.
[**] <5 years old was the target population for Meningitis, Severe acute diarrhea, severe acute respiratory illness defined; <15 years old target population for acute flaccid paralysis; All ages + ≥ for rash and fever illnesses and severe acute resp. illness requiring chest radiograph, blood culture, respectively.
[#] "Author estimated 2.9 billion US$(2002) if every country continues AFP surveillance at the pre-eradication intensity. AFP surveillance amounts to a global total cost of $145 million or $2.9 billion divided by 20 years.
[##] NT- non-transmission period; DT- during transmission period.

Table 3
Surveillance-related cost components included by study.

	Personnel	Volunteer-time	Rent*	Utilities*	Meetings	Office supplies	Lab supplies**	Lab equipment	Refrigerators/ freezers	Transport-ation***	Vehicles	Vehicle maintenance	Training	IEC	Security	Building	Computers + office equipment
Baly	x	x					x							x			
Castaneda-Orjuela	x								x	x	x		x			x	
Erondu N	x	x			x	x	x	x	x	x	x		x				x
Irurzun-Lopez	x	x	x	x				x	x		x			x		x	x
Kaburi	x				x		x						x				
Le Gagasson	x	x	x	x		x			x	x	x	x		x		x	
Lukwago	x				x		x			x	x	x	x				x
Mueller	x		x	x			x			x	x	x	x				x
Somda	x		x	x		x	x	x	x	x	x	x	x	x		x	x
Tebbens	x		x	x			x	x	x	x	x	x	x	x		x	x
Toscano	x			x	x	x	x	x		x	x	x			x	x	

Mtgs = Meetings.
Lab = Laboratory.
IEC = Information education campaigns.
* Overhead.
** -'Lab supplies' includes laboratory reagents, and diagnostic tests.
*** ' Transportation' includes per diem and fuel.

Table 4
Detailed cost features across review articles.

First author	Time Horizon	Cost classification	Shared resources capture method	Annual depreciation	Sensitivity analysis and validation	Cost drivers
Baly	Non-epidemic period vs. outbreak period	Recurrent and capital	Estimated actor (volunteer, health professional) time per dengue control activity. Also collected information on inter-sectoral information (but not in detail).	6% normal length of life and market replacement cost	Not performed	Salaries or non-paid volunteer time (opportunity cost valued at 0.82 USD).
Castañeda-Orjuela	One year (2009)	Recurrent and capital	A costing survey was carried out at four levels (national, departmental, municipality, and health facility) to identify which cost items are partially shared with other public health programmes.	Not reported	Not performed	Personnel (21%); Cold-chain (18%); Vehicles (2%)
Erondu N	Two years	Recurrent and capital Surveillance functions	Allocation of shared costs to meningitis surveillance was made by recording what resource quantity was used for all disease surveillance activities, and then what proportion of those activities were used for meningitis surveillance, based on actual use of resources and estimates of staff workload for each category of resources. If the latter was difficult to estimate by respondents, a tracing ratio based on the number of core diseases that are part of the surveillance system was used.	Used surveillance costs recommendation: A 5% discount rate was applied for annualizing capital costs to reflect the opportunity costs of investing in capital equipment.	10,000 monte carlo simulations around variables of interests	Functions: Laboratory investigation: 40% Data reporting: 14%; Case detection – 23%; Personnel resources comprised the biggest expense type: 37%

Table 4 (*continued*)

