Received: 1 June 2020 | Revised: 22 November 2021 | Accepted: 3 January 2022

DOI: 10.1002/hpm.3423

RESEARCH ARTICLE

WILEY

The evolution of infant mortality and neighbourhood inequalities in four world cities: 1988–2016

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Abstract

Objectives: To determine the level of neighbourhood inequalities in infant mortality (IM) rates in the urban core of four world cities and to examine the association between neighbourhood-level income and IM. We compare our findings with those published in 2004 to better understand how these city health systems have evolved.

Methods: We compare IM rates among and within the four cities using data from four periods: 1988–1992; 1993–1997; 2003–2008 and 2012–2016. Using a maximum-likelihood negative binomial regression model that controls for births, we predict the relationship between neighbourhood-level income and IM.

Results: IM rates have declined in all four cities. Neighbourhood-level income is statistically significant for New York and, for the two most recent periods, in Paris. In contrast, there is no significant relationship between neighbourhood income and IM in London or Tokyo.

Conclusions: Despite programmes to reduce IM inequalities at national and local levels, these persist in New York. Until the early part of this century, none of the other cities experienced a relationship between neighbourhood income and IM, but growing income inequalities within Paris have changed this situation.

Policy implications: Policy-makers in these cities should focus on better understanding the social and economic factors associated with neighbourhood inequalities in IM.

KEYWORDS
income, infant mortality, neighbourhood inequalities, urban small area analysis

Highlights

- Manhattan has a strong negative relationship linking neighbourhood income and infant mortality (IM).
- Paris, since 2003, has a negative relationship between neighbourhood income and IM.
- Inequalities in IM rates in cities are influenced by national health and social policies.
- Reducing neighbourhood inequalities requires targeted public health approaches.

1 | INTRODUCTION/BACKGROUND

Infant mortality (IM), a key indicator of a population's overall health, has continued its decline in the United States and most of the world over the past 30 years. IM rate is strictly speaking not a rate (i.e., the number of deaths divided by the number of population at risk during a certain period of time) but a probability of death derived from a life table and expressed as rate per 1000 live births.[1] The average nationwide rate in the United States is consistently higher and has been slower to improve than in other wealthy nations of the Organization for Economic Cooperation and Development (OECD). A recent study comparing IM rates in the United States, Austria, Belgium, Finland and the United Kingdom concluded that while data reporting differences may explain up to 30% of the US–European gap, socio-economic conditions among disadvantaged groups in the United States account for most of the excess IM.[2]

In this article, we extend such comparative analyses of national health statistics by building on and updating earlier work comparing IM in four world cities over the 1988–1997 period: New York, London, Paris and Tokyo.[3] As we have argued in previous research, these cities have more in common than the institutional differences that distinguish their respective nations.[4] Nonetheless, since their health systems reflect different national health and social policies, these cities may be viewed as a natural experiment for understanding the consequences of national policy at the local level. Moreover, they share a long history of cross-city learning and a greater willingness to innovate and test ideas from abroad than we see at the national level.

In contrast to Tokyo, Paris and London, our previous analysis over the 1988–1997 period found that in New York, there were far greater neighbourhood inequalities in IM rates in the cities' urban cores, as well as a statistically significant association between neighbourhood-level income and IM. Of course, such an association does not establish that the former causes the latter; deaths in the first year of life certainly reflect multiple social determinants of health beyond individual biologic and pregnancy behaviour variables.[5] The New York City Department of Hygiene and Mental Health, aware that high IM—low-income neighbourhoods are also characterised by inadequate provision of family planning, prenatal care and other healthcare services, introduced many new initiatives, over past decades, intended to improve maternal health and reduce IM. Local governments in Paris, Tokyo and London continue to operate nationally funded programmes to follow women during pregnancy and to identify those at high risk and offer them special services.

While we know that IM rates have decreased since the earlier study (1988–1997), our objective here is to evaluate progress in reducing neighbourhood inequalities over the 13-year period (2003–2016) since the earlier study. We replicate the earlier analysis of inequalities in IM among neighbourhoods[3] and investigate whether the statistically significant correlation between neighbourhood income and IM rate still exists in Manhattan in contrast to Paris, London and Tokyo.

