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Supplementary appendix

This appendix formed part of the original submission and has been peer reviewed. We post it as supplied by the authors.

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Supplementary appendix

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Appendix A. Literature review search strategy

Search strategy for community-based studies:

Initially include all 1980–2008 articles from Wolfson and colleagues[1]

Search terms for literature review supplementing Wolfson and colleagues:
(measles[MeSH Terms] OR measles) AND (mortality[MeSH Terms] OR mortality OR "case fatality rate" OR "case fatality ratio")

Exclusion criteria:

- Non-human studies
- Articles published outside data range (from 1980/01/01 to 2016/12/31)
- Included in Wolfson and colleagues
- Duplicate articles
- Did not include primary data (defined as directly collected data from outbreak investigations, cohort studies, analyses of routine surveillance, cross-sectional studies, and hospital-based studies)
- Non-English abstract
- Articles that referred to measles outbreaks in refugee camps or camps of internally displaced persons
- Irrelevant articles: clinical trials, global or regional surveillance, laboratory study, maternal mortality study, high-income countries, hospital study, no information on measles cases/deaths

Search strategy for hospital-based studies:

Search terms:
(measles[MeSH Terms] OR measles) AND (mortality[MeSH Terms] OR mortality OR "case fatality rate" OR "case fatality ratio") AND (hospitals[MeSH Terms] OR hospital)

Exclusion criteria:

- Non-human studies
- Articles published outside data range (from 1980/01/01 to 2016/12/31)
- Duplicate articles
- Did not include primary data (defined as directly collected data from outbreak investigations, cohort studies, analyses of routine surveillance, cross-sectional studies, and hospital-based studies)
- Non-English abstract
- Irrelevant articles: clinical trials, global or regional surveillance, laboratory study, maternal mortality study, high-income countries, community studies, no information on measles cases/deaths

Table B. Summary table of laboratory confirmation and definition of timeframe following rash onset for death to be considered attributable to measles, among community-based and hospital-based studies

	Laboratory confirmation	Definition of timeframe following rash onset for death to be considered attributable to measles included
Community-based articles	39 out of 158 observations	89 out of 158 observations
Hospital-based articles	13 out of 68 observations	12 out of 68 observations*

*Note: We assumed that, when not explicitly defined, hospital-based observations only included measles deaths in hospital.

Figure C. Comparisons of observed vs. predicted measles case fatality ratios (CFRs)

Figure C1. Cross validation for 20% of original measles CFR observations left out of prediction model

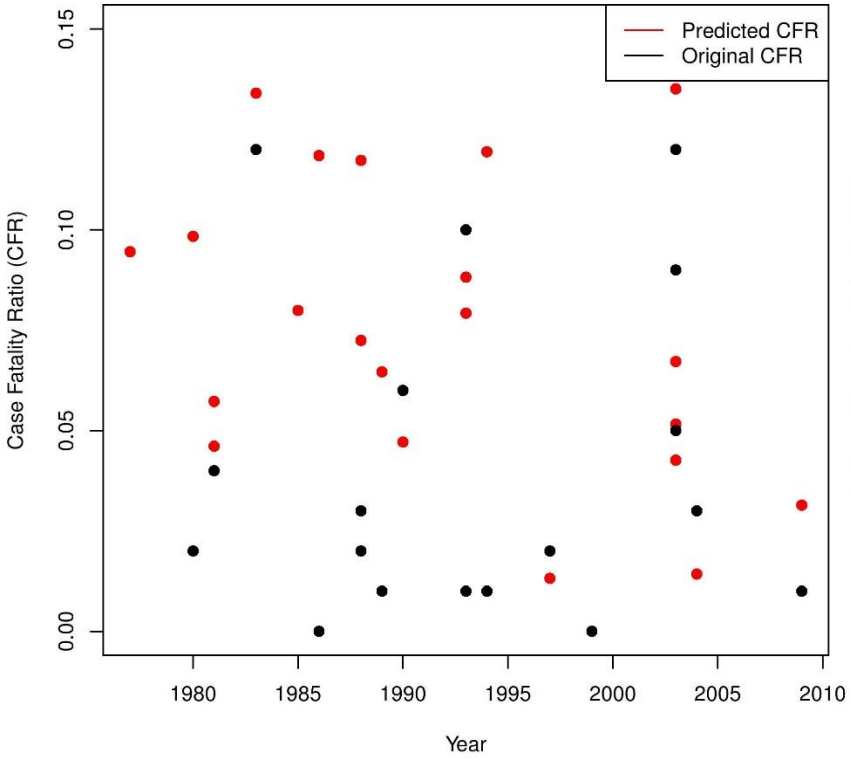
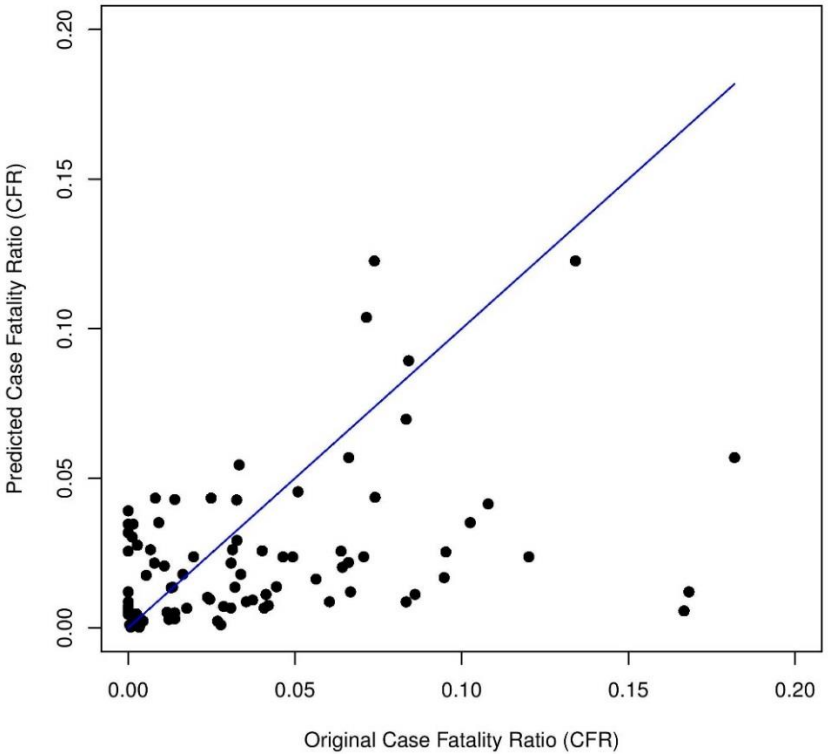


Figure C2. Observed vs. predicted measles CFRs for 1990–2015



Note: Blue line indicates x=y. Original data includes only those CFRs from 1990 or later.

