Vaccine 37 (2019) 2942–2951

Contents lists available at ScienceDirect

Vaccine

journal homepage: www.elsevier.com/locate/vaccine

Are community health workers cost-effective for childhood vaccination in India?

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A R T I C L E I N F O

Article history:
Received 20 November 2018
Received in revised form 12 April 2019
Accepted 12 April 2019
Available online 19 April 2019

Keywords:
Accredited social health activists
ASHA
India
Measles
Vaccine
Cost effectiveness
Community health workers
Sustainable development goals

A B S T R A C T

Introduction: Accredited Social Health Activists (ASHAs) are female community health workers whose primary role is to promote utilization of primary healthcare services and improve sanitation in rural areas and are financially incentivized for services provided. Prior studies evaluating ASHAs have been largely qualitative, and assess their knowledge, skills, and practice. Globally, there have been very few studies that have quantitatively assessed community health workers. We analyzed the cost effectiveness of ASHAs in facilitating measles vaccination among children under 5 years during 2012–2013.
Methods: We utilized Markov modeling simulating a cohort of children in villages with and without ASHAs. We extrapolated the health states to a lifetime of 68 years to estimate the effects of ASHA intervention. Measles vaccination rates were obtained from 2013 District Level Household and Facilities Survey 4. Other parameter estimates were obtained from a review of relevant literature.
Results: ASHA intervention was highly cost effective at $162 per DALY averted compared to no ASHA and remained cost effective with the ASHA incentive increased from $2 to $15, across the range of probabilities and cost parameters. Analyses were sensitive to probability of death due to childhood pneumonia, susceptibility to measles after one dose measles vaccine, and probability of pneumonia after measles infection.
Conclusion: ASHAs were cost-effective under a wide range of scenarios even when a single health outcome such as measles vaccination was considered. The Government of India and individual state governments of India should consider increasing the incentives provided to ASHAs.

1. Introduction

Community health workers (CHWs) comprise a diverse category of healthcare workers who commonly operate in communities outside of healthcare facilities. These workers typically receive some degree of formal training related to their roles and responsibilities, but do not possess professional or paraprofessional training, and are not required to hold a tertiary education degree [1,2]. The role of CHWs oftentimes differ based on the degree of economic development in a given country and vary across high- to low-income, countries [2]. In the latter, CHWs largely focus on maternal and child health outcomes, such as promotion of antenatal care, institutional delivery, postnatal care, childhood nutrition, and childhood immunization in addition to family planning advice and services, and the control of infectious diseases such as HIV, tuberculosis, and malaria [1]. In 2014, there were an estimated 5 million CHWs globally with the largest number, 2.3 million, working in India [2]. Most of the CHWs in India focus on improving rural health given that approximately seventy percent of the population lives rurally where the availability of healthcare workers and facilities is more scarce and the need for health-related services greater.

India is the second most populous country in the world with 1.2 billion residents yet invests only 4.7% GDP in healthcare [3], representing one of the lowest rates in the world. A portion of that investment goes to supporting community health workers in India who mainly comprise three different but overlapping groups: auxiliary nurse midwives (ANMs), Anganwadi workers (AWWs), and accredited social health activists (ASHAs) [4]. ANMs are a category of health care workers whose functions include provision of maternal health care such as antenatal care and institutional delivery, childhood immunization, and family planning services such as distributing contraceptive pills [5]. AWWs are CHWs under the

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https://doi.org/10.1016/j.vaccine.2019.04.038
0264-410X/

Integrated Child Development Scheme in India. Their functions include promotion of health and nutrition of children below 6 years and of pregnant and lactating women aged between 15 and 44 years, and promotion of immunization among children aged less than 6 years in conjunction with the ANMs and ASHAs [6]. ASHAs were introduced throughout India by the Ministry of Health and Family Welfare's (MOH) National Rural Health Mission (NRHM) in 2005 [7].

The role of ASHAs is multi-faceted [8]. ASHAs directly connect mothers and children to health services by accompanying pregnant women for delivery, taking infants and children in for immunization, and referring children with life-threatening conditions such as severe diarrhea and pneumonia for hospitalization. As healthcare providers, they deliver basic antenatal and postnatal advice, counsel mothers on child nutrition, supply family planning advice and oral contraceptive pills, and act as a source for basic medications for infectious diseases. As health activists, they are expected to promote equity in access to healthcare and improve utilization of healthcare services in the rural communities they serve. In most Indian states, ASHAs do not have a regular monthly salary but are instead financially incentivized to perform functions related to their diverse roles. For example, ASHAs receive an incentive of $2.14 (INR 150)* per immunization session for mobilizing village children to receive recommended vaccine doses [9]. However, the repertoire of responsibilities of ASHAs consist of both financially incentivized tasks (e.g. accompanying pregnant women for institutional delivery) and non-incentivized tasks (e.g. counseling of pregnant women). Theoretically, one ASHA is deployed for every 1000 residents but in practice studies report they cover much larger populations [10].

ASHAs have been evaluated following their introduction via NRHM although these studies have largely been qualitative in nature [11,12]. In a 2011 national evaluation of ASHAs [13], India's ministry of health and family welfare cited difficulties in assessing their impact including the wide variation in their work across states and districts within the same state; pervasive inter- and intra-state differences made it substantially more challenging to estimate the contribution of ASHAs to the improvement of specific health outcomes. The report also noted that ASHAs are part of the overall health system in each village, adding to the complexity of isolating their impact from that of other CHWs and physicians.

Prior studies on ASHAs have predominantly addressed their knowledge, attitudes, and skills, and have shown that they function as a link to health care for patients to a much greater degree than they do as actual health care providers or health activists [4]. This research has also revealed that ASHAs are more motivated and more effective at performing incentivized versus non-incentivized tasks and when there is perceived support from the public health system [8]. Studies have also highlighted widespread ASHA discontent with respect to their level of compensation and it has been repeatedly recommended that they receive more generous incentives, especially when serving larger populations. For example, in the 2016 Saprii et al. study [4], twenty-one ASHAs working in a variety of settings uniformly expressed dissatisfaction with their limited, inconsistent and often irregular incentive payments. In another study conducted in few blocks of Uttarakhand [14], ASHAs reported monetary compensation to be the most important motivating factor for doing the work but again, were frustrated with the amount of compensation received.