2 | METHODS

2.1 | City definition

New York City (population 8.6 million), Greater London (8.8 million), Métropole du Grand Paris (7.1 million) and 23 wards of Tokyo Metropolis (8.8 million) have been used as laboratories to study urban health by the World Cities Project[3] and are among the most populous cities among OECD nations. These cities function as hubs in the global economy of transnational corporations, financial services and information exchange.[6,7] They can be defined, spatially, as enormous 'city-regions'.[8] They are 'urban agglomerations', defined by the United Nations as the population contained within the contours of a contiguous territory inhabited at urban density levels without regard to administrative boundaries.[9]

In this paper, as in other research growing out of the World Cities Project,[10–12] we choose to study their urban cores: Manhattan (1.6 million population), Inner London (3.5 million), Paris, *intra muros* (2.2 million) and Inner Tokyo (2.8 million). For simplicity, we refer to these units as Manhattan, London, Paris and Tokyo in the remainder of the paper. These urban cores of world cities share a number of convergent characteristics. Each has a higher population density than its surrounding region and includes a mix of rich, poor and ethnically diverse people living in close proximity. Their economies, based on services and information, serve as employment centres that attract large numbers of commuters from their suburbs. They are medical 'centres-of-excellence' with a disproportionate share of hospitals and specialist physicians. With the exception of Tokyo, they are destinations for large immigrant communities from around the world: the foreign-born population of Paris (2016), London (2011-last census) and Manhattan (2017) is, respectively, 20%, 37% and 29%. Within each urban core, there are neighbourhoods that range from some of the wealthiest to some of the poorest in their nations. Income inequalities within each urban core are important. Table 1 displays the ratio of median income in the highest income/lowest deprivation quartile neighbourhoods of these urban cores to the lowest income/highest deprivation quartile neighbourhoods during the 2015–2017 time period. The largest ratio is found in Manhattan, followed by Tokyo, Paris and London. This reflects a change from the late 1990s when Paris and Tokyo had lower levels of neighbourhood inequality than London. In both of these urban cores, neighbourhood level income/deprivation inequality has grown substantially.

TABLE 1 Comparison of income/deprivation in the highest and lowest income/deprivation neighbourhoods in London, Manhattan, Paris and Tokyo

City	Ratio of higher to lower income/deprivation quartiles 2015–2017 average
London (2015 and 2019)	1.57
Tokyo	2.63
Manhattan	2.98
Paris	2.09

Sources: London: gov.uk accessible at: www.gov.uk/government/statistics/english-indices-ofdeprivation-2015&-2019; Manhattan: American Community Survey accessed via Infoshare at: www.infoshare.org/main/public.aspx; Paris: Insee accessible at: https://www.insee.fr/fr/statistiques/5009236?sommaire=5009255; Tokyo: Tokyo Statistical Yearbook: https://www.toukei.metro.tokyo.lg.jp/tnenkan/tn-eindex.htm#2009

2.2 | Neighborhood Selection

Defining neighbourhoods can be arbitrary. We are aware of the concerns surrounding the Modifiable Area Unit Problem,[13] that summary values may be influenced by both the shape and scale of the aggregation unit, in assessing any association between deprivation and health. In choosing the smallest unit of analysis available, we rely on three criteria: existing designations or administrative boundaries, a reasonable number of units for each city and data availability. We obtained data on live births, infant deaths and an income-related measure for all units of analysis. For Manhattan, we used 12 Community Districts since data for the 10 sub-borough units previously analysed are no longer readily available: Lower East Side (103), Chelsea, Clinton (104), Midtown Business District (105), Murray Hill (106), Upper West Side (107), Upper East Side (108), Manhattanville (109), Central Harlem (110), East Harlem (111), Washington Heights (112); for London, we used 13 boroughs of Inner London: Hackney and the City of London are combined; Camden, Hammersmith and Fulham, Haringey, Islington, Kensington and Chelsea, Lambeth, Lewisham, Newham, Southwark, Tower Hamlets, Wandsworth and Westminster; for Paris, the 20 *arrondissements*; and for Tokyo, the 11 inner *ku* -wards (Chiyoda, Chuo, Minato, Shinjuku, Bunkyo, Taito, Sumida, Koto, Shibuya, Toshima and Arakawa).