Appendix D. Equations of fitted, prediction, and projection models listed in Table 1 with accompanying definitions and sources

Fitted model equations including all covariates

Log-linear

$\ln(CFR) \sim Norm(\ln(\mu), \sigma^2)$,

where $\ln(\mu) =$

$$\beta_0 + \beta_1 * Year\ of\ study + \beta_2 * MCV1\ coverage + \beta_3 * Community\ indicator + \beta_4 * Under\ 5\ indicator + \beta_5 * Outbreak\ setting + \beta_6 * Attack\ rate + \beta_7 * \ln(GDP) + \beta_8 * \ln(Under\ 5\ mortality) + \beta_9 * \ln(Population\ density) + \beta_{10} * \ln(TFR) + \beta_{11} * Percentage\ urban + \beta_{12} * Region + \beta_{13} * Income\ level + \beta_{14} * Educational\ attainment + \beta_{15} * Urban\ setting + \beta_{16} * SIA + \beta_{17} * HIV$$

and $\sigma^2 =$ variance of $\ln(CFR)$

Poisson

$Deaths \sim Poisson(\lambda)$,

where $\ln(\lambda) =$

$$\beta_0 + \beta_1 * Year\ of\ study + \beta_2 * MCV1\ coverage + \beta_3 * Community\ indicator + \beta_4 * Under\ 5\ indicator + \beta_5 * Outbreak\ setting + \beta_6 * Attack\ rate + \beta_7 * \ln(GDP) + \beta_8 * \ln(Under\ 5\ mortality) + \beta_9 * \ln(Population\ density) + \beta_{10} * \ln(TFR) + \beta_{11} * Percentage\ urban + \beta_{12} * Region + \beta_{13} * Income\ level + \beta_{14} * Educational\ attainment + \beta_{15} * Urban\ setting + \beta_{16} * SIA + \beta_{17} * HIV$$

Negative binomial

$Deaths \sim NBin(r, p)$,

where mean $= \frac{pr}{1-p} =$

$$\beta_0 + \beta_1 * Year\ of\ study + \beta_2 * MCV1\ coverage + \beta_3 * Community\ indicator + \beta_4 * Under\ 5\ indicator + \beta_5 * Outbreak\ setting + \beta_6 * Attack\ rate + \beta_7 * \ln(GDP) + \beta_8 * \ln(Under\ 5\ mortality) + \beta_9 * \ln(Population\ density) + \beta_{10} * \ln(TFR) + \beta_{11} * Percentage\ urban + \beta_{12} * Region + \beta_{13} * Income\ level + \beta_{14} * Educational\ attainment + \beta_{15} * Urban\ setting + \beta_{16} * SIA + \beta_{17} * HIV$$

and variance $= \frac{pr}{(1-p)^2} =$ variance of the above

Fitted model equations including the covariates with less than 10% data missing

Log-linear

$\ln(CFR) \sim Norm(\ln(\mu), \sigma^2)$,

where $\ln(\mu) =$

$$\beta_0 + \beta_1 * Year\ of\ study + \beta_2 * MCV1\ coverage + \beta_3 * Community\ indicator + \beta_4 * Under\ 5\ indicator + \beta_5 * Attack\ rate + \beta_6 * \ln(GDP) + \beta_7 * \ln(Under\ 5\ mortality) + \beta_8 * \ln(Population\ density) + \beta_9 * \ln(TFR) + \beta_{10} * Percentage\ urban + \beta_{11} * Region + \beta_{12} * Income\ level$$

and $\sigma^2 =$ variance of $\ln(CFR)$

Poisson

$Deaths \sim Poisson(\lambda)$,

where $\ln(\lambda) =$

$$\beta_0 + \beta_1 * Year\ of\ study + \beta_2 * MCV1\ coverage + \beta_3 * Community\ indicator + \beta_4 * Under\ 5\ indicator + \beta_5 * Attack\ rate + \beta_6 * \ln(GDP) + \beta_7 * \ln(Under\ 5\ mortality) + \beta_8 * \ln(Population\ density) + \beta_9 * \ln(TFR) + \beta_{10} * Percentage\ urban + \beta_{11} * Region + \beta_{12} * Income\ level$$

Negative binomial

$Deaths \sim NBin(r, p)$,

where mean $= \frac{pr}{1-p} =$

$$\beta_0 + \beta_1 * Year\ of\ study + \beta_2 * MCV1\ coverage + \beta_3 * Community\ indicator + \beta_4 * Under\ 5\ indicator + \beta_5 * Attack\ rate + \beta_6 * \ln(GDP) + \beta_7 * \ln(Under\ 5\ mortality) + \beta_8 * \ln(Population\ density) + \beta_9 * \ln(TFR) + \beta_{10} * Percentage\ urban + \beta_{11} * Region + \beta_{12} * Income\ level$$

and variance $= \frac{pr}{(1-p)^2} =$ variance of the above

Log-linear fitted model selected based on Akaike Information Criterion

$$\ln(CFR) = \beta_0 + \beta_1 * Year\ of\ study + \beta_2 * MCV1\ coverage + \beta_3 * Community\ indicator + \beta_4 * Under\ 5\ indicator + \beta_5 * Attack\ rate + \beta_6 * \ln(Under\ 5\ mortality) + \beta_7 * \ln(Population\ density) + \beta_8 * \ln(TFR) + \beta_9 * Percentage\ urban$$

Table D1. Fitted model definitions and sources

Variable	Type	Definition	Source(s)
CFR	Dependent	The measles case fatality ratio in the specified year as indicated in the selected study.	Appendices N and O
Year of study	Independent	The midpoint year was used in the case of studies across multiple years.	Appendices N and O
MCV1 coverage	Independent	Routine measles immunization first-dose (MCV1) coverage.	WHO (2017)[2]
Community indicator	Independent	A dummy variable used to indicate if a study is in a community-based setting.	Appendices N and O
Under 5 indicator	Independent	A dummy variable used to indicate if a study includes cases and deaths limited to a population under five years of age.	Appendices N and O
Outbreak setting	Independent	A dummy variable used to indicate if a study takes place during a measles outbreak.	Appendices N and O
Attack rate	Independent	Defined as estimated measles incidence divided by the annual birth cohort.	Ferrari (2016)[3]; World Bank (2017)[4]
GNI	Independent	Gross national income per capita in US dollars.	World Bank (2017)[4]
Under 5 mortality	Independent	All-cause under 5 mortality rate per 1000 live births.	World Bank (2017)[4]
Population density	Independent	People per square kilometer of land area.	World Bank (2017)[4]
TFR	Independent	Total fertility rate.	World Bank (2017)[4]
Percentage urban	Independent	Percentage of population in urban areas.	World Bank (2017)[4]
Region	Independent	World Health Organization region.	WHO (2018)[5]
Income level	Independent	World Bank income level.	World Bank (2017)[4]
Educational attainment	Independent	Estimates of average years of educational attainment per capita for people over the age of 15.	IHME (2015)[6]
Urban setting	Independent	A dummy variable used to indicate if a study is in an urban setting.	Appendices N and O
SIA	Independent	A dummy variable used to indicate if a study took place during the same year as supplementary immunization activities.	WHO (2014)[7]
HIV	Independent	Percentage of people aged 15-49 who are infected with HIV.	World Bank (2017)[4]

The fitted model can be used to predict a country-specific CFR with the country-specific inputs from the sources specified in the equations and tables below alongside inputs for year, community-based vs. hospital-based setting indicator, and under 5 vs. over 5 years of age indicator.