Globally, few studies have attempted to quantitatively assess the performance of CHWs [1]. One of the few studies to do so was a 1984 Kenya-based cost-benefit analysis of the country's CHW program [15] that demonstrated a large cost-benefit ratio of about 9.5. In India, a few studies focused on interventions aimed at reducing maternal mortality have been published, but showed that these interventions by CHWs were cost effective [1]. We address this gap in the quantitative assessment of ASHAs using information on health care facilities and health care workers in villages in India combined with individual-level childhood immunization data to build a cost-effectiveness model to assess the impact of the ASHA program. We specifically examine the impact of ASHAs on measles vaccination among children aged 0–5 years using data from the District Level Household and Facilities Survey 4. Such information can provide policy makers with more quantitative evidence for support of CHW programs and inform appropriate levels of incentives. To the authors' knowledge, this is one of the first studies attempting to quantify the benefits of the ASHA program in India.

2. Methods

2.1. Overview of model and analysis

We conducted a cost effectiveness analysis comparing the availability of an ASHA in a village, with a village without an ASHA. We used a logistic regression model to assess the prevalence of measles vaccination among children aged less than 5 years in villages with and without ASHA. The logistic regression model used to calculate the prevalence of measles vaccination and the formula used to convert odds ratio to prevalence ratio have been provided in Appendix A. We utilized the data from the state of Maharashtra in DLHS 4 in our base model.

Health is a state matter in India and, as such, major health programs and policies are drafted at the national level by the central government although importantly, state governments can and often do modify and implement these programs according to their specific needs and resources. As a result, the effectiveness of ASHAs may differ among states because of potentially substantial differences in health infrastructure, resource allocation, and training modalities. Consequently, we chose to conduct this analysis utilizing data from a single state, and then conduct univariate, bivariate and multivariate sensitivity analyses to encompass potential parameter values in different states of India.

We specifically selected a state where the ASHA program was implemented but ASHAs were available in less than 80% of villages. This enabled us to calculate the proportion of study population with the desired health outcomes in villages both with and without ASHA availability while avoiding large standard errors. The state of Maharashtra fulfilled all these requirements and was thus chosen for our analysis.

We have provided a simplified flow chart of our model in Fig. 1. Using 2011 census data, we estimated that a village will have approximately 84 children aged below 60 months in a population of 1000. We assumed every child from the age of 9 months up to 60 months is eligible for a dose of measles containing vaccine (MCV) and used a cohort Markov model to assess the impact of the presence of an ASHA in the village on MCV vaccination and measles outcomes in children. The primary outcomes of interest were costs and disability-adjusted life years (DALYs). The model was programmed in R (The R Foundation, Vienna, Austria) and we generated graphical outputs of our models via ggplot2 [16] package in R.

We considered measles vaccine-induced encephalitis and potential complications of measles infection in the model including pneumonia, otitis media, keratomalacia, malnutrition, and encephalitis. These complications can lead to serious clinical sequelae comprising death from pneumonia, permanent hearing loss from otitis media, corneal scarring and permanent blindness from keratomalacia, death from malnutrition, and neurological injury and death following encephalitis. We considered the costs and benefits of each scenario from a societal perspective.

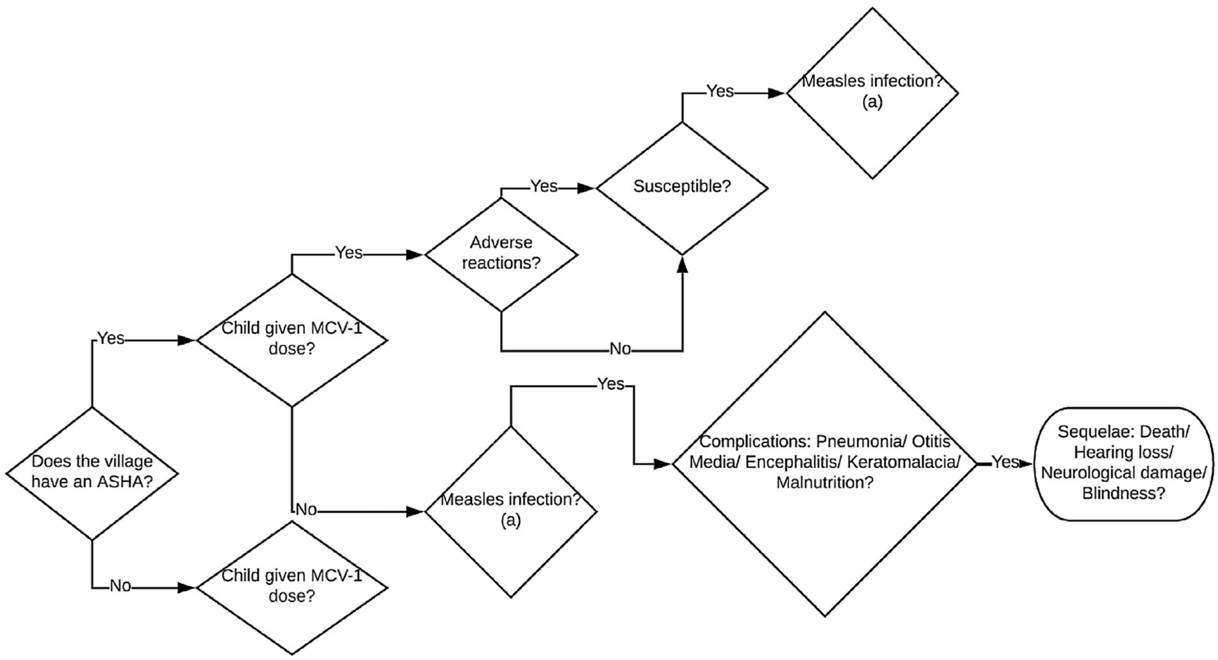

Fig. 1. Proximal branches of simplified flow chart used in the analyses. Footnote: Background annual mortality rate: 0.4% between the ages of 0–5 years.

We incorporated measles infection and its complications over the first five years of life, and the lifetime effects of these complications. We constructed our model for 68 years because the average life expectancy of an Indian citizen was 68.3 years [17]. We estimated the burden of measles infection and its complications over the first five years, with the endpoint health states consisting of: healthy, permanent blindness, permanent hearing loss, permanent neurological damage, and death. Subsequently, we estimated the lifetime effects of these health states between 5 and 68 years.