2.3 | Selection of time periods

IM—deaths in the first year of life—is defined as the number of infant deaths, over a period, divided by the number of live births for that period. Neighbourhoods with relatively small numbers of births and deaths have less stable neighbourhood IM rates. Since some neighbourhoods in the four cities have a small number of annual live births, to increase the stability of the IM rates for these neighbourhoods, we study 5-year time periods: 1988–1992; 1993–1997; 2003–2008 and 2012–2016. We analyse the relationship between IM and an income-related measure. Data for births and infant deaths are as comparable as one can find in making international comparisons of IM rates.[14,15]

2.4 | Measures of income

Pretax median household income, by neighbourhood, is available for Manhattan and Paris. For Tokyo, median household income is recorded only for 2008–2013. But we can define a deprivation index for 2012–2016 based on the percentage of households receiving income assistance. Since household income data are not available in the United Kingdom, for London, following British custom, we use 'deprivation' indices in place of direct income measures. To facilitate comparisons, we used both income and deprivation indices to define an income-related indicator used as the explanatory variable (I) in the models. We let (I) = 0 for a neighbourhood if it is in the lowest income/most deprived quartile of neighbourhoods. This lowest quartile consists of three neighbourhoods in Manhattan, five in Paris, three in Tokyo and four in London. We feel confident that our combination of income and deprivation indicators selects the most disadvantaged quartile of neighbourhoods for all 4 cities (henceforth referred to as the lowest income quartile neighbourhoods). For all other neighbourhoods, we let (I) = 1.

2.5 | Statistical analysis

Variation in births is likely to influence variation in deaths or variation in IM rate. For example, if a neighbourhood has 1000 births and 10 deaths and another has 10,000 births and 100 deaths, they would both have IM rates of 10 per 1000 and would be indistinguishable in a model that does not control for births. Thus, we control for births. Because deaths is a non-negative count variable, to account for greater variation than in a true Poisson process, we use

instead a maximum-likelihood negative binomial regression model that constrains the predicted number of deaths to a nonnegative number. Number of deaths is the response, number of births is the exposure, and the income-related variable (I) is the explanatory variable. We report not the estimate of the underlying coefficient of (I) but the exponential of the estimate, that is, the estimated incident rate ratio (IRR). The IRR is the ratio of the value of the IM rate in the rest of the city to its value in the lowest income (or high-deprivation) neighbourhoods. Our null hypothesis in each city and period is that the value of the IRR for (I) is 1; there is no difference in IM rates between the lowest income (or highest deprivation) neighbourhoods and those in the rest of the city. Our alternative hypothesis is that the IRR rate is less than 1, that is, the low-income (or high deprivation) neighbourhoods have higher IM rates than those in the rest of the city.

3 | RESULTS

As noted earlier, there has been a decline in citywide IM rates in all four cities over the almost 3 decades of our study (Table 2). Over the 2003–2016 period, we find that Manhattan no longer has the highest IM rate. Instead, London has the highest rate, followed by Paris, Manhattan and Tokyo. In comparison to the first periods (1988–1997), we note the lower percent decrease in IM rate in Paris over the 2003–2016 period.

Beyond the clear decrease in IM rates for all four cities, a comparison of box plots, by time periods, indicates some narrowing in the persistent variance of IM rates among neighbourhoods (Figure 1). The two more recent distributions of neighbourhood IM rates across the cities indicate that, over the 2003–2008 period, in order of median neighbourhood rate (lowest median first), the cities are Tokyo, Paris, Manhattan and London. The median rate of IM in Manhattan was lower than London and Paris during the 2012–2017 period, but the lowest income quartile neighbourhoods of Manhattan continued to experience the highest rates of IM. While the variance in IM rates, among neighbourhoods, is highest for Manhattan over the entire 2003–2017 period, the decline in variance is far greater for London than for the other cities. This suggests that there is less inequality among London's neighbourhood IM rates than in Paris and Manhattan.