Log-linear prediction model

$$\ln(CFR_c) = \beta_0 + \beta_1 * Year + \beta_2 * MCV1\ coverage_c + \beta_3 * Community\ indicator + \beta_4 * Under\ 5\ indicator + \beta_5 * Attack\ rate_c + \beta_6 * \ln(Under\ 5\ mortality_c) + \beta_7 * \ln(Population\ density_c) + \beta_8 * \ln(TFR_c) + \beta_9 * Percentage\ urban_c$$

Log-linear projection model

$$\ln(CFR_c) = \beta_0 + \beta_1 * Year + \beta_2 * MCV1\ coverage_c + \beta_3 * Community\ indicator + \beta_4 * Under\ 5\ indicator + \beta_5 * \ln(Under\ 5\ mortality_c) + \beta_6 * \ln(Population\ density_c) + \beta_7 * \ln(TFR_c) + \beta_8 * Percentage\ urban_c$$

Table D2. Results of the log-linear prediction model selected for 1990-2015 measles CFR predictions in LMICs

	Coefficient	Standard error	P-value
Intercept	5·12	30·14	0·865
Year of study	-0·01	0·02	0·526
Routine first-dose measles immunization (MCV1) coverage	-0·17	0·37	0·642
Community study indicator	-0·67	0·14	<0·001
Under-5 indicator	1·29	0·54	0·019
Attack rate	0·16	0·07	0·026
Log under-5 mortality rate	1·57	0·32	<0·001
Log population density	-0·02	0·07	0·817
Log total fertility rate (TFR)	0·62	0·72	0·394
Percentage urban	4·84	0·75	<0·001

Table D3. Prediction and projection model definitions and sources

Variable	Type	Definition	Source(s)
CFR_c	Dependent	The measles case fatality ratio predicted for a specified year by country.	
Year	Independent	Linear time by year: 1990 – 2015 for the prediction model and 2016 – 2030 for the projection model.	Input
MCV1 $coverage_c$	Independent	Routine measles immunization first-dose (MCV1) coverage.	WHO (2017)[2]
Community indicator	Independent	A dummy variable used to indicate predictions in either a community-based or hospital-based setting.	Input
Under 5 indicator	Independent	A dummy variable used to indicate predictions in either a population under five years of age or a population over five years of age.	Input
Attack $rate_c$*	Independent	Defined as estimated measles incidence divided by the annual birth cohort.	Ferrari (2016)[3]; World Bank (2017)[4]
Under 5 $mortality_c$	Independent	All-cause under 5 mortality rate per 1000 live births.	World Bank (2017)[4]
Population $density_c$	Independent	People per square kilometer of land area.	World Bank (2017)[4]
TFR_c	Independent	Total fertility rate.	World Bank (2017)[4]
Percentage $urban_c$	Independent	Percentage of population in urban areas.	World Bank (2017)[4]

*Not included in projection model.

Appendix E. Community-based studies* included in the measles case fatality ratio (CFR) analysis

Country	Year(s) of study	Midpoint year	Setting	Type of study	Outbreak setting (Y/N)	Under five indicator*	Cases	Deaths	Case fatality ratio	Ref.
Bangladesh	1975	1975	Rural	Analysis of routine surveillance	N	1	510	22	4·31%	[8,9]
Bangladesh	1980	1980	Rural	Cohort study	N	1	3,458	61	1·76%	[10]
Bangladesh	1980	1980	Rural	Analysis of routine surveillance	Y	1	77	1	1·30%	[11]
Bangladesh	1984	1984	Rural	Cohort study	N	1	2,354	41	1·74%	[12]
Bangladesh	1984	1984	Rural	Cohort study	N	0	931	5	0·54%	[12]
Bangladesh	1980-1988	1984	Rural	Analysis of routine surveillance	N	1	2,430	48	1·98%	[13]
Bangladesh	1980-1988	1984	Rural	Analysis of routine surveillance	N	0	1,084	3	0·28%	[13]
Bangladesh	1989	1989	Rural	Analysis of routine surveillance	N	1	3,607	30	0·83%	[14]
Bulgaria	2009	2009	Both	Outbreak investigation	Y	1	24,253	24	0·10%	[15]
Burkina Faso	2000	2000	Urban	Analysis of routine surveillance	N	1	940	29	3·09%	[16]
Burkina Faso	2000	2000	Urban	Analysis of routine surveillance	N	0	2,035	16	0·79%	[16]
Burkina Faso	2009	2009	Both	Outbreak investigation	Y	1	125	4	3·20%	[17]
Burkina Faso	2009	2009	Both	Outbreak investigation	Y	0	301	4	1·33%	[17]
Burundi	1988	1988	Rural	Outbreak investigation	Y	1	357	22	6·16%	[18]
Cambodia	2000	2000	Rural	Outbreak investigation	Y	NA	228	4	1·75%	[19]
Central African Republic	2011	2011	Both	Outbreak investigation	Y	NA	723	2	0·28%	[20]
Chad	1993	1993	Urban	Outbreak investigation	Y	1	824	61	7·40%	[21]
Chad	2004	2004	Urban	Outbreak investigation	Y	1	473	19	4·02%	[22]
China	2005	2005	Both	Analysis of routine surveillance	Y	NA	124,865	55	0·04%	[23]
Congo, Democratic Republic of the	1974-1977	1976	Urban	Cohort study	N	1	1,069	65	6·08%	[8,24]
Congo, Democratic Republic of the	2010	2010	Both	Analysis of routine surveillance	Y	NA	77,241	1,085	1·40%	[25]
Congo, Democratic Republic of the	2011	2011	Both	Outbreak investigation	Y	NA	10,742	403	3·75%	[26]
Ethiopia	1981	1981	Urban	Cohort study	Y	1	63	17	26·98%	[8,27]
Ethiopia	2004-2009	2007	Both	Analysis of routine surveillance	Y	NA	8,044	112	1·39%	[28]
Gambia	1981	1981	Rural	Outbreak investigation	Y	1	77	18	23·38%	[29]

Country	Year(s) of study	Midpoint year	Setting	Type of study	Outbreak setting (Y/N)	Under five indicator*	Cases	Deaths	Case fatality ratio	Ref.
Gambia	1981	1981	Rural	Outbreak investigation	Y	0	57	2	3·51%	[29]
Gambia	1981	1981	Rural	Outbreak investigation	Y	1	87	8	9·20%	[30]
Gambia	1981	1981	Rural	Outbreak investigation	Y	0	54	2	3·70%	[30]
Gambia	1984	1984	Rural	Outbreak investigation	Y	NA	54	0	0·00%	[31]
Ghana	1989	1989	Rural	Cohort study	N	1	717	132	18·41%	[32]
Ghana	1989	1989	Rural	Cohort study	N	0	244	19	7·79%	[32]
Guinea-Bissau	1979	1979	Urban	Outbreak investigation	Y	1	78	14	17·95%	[33]
Guinea-Bissau	1979	1979	Urban	Outbreak investigation	Y	0	20	1	5·00%	[33]
Guinea-Bissau	1979	1979	Both	Analysis of routine surveillance	N	1	356	74	20·79%	[34]
Guinea-Bissau	1979	1979	Both	Analysis of routine surveillance	N	0	103	3	2·91%	[34]
Guinea-Bissau	1979-1982	1981	Rural	Cohort study	N	1	101	34	23·66%	[35]
Guinea-Bissau	1979-1982	1981	Rural	Cohort study	N	0	61	4	6·56%	[35]
Guinea-Bissau	1980-1982	1981	Urban	Analysis of routine surveillance	Y	1	104	14	13·46%	[36]
Guinea-Bissau	1980-1982	1981	Urban	Analysis of routine surveillance	Y	0	34	3	8·82%	[36]
Guinea-Bissau	1980-1982	1981	Urban	Cohort study	N	NA	161	23	14·29%	[37]
Guinea-Bissau	1980-1984	1982	Both	Analysis of routine surveillance	N	1	367	42	11·44%	[34]
Guinea-Bissau	1980-1984	1982	Both	Analysis of routine surveillance	N	0	118	6	5·08%	[34]
Guinea-Bissau	1982-1984	1983	Urban	Analysis of routine surveillance	N	1	114	9	7·89%	[38]
Guinea-Bissau	1985-1987	1986	Urban	Analysis of routine surveillance	N	1	112	11	9·82%	[38]
Guinea-Bissau	2003-2004	2003	Urban	Other	Y	1	77	7	9·09%	[39]
India	1974	1974	Rural	Cohort study	Y	NA	112	4	3·57%	[8,40]
India	1974	1974	Rural	Cohort study	Y	NA	25	0	0·00%	[8,40]
India	1976-1978	1977	Rural	Cohort study	N	NA	862	2	0·23%	[41,42]
India	1977	1977	Rural	Outbreak investigation	Y	1	56	9	16·07%	[43]
India	1977	1977	Rural	Outbreak investigation	Y	0	9	0	0·00%	[43]
India	1979	1979	Rural	Outbreak investigation	Y	1	78	8	10·26%	[44]
India	1974-1986	1980	Rural	Cohort study	N	1	291	8	2·75%	[45]