We calculated the probability of measles vaccination among children aged between 0 and 5 years with and without an ASHA available in the village using the district level households and facilities survey 4 (DLHS-4) dataset collected in 2012–2013 by the International Institute of Population Sciences (Mumbai, India). DLHS-4 utilized a multi-stage, stratified survey design, and collected data from healthcare facilities, villages and households. We merged the village and household level datasets to combine individual level childhood vaccination and village level healthcare facilities and professionals' availability information using SAS (SAS Institute Inc., Cary, NC).

We initially calculated the baseline prevalence of childhood measles vaccination in villages without an ASHA available using the surveyfreq procedure in SAS to be 68.78%. We then calculated the odds ratio of MCV vaccination if an ASHA is available in a village, after adjusting for the availability of a health care center, and availability of ANMs and AWWs in the village. The logistic regression model and the formula used for converting the odds ratio into prevalence ratio are available in Appendix A. The prevalence of measles vaccination when an ASHA was not available in the village was multiplied by the prevalence ratio to obtain the prevalence of measles vaccination rate when an ASHA was available in a village. Model relevant cost data has been provided in Appendix B.

Utility weights for measles complications were obtained via the 2017 Global Burden of Disease study [18] wherever available. We applied a standard discount rate of 3% per year in our analyses. Calculation of the incremental cost-effectiveness ratio (ICER) and determination of level of cost-effectiveness is in Appendix C.

We conducted several sensitivity analyses. We calculated the ICER for every percent increase in MCV vaccination from baseline, keeping other parameters constant, up to a 20% increase. We also conducted univariate, bivariate and multivariate, probabilistic analyses of the other parameters to measure the uncertainty of our analysis. We determined the range of values for each parameter of our model based on the available literature. For those parameters for which ranges were not available, we considered +/-25% as a conservative estimate of the range while ensuring that the ranges did not exceed plausible values of the parameters. The value of the parameters used in our analyses, their ranges, their distributions, and their sources have been provided in Table 1.

3. Results

The rate of childhood measles vaccination when an ASHA was available in a village was 79.3%, an increase by around 10% relative to when an ASHA was not available in a village. The annual total costs associated with the availability of an ASHA in a village with respect to measles vaccination was $312.72 (INR 21919) and the total costs were $69.45 (INR 4868) when an ASHA was not available in a village (Table 2). Availability of ASHAs was associated with 5.96 DALYs lost to measles in the village over the lifetime, while a village without an ASHA lost 7.59 DALYs. The cost per DALY averted when an ASHA was available in a village was $161.29 (INR 10484), which was well below the per-capita GDP of $1098.42 (INR 76990) in India in 2013. Hence, having an ASHA available in a village was highly cost-effective. The impact of measles vaccination has been compared with a study assessing the cost-effectiveness of second dose of measles vaccine in India [19] (see Appendix D and Table A1).

Fig. 2 shows the results of univariate sensitivity analyses. Overall, the parameters affecting the ICER the most were probability of death following pneumonia infection (range: 1.95–16.7%), susceptibility to measles infection after receiving one dose of MCV (range: 0–54%), and probability of pneumonia after measles infection (range: 10–30%). The highest cost per DALY averted was $415.74

Table 1
Probabilities, costs and utilities utilized in the analyses.

Probabilities				
Variable	Median/Mean	Range (IQR[a]/95% CI[b])	Distribution for PSA[c]	Source(s)
Measles vaccination given the presence of ASHA[d] in the village	79.3%	72.08–85.01%		DLHS[e] 4 (rural Maharashtra), after adjustment for availability of a health center, ANM and AWW in the village
Measles vaccination without an ASHA in the village	68.78%	60.24–77.33%		DLHS 4 (rural Maharashtra)
Encephalitis after measles vaccination	1/1,000,000			Dabral, 2009 [19]
Susceptibility to measles after measles vaccination	15%	0–54%	Beta	Dabral, 2009 [19] Uzicanin & Zimmerman, 2011 [28] Puri et al., 2001 [29]
Susceptibility to measles without measles vaccination	100%			
Measles infection among susceptible individuals per year	7%	6–8%	Normal	Sharma et al., 2004 [30] Thakur et al., 2002 [31]
Pneumonia among children with measles infection	20%	10–30%	Normal	Dabral, 2009 [19]
Otitis media among children with measles infection	5%	5–15%	Normal	Dabral, 2009 [19]
Encephalitis among children with measles infection	0.1%	0.1–0.3%	Beta	Dabral, 2009 [19] Fisher et al., 2014 [32]
Keratomalacia among children with measles infection	0.1%	0.05–0.2%	Normal	Dabral, 2009 [19]
Malnutrition among children with measles infection	3.5%	3–4%	Normal	Dabral, 2009 [19]
Probability of death among children with pneumonia	10%	1.95–16.7%	Normal	Farooqui et al., 2015 [33]
Probability of death among children with encephalitis	50%	10–75%	Normal	Fisher et al., 2014 [32]
Probability of death after malnutrition	15%	10–23%	Normal	Rice et al., 2000 [34]
Probability of hearing loss among children with otitis media	1%	0.5–2%	Normal	
Probability of permanent neurological damage after measles encephalitis	25%	20–30%	Normal	Fisher et al., 2014 [32]
Probability of blindness among children with keratomalacia	5%	2.5–10%	Normal	Sommer, 1989 [35]
Probability of death among children with no complications, keratomalacia and otitis media	0.4%			Dabral, 2009 [19]
Probability of obtaining treatment after encephalitis	20% (Hospital) 30% (OPD[f])	5–40% 20–40%	Beta Normal	
Probability of obtaining treatment after pneumonia	5% (Hospital) 30% (OPD)	2–20% 20–40%	Beta Normal	
Probability of obtaining treatment after otitis media	5% (Hospital) 30% (OPD)	2–20% 20–40%	Beta Normal	
Probability of obtaining treatment after keratomalacia	20% (Hospital) 30% (OPD)	5–40% 20–40%	Beta Normal	
Probability of obtaining treatment after malnutrition	5% (Hospital) 10% (OPD)	2–20% 5–20%	Beta Beta	
Utilities (DALYs[g])				
Variable	Disability weight (2017)	Duration	Source of disability weights	Source of duration
Measles Episodes	0.133	7 days	Global Burden of Disease Study, 2017 [36]	Dabral, 2009 [19]
Encephalitis after measles vaccination	0.133	1 month	Global Burden of Disease Study, 2017 [36]	
Encephalitis after measles infection	0.133	1 month	Global Burden of Disease Study, 2017 [36]	Dabral, 2009 [19]
Pneumonia after measles infection	0.133	7 days	Global Burden of Disease Study, 2017 [36]	Dabral, 2009 [19]
Otitis media after measles infection	0.00	2 years	Global Burden of Disease Study, 2017 [36]	Dabral, 2009 [19]
Keratomalacia after measles infection	Corneal scar: 0.277	Until death	WHO Global Burden of Disease 2004 disability weights [37]	
Malnutrition after measles infection	Severe wasting without edema: 0.128	1 month	Global Burden of Disease Study, 2017 [36]	Dabral, 2009 [19]
Neurological damage after encephalitis	Severe motor + cognitive impairments associated with encephalitis: 0.542	Until death	Global Burden of Disease Study, 2017 [36]	
Hearing loss after otitis media	0.316	Until death	Global Burden of Disease Study, 2017 [36]	
Blindness after keratomalacia	0.187	Until death	Global Burden of Disease Study, 2017 [36]	