As in our earlier study, results of the maximum-likelihood negative binomial regression, controlling for births, indicate that with the exception of Tokyo in the 1993–1997 and 2012–2017 periods, in all other cities, higher income (or lower deprivation) neighbourhoods are associated with a lower IM rate; all of the IRRs are less than 1 (Table 3). With births fixed, shifting a neighbourhood out of the lower income (or higher deprivation quartile) lowers its number of deaths (IM rate). Across all time periods, the IRR for Manhattan was statistically significant. For London, it was significant only for the 1993–1997 periods. What has changed is that, for the two recent periods, the IRR is now statistically significant for Paris in contrast to London and Tokyo where we find no statistically significant difference. For the 2003–2008 period estimates, the IRRs indicate that the IM rates in the higher income neighbourhoods of Manhattan and Paris are, respectively, 50% and 79% of the rate in the lower income neighbourhoods. For the most recent period (2012–2017), these IM rates are, respectively, 42% and 77% of those in the lower income neighbourhoods,

TABLE 2 Citywide infant mortality rates

	London	Manhattan	Paris	Tokyo
1988–1992	8.75	10.63	7.50	4.42
1993–1997	7.13	7.42	5.65	4.52
Percent change (= $IM_{1993-1997}/IM_{1988-1992}$)	−18/.5	−30.2	−24.7	+2.2
2003–2008	5.33	4.26	3.79	2.61
2012–2016	3.65	3.35	3.43	1.81
Percent change recent periods (= $IM_{2012-2016}/IM_{2003-2008}$)	−31.5	−21.4	−9.5	−30.6

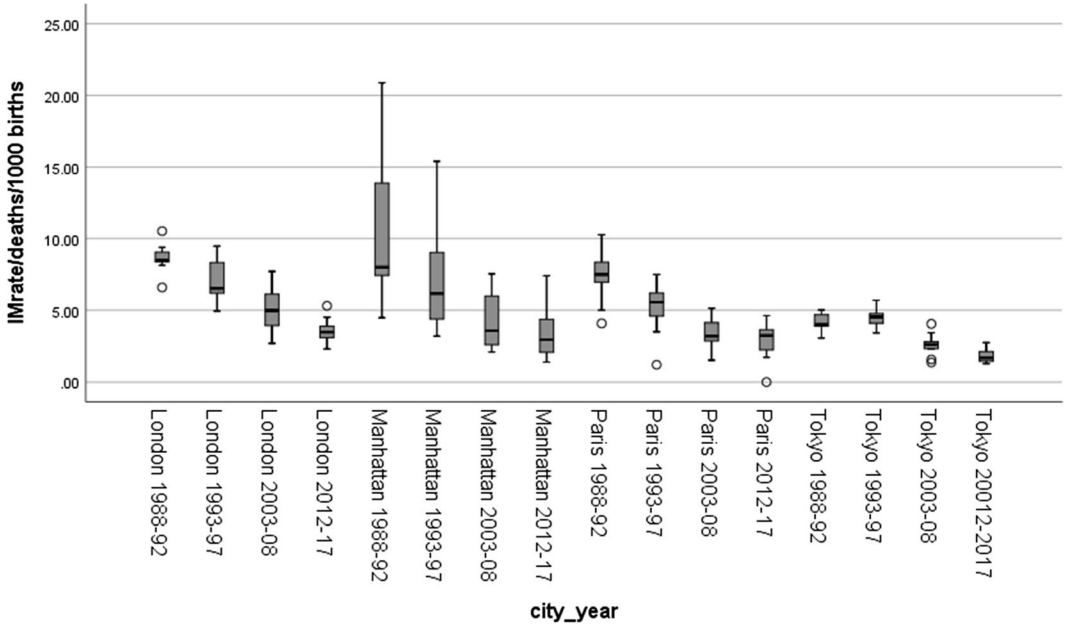

FIGURE 1 Box plots of neighbourhood infant mortality (IM) rate distributions: London, Manhattan, Paris and Tokyo (1988–2017). The common vertical axis is the neighbourhood IM rate. The thick middle horizontal line across the full rectangle is at the median neighbourhood rate on the vertical axis. The upper and lower horizontal lines of the full rectangle are at the 75th and 25th percentile rates, respectively. The remaining two horizontal lines, the whiskers, are at the largest and smallest rates of the distribution on the vertical axis, unless there are rates a substantial distance from the others. Such rates are outliers, and a box plot represents them as dots

TABLE 3 Results of maximum-likelihood negative binomial regression controlling for births