Country	Year(s) of study	Midpoint year	Setting	Type of study	Outbreak setting (Y/N)	Under five indicator*	Cases	Deaths	Case fatality ratio	Ref.
India	1974-1986	1980	Rural	Cohort study	N	0	120	1	0·83%	[45]
India	1980	1980	Rural	Analysis of routine surveillance	N	NA	266	9	3·38%	[46,47]
India	1980	1980	Rural	Other	Y	NA	55	Not listed	12·73%	[46]
India	1980	1980	Urban	Cohort study	N	NA	731	10	1·37%	[46,48]
India	1980-1981	1981	Rural	Cohort study	N	1	82	3	3·66%	[49]
India	1982	1982	Rural	Outbreak investigation	Y	NA	113	0	0·00%	[46,50]
India	1982	1982	Rural	Outbreak investigation	Y	1	88	4	4·55%	[46,51]
India	1983	1983	Rural	Cross-sectional study	N	NA	241	2	0·83%	[52]
India	1983	1983	Rural	Analysis of routine surveillance	N	1	132	0	0·00%	[53]
India	1984	1984	Rural	Outbreak investigation	Y	NA	515	14	2·72%	[54]
India	1984	1984	Rural	Analysis of routine surveillance	N	NA	430	7	1·63%	[46,55]
India	1984	1984	Rural	Outbreak investigation	Y	NA	133	19	14·29%	[46,56]
India	1985	1985	Rural	Other	Y	1	2,218	Not listed	3·11%	[46]
India	1985	1985	Rural	Other	Y	1	46	Not listed	23·92%	[46]
India	1985	1985	Urban	Cross-sectional study	N	NA	189	0	0·00%	[46,57]
India	1986	1986	Rural	Outbreak investigation	Y	1	292	47	16·10%	[58]
India	1986	1986	Rural	Outbreak investigation	Y	0	448	28	6·25%	[58]
India	1986	1986	Rural	Cross-sectional study	N	1	97	1	1·03%	[59]
India	1986	1986	Rural	Outbreak investigation	Y	NA	217	11	5·07%	[46,60]
India	1991	1991	Rural	Outbreak investigation	Y	1	44	15	34·09%	[61]
India	1991	1991	Rural	Outbreak investigation	Y	0	4	0	0·00%	[61]
India	1991	1991	Rural	Outbreak investigation	Y	1	113	19	16·81%	[61]
India	1991	1991	Rural	Outbreak investigation	Y	0	15	1	6·67%	[61]
India	1992	1992	Rural	Other	Y	NA	93	Not listed	8·60%	[46]
India	1992	1992	Rural	Outbreak investigation	Y	NA	14,522	600	4·13%	[62]
India	1993	1993	Rural	Outbreak investigation	Y	NA	6,392	152	2·38%	[62]
India	1994	1994	Rural	Outbreak investigation	Y	NA	10,561	258	2·44%	[62]

Country	Year(s) of study	Midpoint year	Setting	Type of study	Outbreak setting (Y/N)	Under five indicator*	Cases	Deaths	Case fatality ratio	Ref.
India	1995	1995	Rural	Outbreak investigation	Y	NA	1,931	72	3·73%	[62]
India	1996	1996	Rural	Outbreak investigation	Y	1	1,160	70	6·03%	[62]
India	1996	1996	Rural	Outbreak investigation	Y	0	819	29	3·54%	[62]
India	1999	1999	Urban	Cross-sectional study	N	1	290	0	0·00%	[63]
India	1999	1999	Rural	Outbreak investigation	Y	NA	70	2	2·86%	[41,64]
India	1999	1999	Both	Outbreak investigation	Y	NA	283	0	0·00%	[65]
India	2003	2003	Urban	Outbreak investigation	Y	NA	12	2	16·67%	[66]
India	2003	2003	Urban	Outbreak investigation	Y	NA	58	0	0·00%	[67]
India	2004	2004	Rural	Outbreak investigation	Y	NA	1,204	14	1·16%	[68]
India	2004	2004	Rural	Outbreak investigation	Y	NA	69	0	0·00%	[41,69]
India	2004-2006	2005	Both	Outbreak investigation	Y	NA	432	6	1·39%	[70]
India	2006	2006	Rural	Outbreak investigation	Y	NA	59	0	0·00%	[41,64]
India	2009-2011	2010	Both	Analysis of routine surveillance	Y	NA	772	2	0·26%	[71]
India	2011-2012	2011	Both	Outbreak investigation	Y	1	1,636	20	1·22%	[72]
India	2011-2012	2011	Both	Outbreak investigation	Y	0	2,034	8	0·39%	[72]
Iran	1990	1990	Both	Outbreak investigation	Y	NA	745	4	0·54%	[73]
Kenya	1985	1985	Rural	Outbreak investigation	Y	1	98	12	12·24%	[74]
Kenya	1985	1985	Rural	Outbreak investigation	Y	0	41	1	2·44%	[74]
Kenya	1987	1987	Rural	Outbreak investigation	Y	1	143	18	12·59%	[75]
Kenya	1987	1987	Rural	Outbreak investigation	Y	0	67	2	2·99%	[75]
Malawi	1996-1998	1997	Both	Analysis of routine surveillance	N	1	237	8	3·38%	[76]
Malawi	1996-1998	1997	Both	Analysis of routine surveillance	N	0	305	5	1·64%	[76]
Malawi	2010	2010	Both	Outbreak investigation	Y	1	54,138	139	0·26%	[77]
Malawi	2010	2010	Both	Outbreak investigation	Y	0	53,620	83	0·15%	[77]
Marshall Islands	1977-1978	1977	Rural	Outbreak investigation	Y	NA	340	2	0·59%	[8,78]
Marshall Islands	2003	2003	Both	Outbreak investigation	Y	1	334	1	0·30%	[79]
Marshall Islands	2003	2003	Both	Outbreak investigation	Y	0	487	2	0·41%	[79]
Mexico	1988	1988	Rural	Outbreak investigation	Y	1	70	7	10·00%	[80]