First author	Time Horizon	Cost classification	Shared resources capture method	Annual depreciation	Sensitivity analysis and validation	Cost drivers
Irurzun-Lopez	Two years	Recurrent and capital Surveillance functions	Shared cost was collected using cost survey and proportion of time, resource quantity used for surveillance activities. Shared costs were estimated across administrative levels.	Used surveillance cost for annualization of capital costs. A 5% discount rate was applied for annualizing capital costs to reflect the opportunity costs of investing in capital equipment.	Not performed	Functions: Laboratory investigation (Chad, 40%) (Niger, 51%); Data reporting – Niger 20% Chad 14%; Case detection – Niger 19%, Chad 23%; Personnel resources comprised the biggest expense type: 37% of total costs in Niger and 26% in Chad.
Kaburi	Six years	Recurrent only	Did not attempt to disentangle nonspecific meningitis surveillance resources from other dx-specific surveillance costs; meningitis Surveillance had no separate budget allowance	Not included	Not performed	Does not provide
Le Gagasson	Five months	Recurrent and capital	Inputs were allocated to specific activities	Annualized and discounted at 3%	Not performed	Salary but also surveillance as part of vaccine intro costs; Salaried labour (61%); Vaccine and supplies (19%)
Lukwago	Three years (1996–1999)	Recurrent and capital Surveillance functions	This was a multiple diseases system cost analysis. Did not allocate time to specific diseases.	Capital costs were depreciated at 5% annually over a 10-year useful-life time horizon.	Not performed	National level: Investigation and response (27%) Regional level: Vehicle and maintenance (29%) District level: Personnel and support (60%)
Mueller	Four years (2002–2006)	Recurrent and capital Setup costs and running costs Surveillance activities	Researchers estimated staff time spent on malaria	All capital expenditures were annualized across their useful lifetime at a discount rate of 5%.	Modeled variations such as the inclusion of external technical assistance, a 10% increase in salary of health staff, changes in the discount rate from 5% to 3% and 7%	**Uganda-** the largest proportion of salaries was used to support staff at the peripheral (health centre) level (Salary cost = 41%) **Kenya** - the largest proportion of salaries was related to national level supervision. (Salary cost = 56%) Secondary driver: Equipment (i.e. vehicles & computers) 27% In Uganda & 26% in Kenya
Somda	Burkina Faso and Eritrea: 2002–2005 Mali: 2000–2005.	Recurrent and capital Surveillance activities	Self-reported staff time and review of log books on health related surveillance activities. Researchers apportioned time	Used the general consumer price index from each country and a discount rate of 3% to adjust all costs into 2002 US dollars equivalent.	Not performed	Outbreak investigation and treatment of confirmed cases also constituted a substantial component (23% to 67%) of the total IDSR cost.
Tebbens	20 years	Recurrent and capital	Did not discuss/include shared resource methodology	3% discount rate	Explored this uncertainty by varying the threshold to trigger potentially effective exportations, which demonstrate substantial impact on the ability to control outbreaks after OPV cessation.	Does not provide
Toscano	Three years (2007–2010). *Preparatory phase 2007–2009: implementation phase: September 2009 – August 2010.*	Recurrent and capital	Estimated current market values for building and spaces. and computed the estimated attributable iVPD surveillance fraction for capital costs by dividing the number of full-time-equivalent (FTE) surveillance staff by the total staff in the building or as a percentage of the building area occupied by surveillance FTE staff.	Annual 5% depreciation rate to buildings, vehicles, and office and laboratory equipment over 50-year, 10-year, and 5-year useful-life time horizons, respectively.	Not performed	Personnel (58%), Laboratory (28%)

4. Discussion

This was the first systematic review of costing studies for VPD surveillance systems in LMICs. While this review highlighted that there is a dearth of literature in this area, the studies included reflected individual costing studies as well as opportunistic cost studies that were conducted during new vaccine introductions, as part of disease surveillance system evaluations, during testing of new devices or software for electronic surveillance, and during EPI programme evaluations. Overall, these costing studies followed systematic economic principles and combined provide a menu of options of methods, parameters, and potential challenges to consider when conducting this exercise in LMICs. Although, the studies provide an important starting point to building an evidence base of reference costs estimates for planning and implementing surveillance in LMICs, due to variable purposes for costing, small sample sizes, and disease specific considerations within estimates (i.e., case management of suspected case), it is difficult to provide one estimate of the cost of surveillance in low income countries.

Another challenge in comparing study findings is the difference in categorising costs; for example, a 'unit-cost' result is not comparable to a 'capital versus recurrent' cost analysis. Furthermore, it is difficult to understand cost savings due to the absence of cost benefit objectives among these studies; only one study, Tebbens et al., provided cost and health outcome scenarios based on policy variations to polio vaccine cessation. However, the findings from the included studies could provide the cost data to conduct such cost-benefit studies in the future. In light of these challenges, this review still provides several themes for consideration for future VPD surveillance cost studies.

4.1. Improving accuracy of VPD surveillance cost studies

Costing studies strive to provide a close estimate that can impact local planning, thus all studies collected unit prices and other costs in local currency and then converted the estimates into US or international dollars. Additionally, the more laborious but more accurate bottom-up/micro-costing approach proved to provide the most granular estimates and studies that stratified costs to sub-national levels were able to perform more realistic and appropriate extrapolations. Also, most of the information available focuses on the incremental cost of new systems—almost no information is available on the cost of the base VPD surveillance system in LMICs. Throughout the reviewed studies, the sampling strategy used was often a limitation to generalizability. Future studies should resist purposive sampling when the objective is to guide country or regional surveillance activities [20]. Researchers and surveillance practitioners must encourage representative sampling of multiple sites and multiple health system levels.