(*continued on next page*)

Table 1 (*continued*)

Costs (in INR[h])				
Variable	Median/ Mean	IQR/ 95% CI	Distribution in PSA	Source
Accredited Social Health Activists (Fixed costs)	10,000			Evaluation of ASHA programme, 2010–2011 [38]
Accredited Social Health Activists (Incentive per MCV dose per child)	112	89–138	Normal	Prinja et al., 2014 [39]
MCV[i] dose	30			Dabral, 2009 [19]
Encephalitis after measles vaccination inpatient treatment	23,984	7482–34,561	Normal	Key Indicators of Social Consumption in India, 2014 [40]
Encephalitis after measles infection inpatient treatment	23,984	7482–34,561	Normal	Key Indicators of Social Consumption in India, 2014 [40]
Pneumonia after measles infection inpatient treatment	12,820	4811–18,705	Normal	Key Indicators of Social Consumption in India, 2014 [40]
Keratomalacia after measles infection inpatient treatment	9307	1778–13,374	Normal	Key Indicators of Social Consumption in India, 2014 [40]
Otitis media after measles infection inpatient treatment	15,285	6626–19,158	Normal	Key Indicators of Social Consumption in India, 2014 [40]
Malnutrition after measles infection inpatient treatment	14,117	4625–19,206	Normal	Key Indicators of Social Consumption in India, 2014 [40]
Outpatient treatment per ailing person suffering from an ailment	629	386–785	Normal	Key Indicators of Social Consumption in India, 2014 [40]

[a] IQR: Inter-quartile range.
[b] CI: Confidence Interval.
[c] PSA: Probabilistic Sensitivity Analysis.
[d] ASHA: Accredited Social Health Activist.
[e] DLHS 4: District Level Household and Facility Survey 4. 2012–2013.
[f] OPD: Outpatient department.
[g] DALY: Disability adjusted life-year.
[h] INR: Indian Rupees.
[i] MCV: Measles containing vaccine.

Table 2
Projected costs and DALYs[a] associated with availability of ASHAs[b] in a cohort of eighty-four children below 5 years, 2012–2013.

	No ASHA available	ASHA available
Cohort size	84	84
Total costs (INR[c])	4867.66	21918.65
Fixed costs of ASHAs (INR)	–	10,000
Incentive based costs of ASHAs (INR)	–	7460.54
Number of MCV doses administered	57.78	66.61
MCV[d] cost per dose administered (INR)	30	30
Medical costs (INR)	4867.66	4458.1
Number of cases of measles	10.62	8.33
Number of cases of pneumonia	2.12	1.67
Number of cases of otitis media	1.06	0.83
Number of cases of keratomalacia	0.01	0.0083
Number of cases of malnutrition	0.37	0.29
Number of deaths due to complications of measles	0.27	0.21
DALYs	7.59	5.96
Incremental DALYs	0	1.63
Cost in INR per DALY averted	0	10483.77

[a] DALY: Disability adjusted life year.
[b] ASHA: Accredited Social Health Activist.
[c] INR: Indian Rupees.
[d] MCV: Measles containing vaccine.

(INR 27023) when the probability of death following pneumonia infection was 1.95%, so the intervention remained highly cost-effective under all these scenarios.

We examined variations in the increase in measles vaccination rates due to ASHAs would affect cost-effectiveness in Fig. 3. If ASHAs only induce a 1% increase in the vaccination rate the cost per DALY averted was $1644.51 (INR 106893), but if the vaccination rate increased by 20% from the baseline, then ICER decreased to $87.44 (INR 5684). The intervention remained cost-effective when the increase in vaccination was 1% and was highly cost-effective when the increase in measles vaccination rate was 2% or higher.

We assumed that the cohort size of children available for measles vaccination decreased over time as more children were vaccinated. Initially, an ASHA will work to vaccinate all children under 5, but eventually, will only impact newly-born children. Therefore, we estimated the long-term cost effectiveness of the ASHA intervention by reducing the cohort size of children eligible for measles vaccination (Fig. 4). We varied the cohort size of children in villages between five and eighty-four. The cost per DALY averted increased as the cohort of children decreased. Even with an annual cohort of five children eligible for measles vaccination, the cost per DALY averted was $1655.84 (INR 107630), which was cost effective. At cohort size of 8 or higher, the ICER was highly cost effective.

Based on the results of univariate sensitivity analyses, we conducted bivariate sensitivity analyses with two pairs of parameters: probability of pneumonia among measles cases vs. probability of death among pneumonia cases (Fig. 5), and incentivization costs associated with an ASHA vs. probability of death among pneumonia cases (Fig. 6). Increased probability of pneumonia among measles cases and increased probability of death among pneumonia cases were associated with reduced cost per DALY averted. The highest cost per DALY averted, $519.65 (INR 33777), was obtained when the probability of pneumonia among measles cases was 10%, and the probability of death among pneumonia cases was 1.95%. The intervention was highly cost effective for all combinations of values of probability of pneumonia and probability of death among pneumonia cases.