Country	Year(s) of study	Midpoint year	Setting	Type of study	Outbreak setting (Y/N)	Under five indicator*	Cases	Deaths	Case fatality ratio	Ref.
Mexico	1988	1988	Rural	Outbreak investigation	Y	0	130	2	1·54%	[80]
Mozambique	1993	1993	Urban	Analysis of routine surveillance	N	NA	2,363	33	1·40%	[81]
Mozambique	1998	1998	Urban	Analysis of routine surveillance	N	NA	2,720	4	0·15%	[81]
Mozambique	2001-2004	2003	Rural	Analysis of routine surveillance	Y	1	106	7	6·60%	[82]
Myanmar	1983	1983	Rural	Other	N	1	91	11	12·09%	[83]
Myanmar	1983	1983	Rural	Other	N	0	75	3	4·00%	[83]
Nepal	2004	2004	Both	Cross-sectional study	Y	1	1,941	52	2·68%	[84]
Nepal	2004	2004	Both	Cross-sectional study	Y	0	2,705	12	0·44%	[84]
Nepal	2010	2010	Rural	Outbreak investigation	Y	NA	36	1	2·78%	[85]
Niger	1991	1991	Rural	Outbreak investigation	Y	1	418	76	18·18%	[86]
Niger	1991	1991	Urban	Outbreak investigation	Y	1	242	16	6·61%	[87]
Niger	2003	2003	Urban	Outbreak investigation	Y	1	625	29	4·64%	[22]
Niger	2003	2003	Rural	Outbreak investigation	Y	1	641	77	12·01%	[88]
Niger	2003	2003	Rural	Outbreak investigation	Y	0	304	15	4·93%	[88]
Nigeria	1992	1992	Urban	Outbreak investigation	Y	1	481	16	3·33%	[89]
Nigeria	2004	2004	Rural	Outbreak investigation	Y	1	630	68	10·79%	[22]
Nigeria	2007-2012	2010	Rural	Analysis of routine surveillance	N	NA	1,631	2	0·12%	[90]
Nigeria	2008	2008	Rural	Outbreak investigation	Y	1	16	0	0·00%	[91]
Nigeria	2008	2008	Rural	Outbreak investigation	Y	0	2	0	0·00%	[91]
Pakistan	1990	1990	Rural	Outbreak investigation	Y	1	47	3	6·38%	[92]
Pakistan	1990	1990	Rural	Outbreak investigation	Y	0	57	0	0·00%	[92]
Pakistan	2014	2014	Rural	Outbreak investigation	Y	1	48	4	8·33%	[93]
Pakistan	2014	2014	Rural	Outbreak investigation	Y	0	7	0	0·00%	[93]
Peru	1993	1993	Rural	Outbreak investigation	Y	1	39	4	10·26%	[94]
Peru	1993	1993	Rural	Outbreak investigation	Y	0	109	1	0·92%	[94]
Philippines	1983	1983	Rural	Outbreak investigation	Y	NA	126	8	6·35%	[95]
Senegal	1977	1977	Rural	Outbreak investigation	Y	1	160	43	26·88%	[8,96]
Senegal	1977	1977	Rural	Outbreak investigation	Y	0	300	10	3·33%	[8,96]

Country	Year(s) of study	Midpoint year	Setting	Type of study	Outbreak setting (Y/N)	Under five indicator*	Cases	Deaths	Case fatality ratio	Ref.
Senegal	1983-1986	1985	Rural	Analysis of routine surveillance	N	1	966	93	9·63%	[97]
Senegal	1983-1986	1985	Rural	Analysis of routine surveillance	N	0	534	5	0·94%	[97]
Senegal	1985	1985	Rural	Outbreak investigation	Y	1	44	9	20·45%	[98]
Senegal	1985	1985	Rural	Outbreak investigation	Y	0	22	0	0·00%	[98]
Senegal	1987-1990	1989	Rural	Analysis of routine surveillance	N	1	193	6	3·11%	[99]
Senegal	1987-1990	1989	Rural	Analysis of routine surveillance	N	0	437	4	0·92%	[99]
Senegal	1991-1994	1993	Rural	Analysis of routine surveillance	N	1	201	5	2·49%	[100]
Senegal	1991-1994	1993	Rural	Analysis of routine surveillance	N	0	370	3	0·81%	[100]
Senegal	1994	1994	Rural	Outbreak investigation	Y	NA	209	0	0·00%	[101]
Somalia	1978	1978	Rural	Outbreak investigation	Y	NA	910	9	0·99%	[8,102]
South Africa	1980-1998	1989	Rural	Analysis of routine surveillance	N	NA	10,371	101	0·97%	[103]
South Africa	1980-1998	1989	Rural	Analysis of routine surveillance	N	NA	16,406	260	1·58%	[103]
South Africa	2004	2004	Both	Other	Y	NA	109	7	6·42%	[104]
Sri Lanka	1982	1982	Both	Analysis of routine surveillance	N	1	1,630	19	1·17%	[105]
Sri Lanka	1999	1999	Both	Outbreak investigation	Y	1	605	2	0·33%	[106]
Sri Lanka	1999	1999	Both	Outbreak investigation	Y	0	3,913	3	0·08%	[106]
Sudan	1997-1999	1998	Urban	Cohort study	N	NA	95	9	9·47%	[107]
Sudan	2003	2003	Rural	Outbreak investigation	Y	NA	621	8	1·29%	[108]
Thailand	1984	1984	Rural	Outbreak investigation	Y	1	24	8	33·33%	[109]
Thailand	1984	1984	Rural	Outbreak investigation	Y	0	23	3	13·04%	[109]
Zambia	1980-1981	1980	Urban	Outbreak investigation	Y	1	316	5	1·58%	[8,110]
Zimbabwe	1980-1989	1985	Urban	Cross-sectional study	N	1	350	27	7·71%	[111]
Zimbabwe	1980-1989	1985	Urban	Cross-sectional study	N	0	287	1	0·35%	[111]

Note: CFRs from the Aaby, et al.,[8] Sudfeld, et al.,[41] and Singh, et al.[46] reviews include original source references, if the original source was obtained but did not appear in the literature review search results. CFRs in the original source material were prioritized over the data in the published reviews, where applicable.
*Under 5 indicator is listed as 1 if the CFR is specific to children under 5, 0 if the CFR is specific to individuals ages 5 and older, and NA if the CFR was not disaggregated by age.

Appendix F. Hospital-based studies* included in the measles case fatality ratio (CFR) analysis