4.2. Addressing major gaps in existing VPD surveillance cost studies

Several gaps emerged across studies and are detailed in Table 5. A major theme throughout was uncertainty in estimating disease specific costs within with shared systems or extracting costs from general budgets. As integrated systems become more widespread, researchers, donors, and practitioners must determine the usefulness in separating costs by disease area. This is often difficult to do, as the value of shared resources is not as easily parsed among areas. Another challenge was the difficulty in capturing data such as laboratory and overhead costs. Diagnostics are crucial to surveillance confirmation and response and should be included. The lack of studies in this area reflects the difficulty and resource-intensiveness of this exercise. This could be curtailed by ensuring that one or a few lead institutions, (e.g., the World Bank or WHO) compile and update common resource price estimates that are used in most VPD surveillance systems. Additionally, a review of the appropriate use, benefits, and limitations of existing pre-programmed costing tools (e.g., cMYP [25], ProVac [26], SurvCost [21], etc.) should be completed and made available to guide future VPD surveillance cost studies.

The studies reviewed here mainly demonstrate the cost of the underlying health system infrastructure, which in most low-income settings may not be adequate to meet disease eradication/elimination standards. The importance of addressing the existing gaps in the current literature cannot be underestimated considering the need to advocate for resources to maintain momentum on current eradication and elimination initiatives (i.e., the Measles and Rubella Initiative and the Global Polio Eradication Initiative). The evidence in this review demonstrates significant gaps to inform evidence-based decision-making on quantifying the cost of surveillance to meet quality standards for disease eradication/elimination. To fill this gap, researchers should consider comprehensive cost estimates of reaching specific eradication/elimination standards [27].

Lastly, the existing information from studies reviewed seemed to have been generated without a specific target audience; therefore, it is difficult to draw conclusions for advocacy related to eradication and elimination initiatives.

5. Limitations of this review

This review only included low- and middle- income countries and thus the findings may not be generalizable to higher income countries. Surveillance functions, however, are generic and while the adaptation of activities may be different, resources like adequate staff and well-equipped laboratories are integral to VPD surveillance in any setting. We limited this review to studies dating from ten years before the Decade of Vaccines (2010–2020), to the date of the literature searches in 2017. While we could have

Table 5
Gaps Identified from Systematic Review of Vaccine Preventable Disease Cost Studies.

Gap Area	Findings from review
Cost studies in low income countries	• There is a general dearth of individual country studies on the cost of VPD surveillance • Cost evaluation of existing surveillance systems are lacking, yet necessary–especially to justify major VPD initiatives • We do not know the cost of a functioning surveillance system in the LICs
Laboratory costs	• Laboratory costs were not often included in VPD cost studies; when included, inputs were not captured in detail.
Costs to inform global disease aims	• The cost of elimination-standard surveillance is missing from the literature
Targeting of studies to audience	• There is a need to consider the audience for which the evidence is being generated and the information needs for mobilizing resources for global VPD control, elimination, and eradication goals.
Costing shared resources/ activities	• There are challenges attributing shared costs for surveillance • There is a potential measurement error; included studies measure the cost of surveillance by health system level when most systems are built on existing structures (i.e studies mainly observe the cost of underlying health system structure)
Vaccine introduction	• There is a missed opportunity to use introduction of new vaccines as an opportunity to evaluate the cost of surveillance systems

missed some earlier relevant costing studies, we chose to examine the decade of vaccines because it represents a pivotal timeframe for global immunization during which significant financial investments in immunizations were mobilized with the vision of a world free of VPDs. However, we found very few studies focusing on evaluating the cost of VPD surveillance during this timeframe. Furthermore, we found few studies to permit generalizable interpretations of the two main objectives of the review and the lack of a consistent framework across studies limits the extent to which these studies can be synthesized or summarized. Moving forward, it would be most beneficial for a framework or consensus document to guide future costing studies for VPD surveillance. Surveillance experts from LMICs and health economists working in these settings should inform this effort.

6. Conclusions

Costing studies for VPD surveillance systems are necessary and can provide important information upon which other studies, such as economic evaluations or cost-of-illness analyses, can build [24]. Though surveillance studies with cost-components are sparse, this review summarized how standard health economic principles have been applied to gain cost information about VPD surveillance and provides a starting point to guide low-and middle-income countries in investing in and advocating for more robust VPD surveillance systems.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary material

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