In our second bivariate sensitivity analysis, we varied the incentive costs associated with ASHAs per MCV dose delivered between INR 89 and INR 1000. The ICER increased as we increased the incentive costs associated with ASHAs per MCV dose and decreased as the probability of death due to pneumonia increased. The highest cost per DALY averted, $1857.95 (INR 120767), was obtained when the incentive costs associated with ASHA was $14.27 (INR 1000) and the probability of death among children with pneumonia was 1.95%. In our model, ASHAs were more cost-effective when

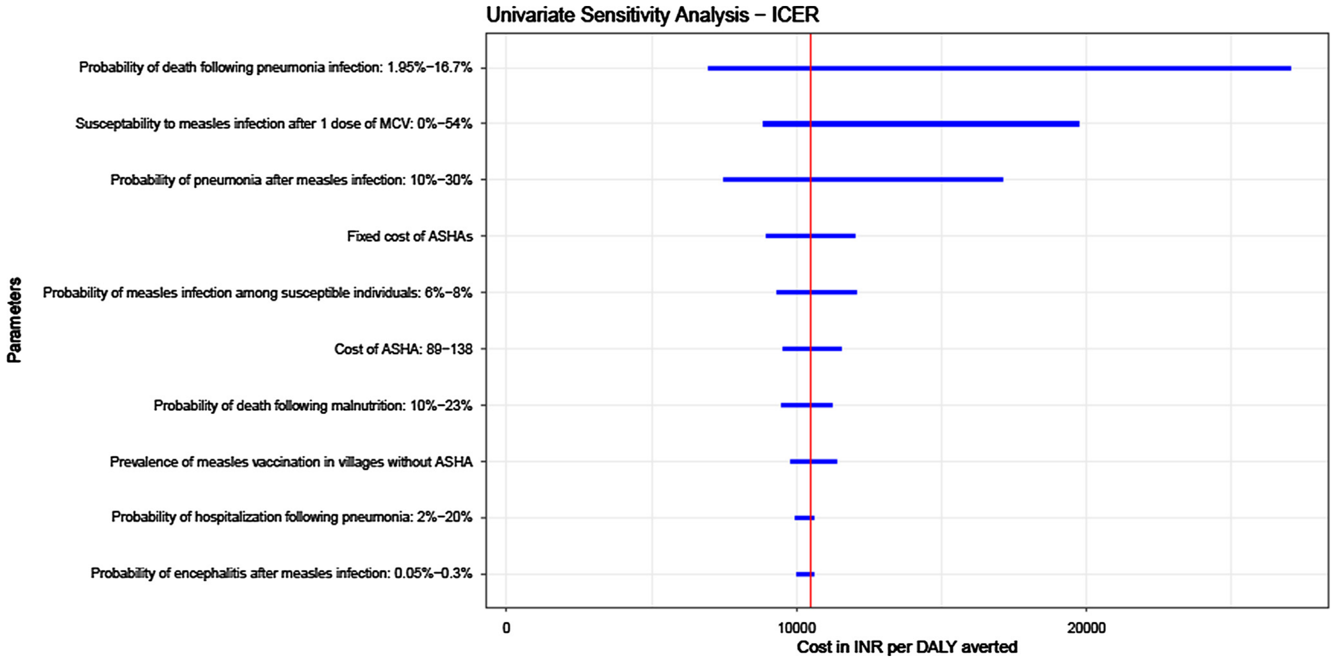

Fig. 2. Tornado diagram generated using univariate sensitivity analyses: note: All parameters were varied, but only top 10 with the highest impact on ICER were shown.

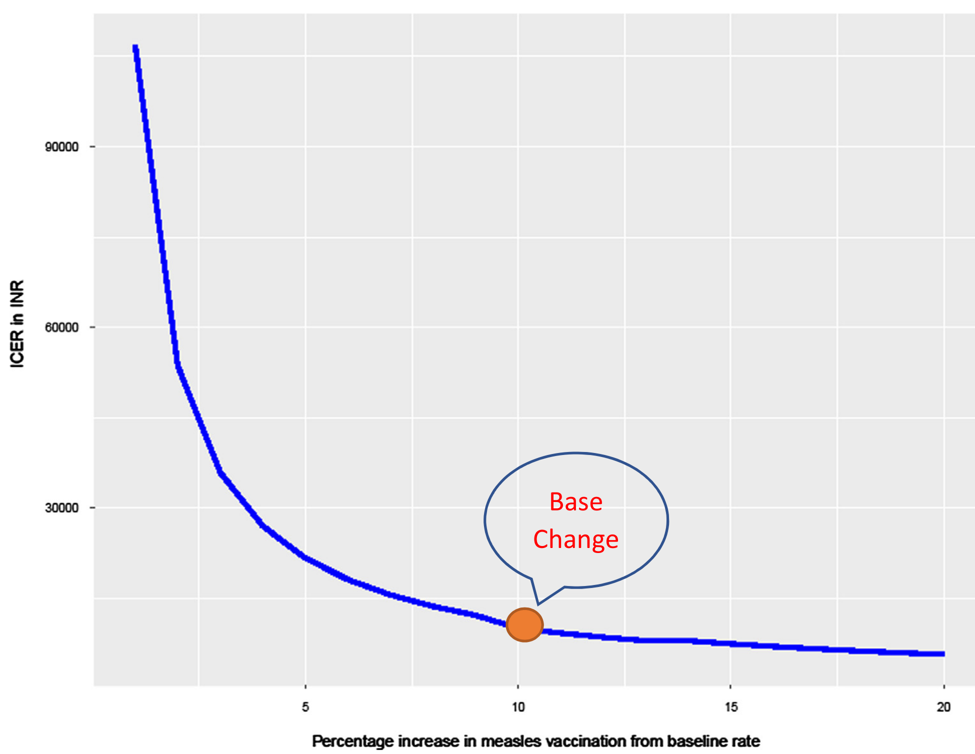

Fig. 3. Changes in ICER for every percentage increase in measles vaccination when an ASHA is available in the village.

the incentive was lower and the probability of death due to pneumonia was higher. Overall, in our bivariate analyses, the cost per DALY averted was highly cost effective in 95.22% of combinations of the values of incentive costs of ASHAs and probability of death among pneumonia cases and cost effective in remaining combinations.

