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Determinants of under-five mortality in informal settlements in Nairobi, Kenya from 2002 to 2018

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Abstract

Background Childhood mortality persists as a significant public health challenge in low and middle-income countries and is uneven within countries, with poor communities such as urban informal settlements bearing the highest burden. There is limited literature from urban informal settlements on the risk factors of mortality. We assessed under-five mortality and associated risk factors from the period 2002 to 2018 in Nairobi urban informal settlements.

Methods We used secondary data from the Nairobi Urban Health and Demographic Surveillance System (NUHDSS), a longitudinal surveillance platform that routinely collects individual and household-level data in two informal settlements (Viwandani and Korogocho) in Nairobi, Kenya. We used Kaplan-Meier curves to estimate overall survival and the Cox proportional hazard model with a frailty term to evaluate the impact of risk factors on survival time.

Results Overall under-five survival rate was 96.8% and this improved from 82.6% (2002-2006) to 95% (2007-2012) and 98.4% (2012-2018). There was a reduced risk of mortality among children who had BCG vaccination, those born to a married mother or a mother not engaging in any income-generating activity (both from 2007 to 2011), children from singleton pregnancy, children born in Viwandani slum and ethnicity of the child.

Conclusion Under-five mortality is still high in urban informal settlements. Targeted public health interventions such as vaccinations and interventions empowering women such as single mothers, those with multiple pregnancies, and more impoverished slums are needed to further reduce under-five mortality in urban informal settlements.

Keywords BCG vaccination, Informal settlements, Nairobi, Frailty model, Child mortality, Survival, NUHDSS

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Introduction

One of the major focus of international health and development goals is the reduction of mortality in children under-five years of age [1]. Under-five mortality rate is an important indicator of population health and is also a fundamental measurement of a country's level of socioeconomic and demographic development, and quality of life, especially of families [2, 3]. The Sustainable Development Goals created an absolute goal of ending preventable child deaths and reducing overall under-five mortality to less than 25 per 1,000 live births by 2030 [4, 5].

Globally, it has been estimated that 5 million children under the age of five years died in 2021, mostly from preventable causes [6]. Despite the sharp decline in global under-five deaths from 91 deaths per 1000 live births in 1990 to 38 per 1000 in 2021 [6], uneven progress has been achieved across and within countries [7]. Most low-income and middle-income countries (LMICs) did not achieve the Millennium Development Goal (MDG) 4 target of reducing under-five mortality by two-thirds between 1990 and 2015, which equates to a 4.4% annualised rate of decrease during this time [8, 9], and therefore there is great need to accelerate the pace of progress in order to achieve the SDG target on child survival.

In sub-Saharan Africa (SSA) specifically, the statistics on death in under-five years are startling and remain unacceptably high. In 2015, deaths in children under-five were 14 times more likely to occur in SSA than in high-income regions of the world [10]. Consequently, the region bears about half of the world's under-five mortality with around 3 million deaths occurring in 2015 [1]. Ahinkorah (2021)[11] estimated the prevalence of dealth in children under-five in SSA to be 4.10% with children born to single and obese women at higher risk.

Kenya did not achieve its MDG targets for child mortality [12]. In 2018 the national under-five mortality rate stood at 51.3%, while in 2021 the figure stood at 37.1 per 1000 live births, falling shot of the SDG target [4, 13, 14]. This is further amplified in the urban slums. A study by Corburn *et al* showed that slum dwellers in Nairobi experience poorer health than their affluent urban counterparts with an under-five mortality rate of 151 per 1000 live births in the slums and 62 per 1000 births in the more affluent suburbs [13].

Like many other health indicators, the burden of under-five mortality is heaviest among the poor and especially the informal settlements [7, 15, 16]. The urban poor are highly vulnerable and have poorer health outcomes including morbidity, mortality, and other health risks compared to urban populations [17]. The challenge of urban slums is particularly concerning in Kenya's capital Nairobi, where informal settlements, occupying less than 10% of the land area, are inhabited by nearly 60% of the city's population [18, 19].

Factors associated with under-five child death nationally have been less well investigated, although it is known that the majority of deaths occur at home and that antenatal care is of variable quality [20, 21]. Previous studies elsewhere have found a host of factors associated with child mortality in SSA, including poor access to healthcare [22], short birth intervals [23], poor health seeking behavior [22], low maternal education [24], maternal age [20], home birth [24], and multiple gestation pregnancies [25].

In the context of urban informal settlements, there is paucity of data on the drivers of under-five mortality. However, achieving the reduction of under-five mortality to set targets requires understanding and tracking the proximate and other determinants of this mortality [1, 26]. Thus, identifying and examining the factors driving child mortality is critical. We, therefore, investigated the trends and drivers of under-five mortality in two informal settlements in Nairobi, Kenya.