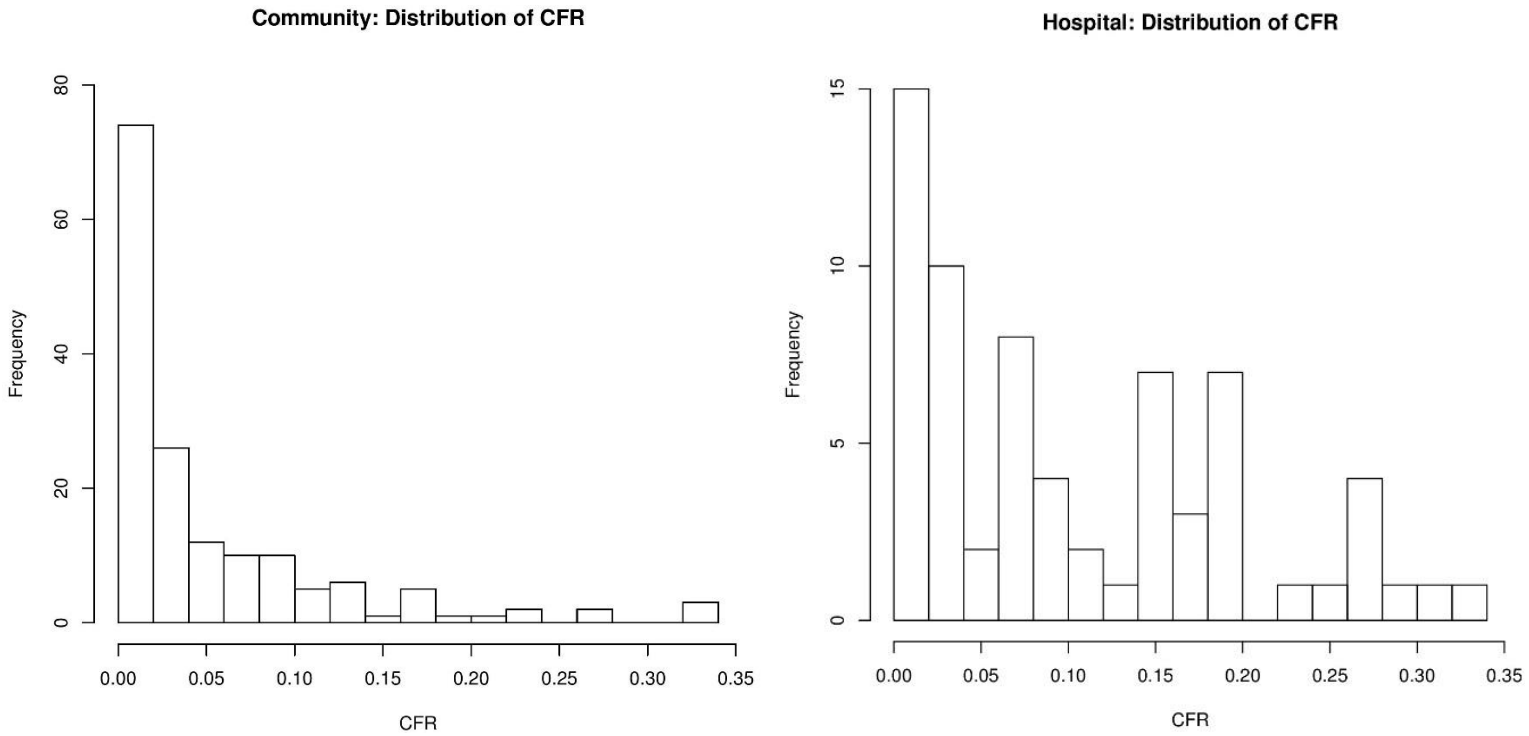
Country	Year(s) of study	Midpoint year	Setting	Outbreak setting (Y/N)	Under 5 indicator**	Cases	Deaths	Case fatality ratio	Ref.
Afghanistan	1978-1979	1978	Both	N	1	367	13	3·19%	[112]
Afghanistan	1978-1979	1978	Both	N	0	40	0	0·00%	[112]
Afghanistan	1980-1982	1981	Both	N	1	715	82	11·47%	[113]
Afghanistan	1980-1982	1981	Both	N	0	69	3	4·35%	[113]
Afghanistan	1983-1985	1984	Both	N	NA	717	104	14·50%	[114]
Burkina Faso	1986-1987	1986	Both	Y	1	693	202	29·15%	[115]
China	2000-2009	2005	Urban	N	NA	1,328	4	0·30%	[116]
Congo, Democratic Republic of the	1986-1987	1986	Rural	Y	NA	175	18	10·29%	[117]
Egypt	1992-1996	1994	Both	N	1	1,201	13	1·08%	[118]
Ghana	1973	1973	Both	N	NA	439	75	17·08%	[119]
Ghana	1974	1974	Both	N	NA	357	52	14·57%	[119]
Ghana	1975	1975	Both	N	NA	602	115	19·10%	[119]
Ghana	1976	1976	Both	N	NA	469	70	14·93%	[119]
Ghana	1977	1977	Both	N	NA	545	94	17·25%	[119]
Ghana	1973	1978	Both	N	1	4,191	725	17·30%	[119]
Ghana	1978	1978	Both	N	NA	375	72	19·20%	[119]
Ghana	1979	1979	Both	N	NA	390	76	19·49%	[119]
Ghana	1980	1980	Both	N	NA	325	50	15·38%	[119]
Ghana	1981	1981	Both	N	NA	336	49	14·58%	[119]
Ghana	1982	1982	Both	N	NA	479	75	15·66%	[119]
Ghana	1996-2000	1998	Both	N	NA	275	14	5·09%	[120]
Guinea-Bissau	2003	2003	Urban	Y	1	157	14	8·92%	[121]
Indonesia	1973-1977	1975	Both	N	1	155	44	28·39%	[122]
Indonesia	1973-1977	1975	Both	N	0	21	2	9·52%	[122]
Indonesia	1982	1982	Both	N	NA	107	29	27·10%	[123]
Indonesia	1983	1983	Both	N	NA	48	13	27·08%	[123]
Indonesia	1984	1984	Both	N	NA	74	15	20·27%	[123]
Indonesia	1985	1985	Both	N	NA	41	11	26·83%	[123]

Country	Year(s) of study	Midpoint year	Setting	Outbreak setting (Y/N)	Under 5 indicator**	Cases	Deaths	Case fatality ratio	Ref.
Indonesia	1986	1986	Both	N	NA	40	3	7·50%	[123]
Kenya	1982-1985	1984	Urban	N	1	7,063	126	1·78%	[124]
Kenya	1982-1985	1984	Urban	N	0	384	4	1·04%	[124]
Kenya	1996-2000	1998	Urban	Y	NA	1,200	Not listed	5·63%	[125]
Malaysia	1990	1990	Both	N	NA	143	2	1·40%	[126]
Mauritania	2011	2011	Both	N	NA	36	3	8·33%	[127]
Mexico	1976-1989	1983	Both	N	1	97	15	15·46%	[128]
Mozambique	2001-2004	2003	Rural	Y	NA	246	8	3·25%	[82]
Myanmar	1989	1989	Both	N	1	107	21	19·63%	[129]
Myanmar	1989	1989	Both	N	0	61	5	8·20%	[129]
Nigeria	1978-1986	1982	Both	N	NA	1,078	Not listed	32·60%	[130]
Nigeria	1982-1984	1983	Urban	N	1	598	71	11·87%	[131]
Nigeria	1983-1986	1985	Both	N	1	267	70	26·22%	[132]
Nigeria	1983-1986	1985	Both	N	0	2	0	0·00%	[132]
Nigeria	1984-1987	1986	Urban	N	1	424	80	18·87%	[133]
Nigeria	1984-1987	1986	Urban	N	0	12	0	0·00%	[133]
Nigeria	1992-1996	1994	Urban	N	1	31	0	0·00%	[134]
Nigeria	1992-1996	1994	Urban	N	0	5	1	20·00%	[134]
Nigeria	1994-2004	1999	Urban	N	1	56	4	7·14%	[135]
Nigeria	2000-2004	2002	Both	N	NA	666	56	8·41%	[136]
Pakistan	2003-2004	2003	Urban	N	1	42	4	9·52%	[137]
Pakistan	2003-2005	2004	Rural	N	1	85	6	5·15%	[138]
Pakistan	2003-2005	2004	Rural	N	0	51	1	5·15%	[138]
Papua New Guinea	1999-2000	1999	Both	Y	NA	238	10	4·20%	[139]
Papua New Guinea	2001	2001	Urban	Y	1	417	17	4·08%	[140]
Papua New Guinea	2001	2001	Urban	Y	0	65	2	3·08%	[140]
Philippines	1993-1996	1995	Urban	N	NA	180	8	4·44%	[141]
South Africa	1992-1996	1994	Urban	N	NA	1,647	11	0·67%	[103]
South Africa	1992-1996	1994	Urban	N	NA	736	23	3·13%	[103]

Country	Year(s) of study	Midpoint year	Setting	Outbreak setting (Y/N)	Under 5 indicator**	Cases	Deaths	Case fatality ratio	Ref.
South Africa	1997-1999	1998	Urban	N	NA	60	0	0·00%	[103]
South Africa	1997-1999	1998	Urban	N	NA	29	0	0·00%	[103]
South Africa	2009	2009	Urban	Y	1	552	18	3·26%	[142]
South Africa	2010	2010	Urban	N	1	58	18	31·03%	[143]
South Sudan	1985	1985	Urban	N	1	208	48	23·08%	[144]
Tanzania	1981-1983	1982	Both	Y	1	913	72	7·89%	[145]
Zambia	1992-1993	1992	Urban	N	1	917	123	13·41%	[146]
Zambia	1992-1993	1992	Urban	N	0	149	11	7·38%	[146]
Zimbabwe	1987-1989	1988	Both	N	1	Not listed	Not listed	3·30%	[147]
Zimbabwe	1987-1989	1988	Both	N	0	Not listed	Not listed	1·50%	[147]
Zimbabwe	1988	1988	Urban	Y	NA	1,399	20	1·43%	[148]