We conducted probabilistic sensitivity analysis with 100,000 Monte Carlo simulation iterations (Fig. 7). The proportion of iterations in which the intervention was cost effective was 90% with a willingness to pay per DALY averted of $384.62 (INR 25000), which is about 33% of the per-capita GDP of India. Hence, ASHAs were highly likely to be highly cost-effective.

4. Discussion

The WHO has historically recommended the use of community health workers, especially in low income countries, to help address

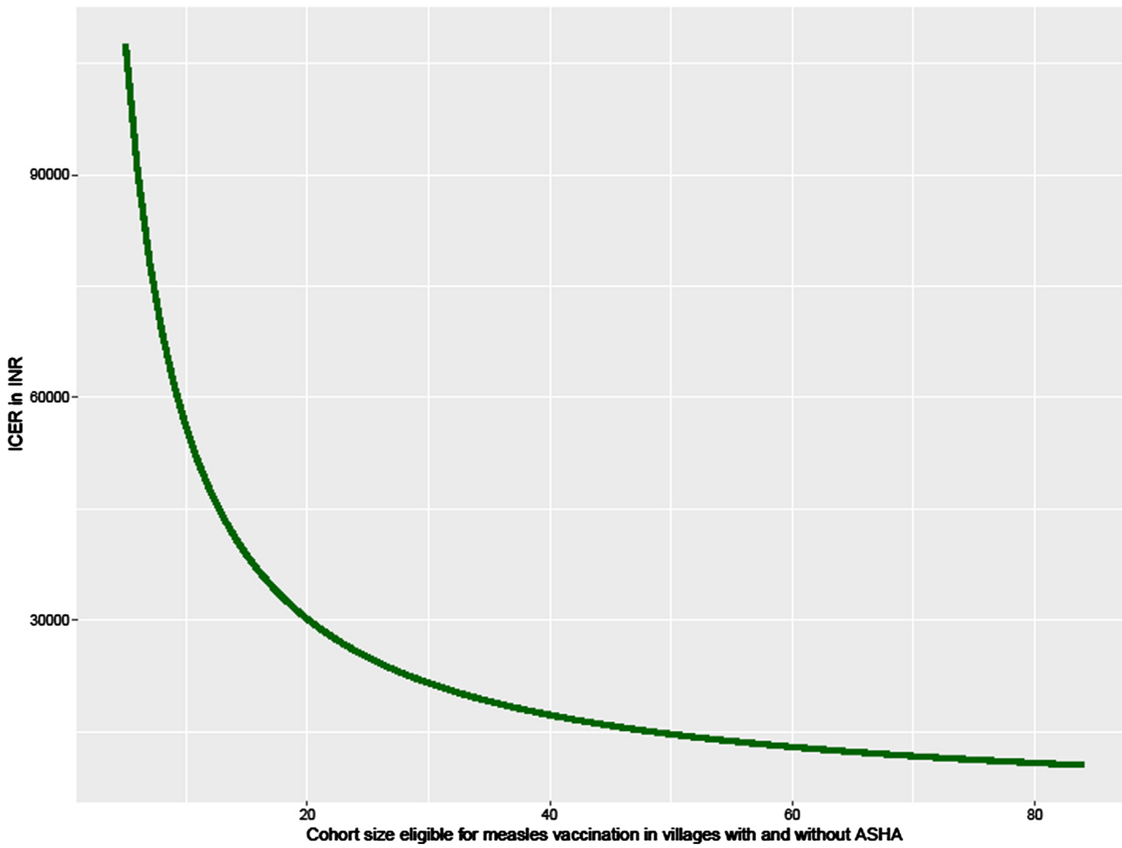

Fig. 4. Association between ICER and changes in cohort size eligible for measles vaccination in villages with and without ASHA.

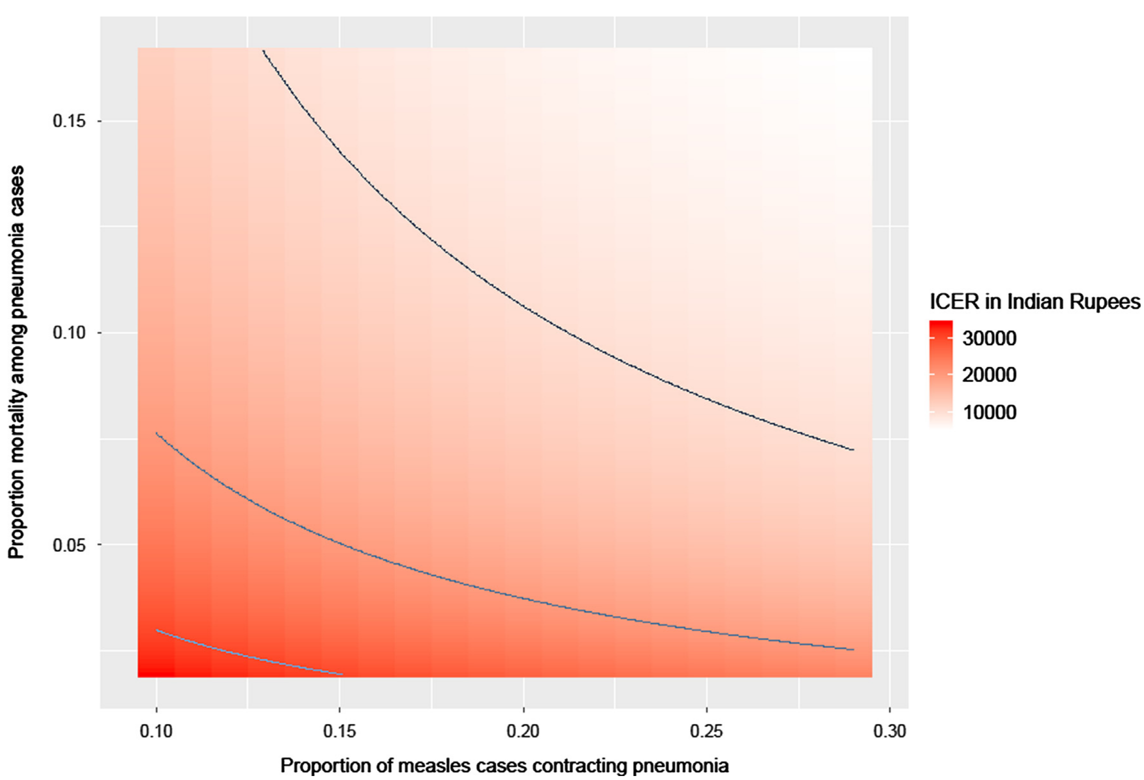

Fig. 5. Heatmap of changes in ICER with simultaneous changes in probability of pneumonia in children with measles infection and probability of death among children with pneumonia.