Materials and methods

Data source

We used secondary data spanning 17 years (2002-2018) on children under the age of five years from the Nairobi Urban Health and Demographic Surveillance System (NUHDSS). The NUHDSS is managed by The African Population and Health Research Center (APHRC) and is a longitudinal surveillance platform that routinely collected social, economic and demographic data on individuals and households in two informal settlements, Korogocho and Viwandani in Nairobi, Kenya. These densely populated areas face challenges such as poor housing, inadequate infrastructure, high levels of violence and insecurity, elevated unemployment rates, and unfavorable health indicators [27, 28]. Due to its closeness to a sizable waste dump, Korogocho has a relatively constant population with a higher percentage of children and long-term inhabitants. However, the area suffers from severe congestion, poverty, and environmental health issues. Viwandani, on the other hand, has a more peripatetic population, primarily made up of young adults looking for work in the adjacent industrial areas. Socioeconomic conditions there are marginally better, but the Ngong River's pollution poses serious environmental problems. The NUHDSS entails the systematic recording of vital demographic events, including births, deaths, and migrations, among residents in all households within the surveillance area.

Outcome variable

The primary outcome was the time until the death of children under-five years old. This was calculated by transforming the data from calendar time to duration, measured in months, starting from the initial recording of a child in the surveillance system to either the occurrence of their death or the conclusion of the observation period if they remained alive. In instances where children survived beyond five years, their survival time is considered censored data.

Explanatory variables

This study considers socio-demographic, child-level and maternal factors that could potentially be associated with child mortality. These are described as follows:

Slums: This variable has two levels, namely, Korogocho and Viwandani, the two slum areas of the study. *Period*: Over the data collection period spanning from 2002 to 2018, there could have been changes in population dynamics, data collection instruments, researchers, contextual factors, and potential stakeholder interventions, among others. To enable us to account for these, we categorized the data into three main periods. The first period is from 2002 to 2006, the second period from 2007 to 2011, and the third period from 2012 to 2018. *Sex of child*: The sex had two levels, *male* and *female*. *BCG vaccination*: This variable indicates the BCG (Bacille Calmette-Guerin) vaccination status and had three levels; *Yes*, if the child has received BCG vaccination, *No*, if the child has not received BCG vaccination, and *Don't know*. *Mother's marital status*: This was classified into two groups; *Currently married* and *currently not married*. *Mother's highest education*: This denotes the mother's highest level of formal education attained and was grouped into *primary*, *at least secondary education* and *don't know*. *Multiple births*: This indicates whether the birth of the child was single birth or multiple birth (twins, triplets, etc.). *Mother's engagement in income generation activity*. This variable indicates whether the mother was involved in any income generating activity, grouped as *yes* or *no*. *Pregnancy duration*: This is a continuous variable that indicates the duration of pregnancy leading to birth of the child. *Wealth status of head of household (HH)*: This is derived using a wealth index computed on various household assets and amenities, such as televisions, bicycles, vehicles, housing materials, access to drinking water, and sanitary facilities. Principal component analysis is used to obtain a score, which is then used to rank households and categorize them by wealth tertile (lowest, middle, and highest). The approach is similar to that employed in the Demographic and Health Surveys (DHS) conducted in various countries. *Ethnicity of HH*: This is the ethnicity of the head of households in the settlement. The levels considered are *Kamba*, *Kikuyu*, *Luhya*, *Luo* and *Other* ethnicity. *Age of HH*: A continuous variable that denotes the age of the head of household at the date of birth of the child. *Household size*: The household size at date of birth of child.

Statistical analyses

To examine the factors influencing the time-to-death of children under 5 years, we employed both descriptive and inferential analytical approaches. Descriptive statistics were computed for each risk factor based on the period of data collection, and the relationship between mortality status and each risk factor was explored. Counts and percentages were reported for categorical variables, while median, first quantile, and third quantile values were reported for continuous variables. Bivariate associations were assessed using Pearson's Chi-square test for relationships involving two categorical variables and linear model ANOVA for variables involving one continuous variable. Kaplan-Meier curves were utilized to visualize overall survival and survival by period. In terms of inferential analysis, the Cox proportional hazard model with a frailty term was employed to evaluate the impact of risk factors on survival time. The inclusion of frailty was necessary to consider the clustering of more than one birth per mother over the study period. Suppose T_{ij} is the survival time of the jth child of the ith mother. The shared gamma frailty model is specified as follows:

$$\begin{aligned} h_{ij}(t|\boldsymbol{X}) =& h_0(t)\omega_i \exp\left(\beta_1 X_{1ij} + \beta_2 X_{2ij} + \cdots + \beta_p X_{pij}\right) \\ =& h_0(t_i)\omega_i \exp\left(\boldsymbol{X\beta}\right) \end{aligned}$$

where $h(.)$ represent the hazard function, $h_0(.)$ represents the baseline hazard function, $\boldsymbol{\beta}$ is a $p \times 1$ vector of regression coefficients, and X_{ij} is covariate vector for the jth child of mother, i. The component, $\omega_i \sim \Gamma\left(\frac{1}{\theta}, \frac{1}{\theta}\right)$ is the frailty term with expectation, $E(\omega_i = 1)$ and variance, $\text{Var}\,(\omega_i) = \theta$. We test the proportional hazard assumptions for each predictor as well as a global test. Parameters of the model are estimated using the general penalized modeling framework implemented in the R **survival** package through the `frailty()` function. All data management, analyses and graphical displays were carried out using the R/RStudio statistical software.