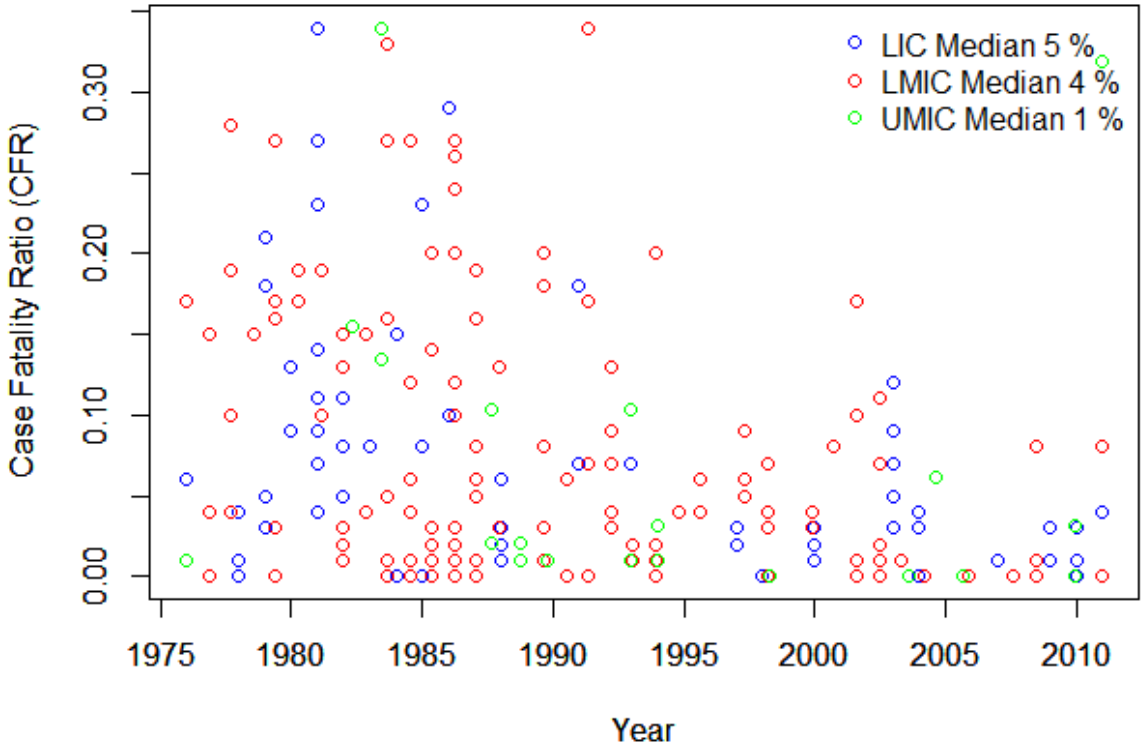
*All studies were cross-sectional studies of hospital admissions.
**Under 5 indicator is listed as 1 if the CFR is specific to children under 5, 0 if the CFR is specific to individuals ages 5 and older, and NA if the CFR was not disaggregated by age.

Figure G. Histogram of overall measles case fatality ratios (CFRs), extracted from the 1980-2016 review of the literature.



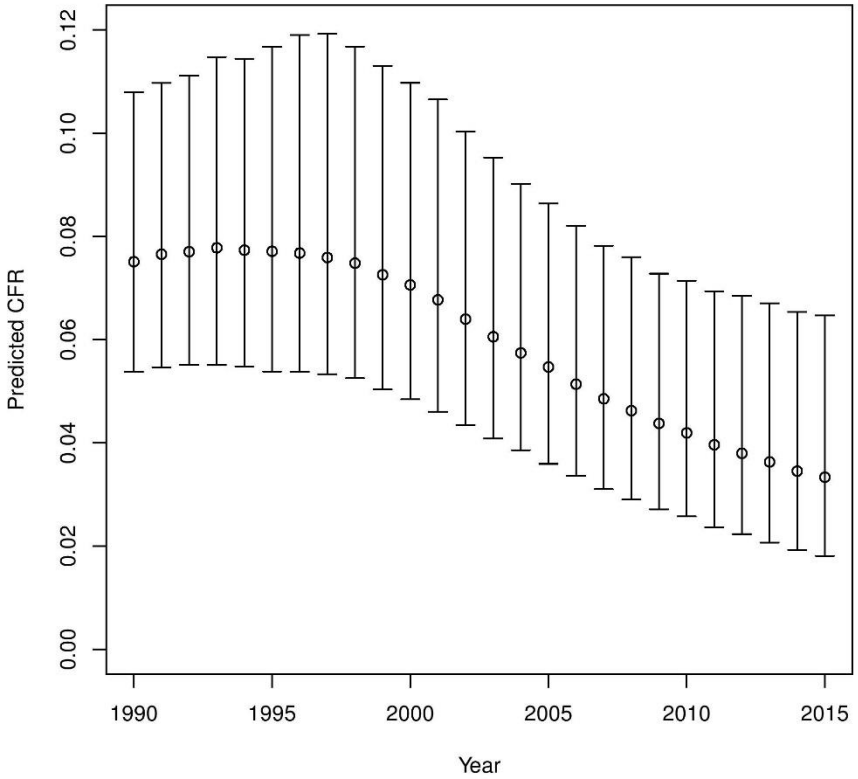
Community-based studies: 158 observations. Hospital-based studies: 68 observations.

Figure H. Measles case fatality ratio (CFR) by country group income level and year of study, extracted from the 1980-2016 review of the literature.



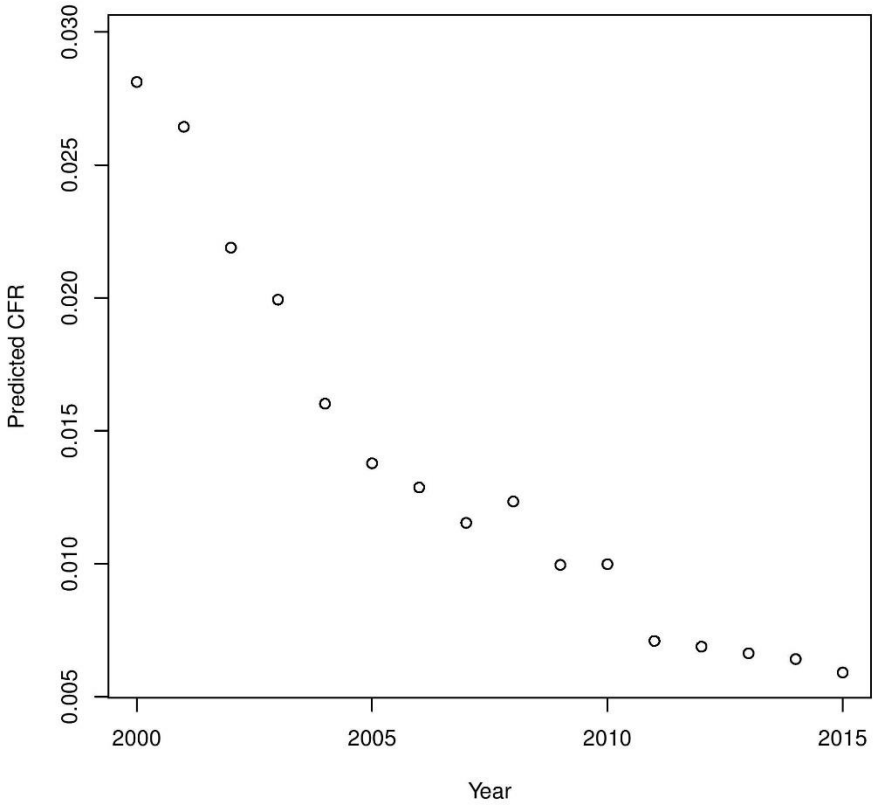
Note: LIC=Low-income country; LMIC=Lower middle-income country; UMIC=Upper middle-income country.
LIC: 65 observations in blue. LMIC: 137 observations in red. UMIC: 24 observations in green.