	2003–2008				2012–2016			
City	**IRR**	**SE**	***Z* stat**	***p* value**	**IRR**	**SE**	***Z* stat**	***p* value**
London	0.839	0.134	−1.09	0.274	0.858	0.106	−1.24	0.214
Manhattan	0.501	0.061	−5.67	<0.05	0.424	0.068	−5.34	<0.05
Paris	0.794	0.087	−2.10	0.04	0.769	0.069	−2.95	0.003
Tokyo	0.856	0.156	−0.85	0.394	1.057	0.191	0.31	0.759
	1988–1992				**1993–1997**			
City	**IRR**	**SE**	**Z stat**	**p value**	**IRR**	**SE**	**Z stat**	**p value**
London	0.941	0.046	−1.24	0.107	0.814	0.082	−2.03	0.021
Manhattan	0.441	0.101	−3.59	<0.05	0.391	0.082	−4.50	<0.05
Paris	0.999	0.58	−0.01	0.496	0.871	0.074	−1.52	0.65
Tokyo	0.922	0.98	−0.77	0.221	1.002	0.121	0.01	0.506

Note: The model controls for births and regresses deaths on an indicator variable for the lower quartile of income (or the upper quartile of deprivation).With births fixed, IRR is the ratio of the IM rate of those in the upper (lower) three quartiles of income (deprivation) to those in the lower (upper) quartile of income (deprivation). Estimations use a maximum-likelihood negative binomial regression. *p* values are for one-sided tests and are asymptotic.

Abbreviations: IRR, incident rate ratio; SE, standard error; *Z* Stat, *Z* statistic.

which suggests that when controlling for births, the gap between neighbourhood quartiles has widened slightly for both cities.

4 | DISCUSSION

Manhattan, London, Paris and Tokyo share world city status due to their concentration of high-level functions in government, business, media, the arts and health services; yet they are all noteworthy for their socio-economic and spatial inequalities. Poorer neighbourhoods are less likely to have satisfactory housing stock, suitable sources of fresh food and local health services, and more adverse environmental exposures (e.g., air pollution). There is evidence of the association of neighbourhood environment with preterm births (PTBs) as well as intrauterine growth retardation, independent of individual-level risk factors (maternal education, age, marital status, race and adequacy of prenatal care), but the causal mechanisms remain unclear.[16,17]

After controlling for births, we found citywide decreases in IM rates for all four cities. While we have noted the persistent gap in IM rates between low- and high-income neighbourhoods in the three other cities, there is an apparent 'Manhattanization' of Paris since both cities, in the recent two periods, exhibit the lowest statistically significant IRR coefficients ($p < 0.05$ level), revealing a strong association between IM rate and neighbourhood-level income. Although, in Paris, there was no statistically significant association between neighbourhood-level income and IM rate over the two earlier periods, over the recent two periods, the situation changed. The magnitude of the IM rate gap, however, remains much higher in Manhattan than in Paris. Moreover, the gap remains relatively stable in Paris across the two recent periods (IRR decreases from 0.79 to 0.77), whereas in Manhattan, the inequalities are staggering (IRR decreases from 0.50 to 0.42). In Manhattan, over the 2010–2014 period, women living in poorer neighbourhoods are known to be more likely to have PTBs and infant deaths compared to their counterparts in more well-to-do neighbourhoods.[18] Socio-economic inequality in Manhattan may contribute to higher IM, in the context of a heterogeneous population, greater racial and ethnic neighbourhood segregation, lack of universal health insurance (UHI) and the absence of paid maternity leave. Great Britain ensures healthcare coverage under its National Health Service; France and Japan provide healthcare coverage through UHI programmes and, despite growing neighbourhood-level income inequality within Tokyo, it has not experienced a growth in neighbourhood-level inequality in rates of IM. Perhaps the extent to which a country lacks a commitment to UHI, specifically for primary care coverage of pregnant women, may strengthen the association between IM and income.