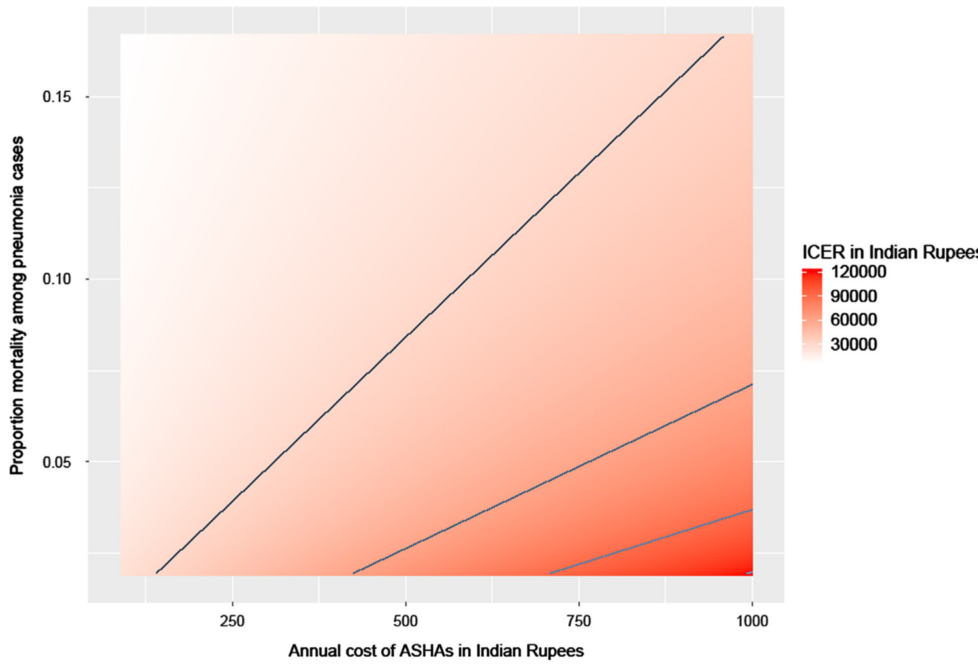

Fig. 6. Heatmap of changes in ICER with simultaneous changes in variable cost (incentives) of ASHAs and probability of death among children with pneumonia.

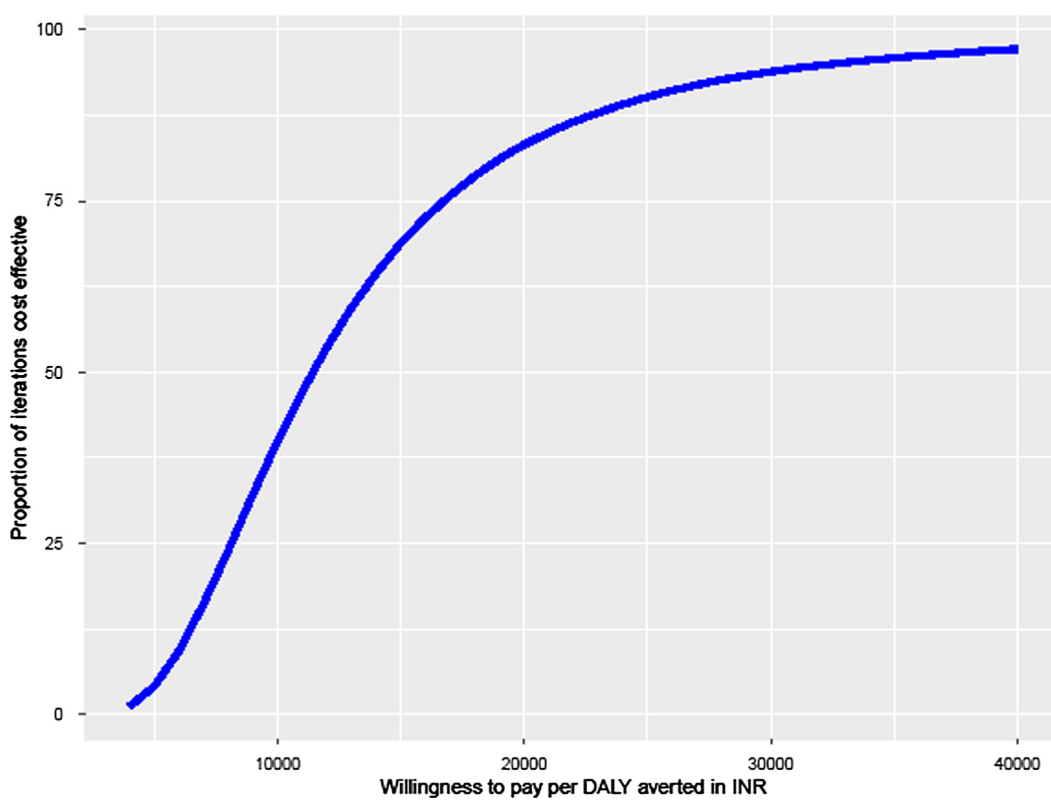

Fig. 7. Probabilistic sensitivity analysis.

the many challenges in providing services given these countries' often overextended and under-resourced health and public health systems [2]. Large-scale community health worker programs have been initiated in many countries globally including the Pakistan's Lady Health Worker program in 1992, Ethiopia's Health Extension Worker program introduced in 2004, and India's ASHAs introduced in 2005, among others [2]. Community health workers can serve as a critical link in the delivery of health care services to the poorest and most underserved populations in pursuit of sustainable development goals; however, more research and evidence regarding their effectiveness in achieving desired health-related outcomes is clearly needed. Childhood immunization is a critical health care service which not only prevents vaccine preventable diseases, but also has important downstream effects such as improving education outcomes and decreasing income inequality [20]. Community health workers can play an important role in ensuring equitable distribution of vaccination.