Figure I. Mean predicted* measles case fatality ratios (CFRs) in each year when the CFR estimate from each study from the literature review is unweighted in the log-linear model estimation.



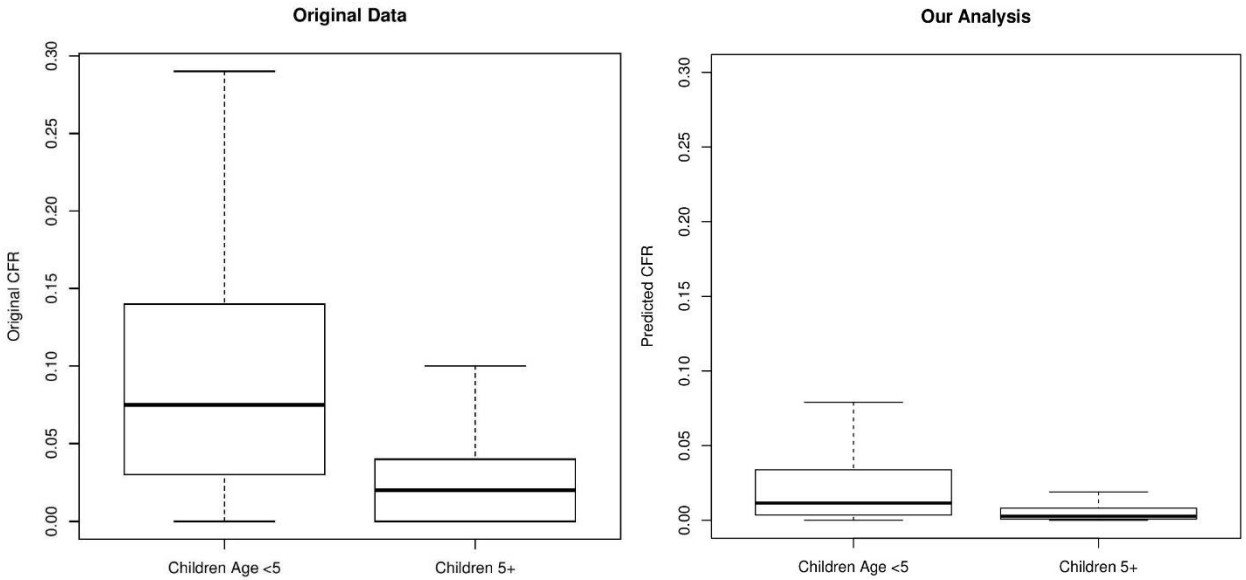
Note: *Predicted CFRs (dots) are averaged arithmetically without weighting across all 136 low- and middle-income countries for all ages in each year in order to provide the mean predicted CFR in that year.

Figure J. Mean predicted* measles case fatality ratios (CFRs) in each year: population-averaged over 136 low- and middle-income countries, all ages.



Note: *Predicted CFRs (dots) are a weighted average according to total country-level population across all 136 low- and middle-income countries for all ages in each year in order to provide the mean predicted CFR in that year.

Figure K. Boxplot comparing original* to predicted measles case fatality ratios (CFRs) (below or above age 5)**



*Original data from our 1980-2016 literature review, including 43 countries.
**Predicted estimates for all 136 low- and middle-income countries over 1990-2015.

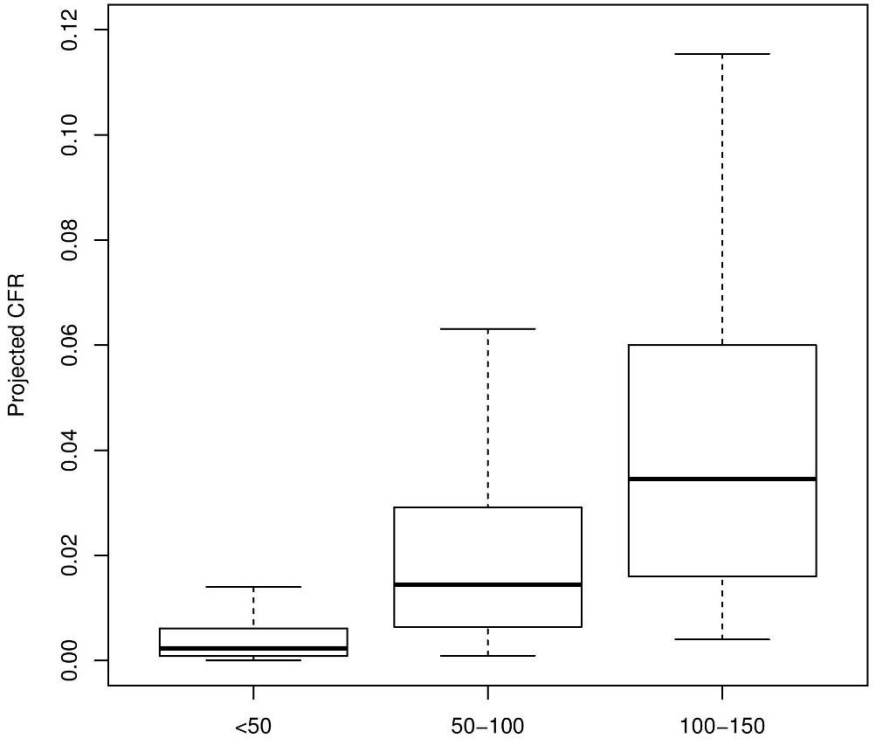
Table L. Information loss between 2016–2030 projection and 1990–2015 prediction models

	AIC
Prediction model	-337
Projection model	-323

AIC: Akaike information criterion.

Note: Prediction model is the log-linear model selected for 1990-2015 covariates (Appendix D); projection model is the same log-linear model for the same covariates in 2016-2030 but without the “attack rate” covariate.

Figure M. Boxplot of projected measles case fatality ratios (CFRs) from 2016-2030 by under-5 mortality rate category for 136 low- and middle-income countries, all ages.



Note: Under-5 mortality rate defined as the estimated number of deaths before age 5 per 1,000 live births.

Table N. Comparison to the findings of Wolfson and colleagues' review of measles case fatality ratios

	Wolfson and colleagues[1] review 1980–2008	**Our review 1980–2016**		**Our analysis 1990–2015**	
	Community-Based	Community-Based	Hospital-Based	Community-Based	Hospital-Based
Mean	7·4% (Range: 0·0–40·2%)	5·4% (IQR: 1·0–7·8%)	10·8% (IQR: 3·0–17·0%)	1·5% (CI: 0·5–3·1%)	2·9% (CI: 0·9–6·0%)
Median	3·9%	3·0%	8·0%	1·5%	2·9%

IQR: Interquartile range; CI: 95% confidence interval.

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