With respect to intra-urban income and wealth inequalities, there are important differences among the cities. New York and London exhibit the largest socio-economic inequalities across neighbourhoods but since 2010–2011, income inequality in London has fallen and the gap in IM rates among neighbourhoods has narrowed in the 2012–2017 period.[19] Among metropolitan areas in the United States, New York City ranks among the top 10 in level of wage inequality reflecting recent findings that urban inequalities are greater among large cities '…that have benefited from strong demand for skill and agglomeration economies, with these factors leading to particularly rapid wage growth for high-skilled workers'.[16] Gentrification, the displacement of working class populations and the transformation of 'run-down' neighbourhoods into more well-to-do residential neighbourhoods have reshaped New York and London. Beyond income inequalities, such polarisation reflects the co-existence of low-skill immigrants with a substantial high-skill, high-wage labour force segment of the population.[20]

In contrast to London and New York, Paris has been known as a 'soft' global city because it provides more income support, maternal and infant services, child care and health services to the poor.[21] However, socio-spatial inequalities have increased massively in the Paris region (Ile-de-France).[22] In a report on the growth of inequality in Ile-de-France since the early 2000s, Mariette Sagot documents the concentration of income and wealth in some neighbourhoods and the entrenched poverty in others. The poorest areas have a concentration of under-qualified workers, often immigrants, with higher rates of unemployment or of 'precarious employment,' and a growing number of single-parent households all contributing to stigmatisation and deteriorating economic conditions.[23] Moreover, women with lower

socio-economic status are more isolated professionally and socially, which places them at a disadvantage with respect to accessing information and obtaining regular monitoring by physicians over the course of their pregnancy. Based on spatial analysis techniques, Padilla and colleagues attribute uneven geographic patterns in neonatal and IM in three French Metropolitan Areas, including Paris, largely to socio-economic and environmental inequalities.[24] Similarly, in their investigation of spatial clustering of PTBs in Paris, Deguen and colleagues find that after adjustment for socio-economic status and NO_2 concentrations, clustering is no longer statistically significant, or shifts geographically suggesting that these characteristics explain the spatial distribution of PTBs.[25]

Local governments in Tokyo, London and Paris operate nationally funded programmes to follow all mothers in the course of their pregnancies and after birth. Moreover, in Paris, there are even financial incentives from the central government—the *Protection Maternelle et Infantile*—for mothers to seek out these services. The New York City Department of Health and Mental Hygiene, well aware of the disparities reported here, introduced several initiatives over the last decade.[26] In spite of such efforts in all four cities, we are struck by the statistically significant association between neighbourhood-level income and IM rate in New York and Paris over the recent period. Of course, even after controlling for births, an association between neighbourhood-level income and IM rate, based on ecological data, does not establish that the former causes the latter; nor does it provide any causal pathway that might be amenable to intervention. Nonetheless, our regression results and broader comparative analysis raise at least three important questions for debates about the direction of policy to reduce IM in world cities.

First, what characteristics of high-IM mortality, low-income neighbourhoods, other than insufficient income, contribute to raising IM? Are such neighbourhoods characterised by inadequate provision of family planning, prenatal care, and other healthcare services leading to low levels of maternal and infant health? Or do these neighbourhoods include low-income individuals with less access to information and monitoring resulting not only from financial barriers to care but also to linguistic and cultural barriers and distrust of the health system? Second, do high-IM, low-income neighbourhoods reflect patterns of racial segregation and other forms of discrimination that might affect both the incomes and access to health care of minority women, especially in Manhattan and Paris? Third, why do inequalities among high- and low-IM Manhattan neighbourhoods remain so high despite the decreases in the overall citywide rates?

5 | CONCLUSIONS

Reducing disparities among neighbourhood IM rates will require intense targeting of high-IM rate neighbourhoods and disproportionate resources directed to them. Improving health, at the population level, requires both a public health and clinical medical approach. Strategies will be required to counter inequalities related to differential uptake of life-style or behavioural changes by disadvantaged populations and/or differences in intervention effectiveness in different groups. These strategies should include broadly: (1) improving women's health before pregnancy, (2) promoting quality and safety in prenatal care, (3) investing in disease prevention and health promotion, (4) improving coordination among health services, (5) strengthening surveillance of women's health and pregnancy outcomes and research, and (6) promoting public/private and community collaboration.

ACKNOWLEDGEMENT

None.

CONFLICT OF INTEREST

All authors report no conflicts of interest.

ETHICS STATEMENT

None.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are either publicly available or available from the corresponding author upon reasonable request.

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How to cite this article: Weisz D, Gusmano MK, Laborde C, Feron V, Rodwin VG. The evolution of infant mortality and neighbourhood inequalities in four world cities: 1988–2016. *Int J Health Plann Mgmt*. 2022; 1-10. https://doi.org/10.1002/hpm.3423