India has the highest number of children with vaccine preventable diseases worldwide [21]. The introduction of National Rural Health Mission in India has resulted in improved vaccination rates and reduced socioeconomic inequality in childhood vaccination across all states of India. However, full childhood vaccination rates remain low, below 70%, with a stagnation in the reduction in the percentage of unvaccinated children over the last decade. Although socioeconomic inequalities in childhood vaccination have been reduced, they still persist [22]. The nationwide ASHA coverage in 2014 was reported to be 70% of all villages;[23] this underlines the need for both better coverage but also improved retention of ASHAs, who can reach out to communities with non- and under-vaccinated children to enhance immunization coverage, thereby improving full vaccination rates and ultimately reducing vaccine preventable diseases and the socioeconomic inequalities that accompany them.

Our analyses showed that the ASHAs are highly cost-effective when only examining the impact on measles vaccination and were particularly cost-effective in situations where the probability of pneumonia as a sequela of measles and probability of death among pneumonia cases were high. We considered probability of pneumonia following measles and probability of death following pneumonia to highlight those healthcare scenarios where the ASHAs would be highly cost-effective. In villages with overall poor living conditions and low availability of healthcare facilities, probability of pneumonia following measles and probability of death due to measles induced pneumonia would be notably high, and hence, according to our models, ASHAs would be especially cost-effective.

Our probabilistic sensitivity analysis shows that ASHAs are very likely to be highly cost-effective at the current levels of fixed and incentive-based costs. Our sensitivity analyses also show they will remain cost effective even when their financial incentives are increased by 10 times. In the longer term, when the cohort of children that were yet to be vaccinated decreased in size, the incremental cost-effectiveness ratio remained highly cost effective at cohort size of 8 and above. Overall, our analyses showed that ASHAs remained cost-effective with respect to measles vaccination under a wide range of values for multiple parameters in our models.

Vaccinations remain among the most cost-effective public health interventions known, and consequently most programs promoting childhood vaccination are also likely to be highly cost-effective. However, this analysis shows that ASHAs remain cost effective with higher levels of financial incentives even under conservative assumptions of our model: despite the training for ASHAs for myriad responsibilities, we only evaluated the benefits of measles vaccination. This finding is important in the context of the widespread dissatisfaction of ASHAs with their financial compensation. In many states, ASHAs have reported working many times more than the average 2–3 h/week stipulated by central and state governments [24], which combined with low monetary compensation may lead to a sense of overburdening. Although literature regarding ASHA retention is not available in India due to the relatively recent implementation of the ASHA program, a Kenyan study published in 2018 reported that monetary incentives were significantly negatively associated with attrition rate among CHWs [25]. Non-availability of monetary incentive was associated with higher attrition rate than when monetary incentive was available among the CHWs in this study. Higher attrition rates can result in higher costs of the ASHA program due to increased training costs for new ASHA recruits. Hence, given the cost effectiveness of the ASHA program, the central and state governments should consider increasing the financial incentives to improve retention of ASHAs. Our calculations show that even with the current proposed increased payments to ASHAs, ASHAs will still be cost-effective.

Like all studies, ours has limitations. One of the main limitations is the ecological nature of the variables used to assess the rate of childhood measles vaccination with and without availability of ASHAs. Due to this, the increase in childhood measles vaccination in villages with ASHAs may not be wholly attributable to ASHAs. We were cognizant of this setback and hence assessed a wide range of 1% to 20% improvement in measles vaccination when ASHAs were available in our sensitivity analyses. Our models predicted that ASHAs would be cost-effective even when they ASHA attributable increase in measles vaccination rate was just 1%. Historically, a second dose of measles vaccine was not part of India's Universal Immunization Program, so this analysis did not evaluate the benefits of ASHAs in increasing rates of two-doses of measles vaccination. If ASHAs also increase two-dose measles vaccination coverage, we would expect the program to be even more cost-effective.

We did not consider all the responsibilities of ASHAs which may add additional benefits and alter costs. We also did not include herd immunity to measles infection which may have resulted in underestimation of the cost effectiveness of ASHAs. We utilized the baseline vaccination rate and vaccination rate with the availability of ASHAs in one state of India, which may not be fully generalizable to other Indian states. However, we conducted univariate, bivariate, and probabilistic sensitivity analyses to mitigate the lack of generalizability.

One of the core-reasons the ASHA program was introduced was to improve the utilization of healthcare services among minorities and difficult-to-reach populations of India who have lower access to traditional healthcare facilities such as primary healthcare centers. This is in tandem with community health workers in other countries of the world, where one of their primary responsibilities is to ensure access to healthcare facilities in hard-to-reach populations which amounts to ensuring equitable distribution of healthcare access in all strata of society. However, even when ASHAs are available, it is possible that previously well-performing communities (in terms of health and healthcare utilization) avail the benefits before poorly performing communities. Data regarding levels of utilization of ASHA services by different populations is not available in the DLHS 4 dataset and is beyond the scope of this paper.

4.1. Public health implications

Quantification of benefits provides a sound rationale for more investment in the community health worker program, and better incentivization of community health workers. Over the last three decades, there has been a global movement to increase CHW numbers and integrate them into existing health systems, with more than half of the CHWs introduced in India [26]. The implementation of the CHW programs is often associated with significant costs and resource allocations from the local governments and ministries [26]. As such, both qualitative and quantitative evidence are required to justify higher investments in the ASHA program by the Indian government, including higher incentives to ASHAs. This analysis supports recent efforts to increase ASHA payments, such as the initiative by the central government to improve fixed incentives to ASHAs [27].

4.2. Future directions

This study provides evidence that a significant increase in financial incentives of ASHAs is cost effective, even when a single health outcome such as measles vaccination is considered. Cost effectiveness analyses of other major responsibilities of ASHAs including promotion of institutional delivery among pregnant women and efforts aimed at improving sanitation in villages, could inform health policy by measuring the impact of ASHAs in different contexts and guiding program prioritization in terms of ASHA responsibilities. This can also provide information regarding the areas in which ASHAs require more training, and responsibilities for which they could be better incentivized. Future models should consider the rapid changes in the health care landscape and demographic characteristics that are underway in India's population.

Conflict of interest

The authors declare that there is no conflict of interest.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2019.04.038.

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