To conduct an assessment of factors influencing child mortality we employed aforementioned Cox proportional hazard model with a frailty term. Initially, the model was applied individually for each analysis period to assess associated factors within defined time frames. Subsequently, the frailty model was fitted by pooling the data together, and adjusting the model with period. Before interpreting the results, a global test for Cox proportional hazard assumption was assessed.

Results

Descriptive analysis across study periods

In Table 1, we present descriptive statistics detailing the distribution of child-level, maternal-level, and household-level characteristics for each respective period.

It was observed that the proportion of male children consistently exceeded that of females throughout the different periods. The majority of children were reported to have received BCG vaccination, and this trend remained consistent across the periods.

Examining maternal characteristics, the proportion of married and unmarried mothers was approximately equal in the first period but married mothers were more in the subsequent period. About two-thirds of mothers

Table 1 Characteristics of the different factors by period

	P2002-2006	P2007-2011	P2012-2018	Total	*p*-value
Sex of child					0.036[a]
Female	1182 (47.5%)	4315 (49.1%)	7793 (47.4%)	13290 (47.9%)	
Male	1304 (52.5%)	4478 (50.9%)	8650 (52.6%)	14432 (52.1%)	
BCG vaccination					< 0.001[a]
No	199 (8.0%)	474 (5.4%)	559 (3.4%)	1232 (4.4%)	
Yes	2050 (82.5%)	7849 (89.3%)	14251 (86.7%)	24150 (87.1%)	
Dont know	237 (9.5%)	470 (5.3%)	1633 (9.9%)	2340 (8.4%)	
Mothers marital status					< 0.001[a]
Currently not married	1244 (50.0%)	2091 (23.8%)	4109 (25.0%)	7444 (26.9%)	
Currently married	1242 (50.0%)	6702 (76.2%)	12334 (75.0%)	20278 (73.1%)	
Mother's highest education					< 0.001[a]
N-Miss	7	117	394	518	
Primary	1661 (67.0%)	5557 (64.1%)	8732 (54.4%)	15950 (58.6%)	
At least secondary	616 (24.8%)	2337 (26.9%)	6119 (38.1%)	9072 (33.3%)	
Dont know	202 (8.1%)	782 (9.0%)	1198 (7.5%)	2182 (8.0%)	
Multiple births					0.280[a]
N-Miss	1	1	2	4	
Multiple	43 (1.7%)	120 (1.4%)	260 (1.6%)	423 (1.5%)	
Single	2442 (98.3%)	8672 (98.6%)	16181 (98.4%)	27295 (98.5%)	
Mom has income generation activity					< 0.001[a]
Yes	–	382 (4.3%)	6617 (40.2%)	6999 (25.2%)	
No	–	765 (8.7%)	5541 (33.7%)	6306 (22.7%)	
Dont know	–	7646 (87.0%)	4285 (26.1%)	14417 (52.0%)	
Slum area					< 0.001[a]
Korogocho	1126 (45.3%)	4096 (46.6%)	6902 (42.0%)	12124 (43.7%)	
Viwandani	1360 (54.7%)	4697 (53.4%)	9541 (58.0%)	15598 (56.3%)	
Sex of HH					< 0.001[a]
N-Miss	14	67	108	189	
Female	353 (14.3%)	1659 (19.0%)	3613 (22.1%)	5625 (20.4%)	
Male	2119 (85.7%)	7067 (81.0%)	12722 (77.9%)	21908 (79.6%)	
Wealth status of HH					< 0.001[a]
N-Miss	45	128	1295	1468	
Lowest	990 (40.6%)	2300 (26.5%)	4289 (28.3%)	7579 (28.9%)	
Middle	734 (30.1%)	2902 (33.5%)	5056 (33.4%)	8692 (33.1%)	
Highest	717 (29.4%)	3463 (40.0%)	5803 (38.3%)	9983 (38.0%)	
Ethnicity of HH					< 0.001[a]
Kamba	603 (24.3%)	1898 (21.6%)	3755 (22.8%)	6256 (22.6%)	
Kikuyu	503 (20.2%)	2415 (27.5%)	4302 (26.2%)	7220 (26.0%)	
Luhya	441 (17.7%)	1394 (15.9%)	2940 (17.9%)	4775 (17.2%)	
Luo	624 (25.1%)	1640 (18.7%)	2287 (13.9%)	4551 (16.4%)	
Others	315 (12.7%)	1446 (16.4%)	3159 (19.2%)	4920 (17.7%)	
Age of HH					< 0.001[b]
N-Miss	14	67	108	189	
Median (Q1, Q3)	29.00 (26.00, 34.00)	32.00 (28.00, 38.00)	33.00 (28.00, 39.00)	32.00 (28.00, 38.00)	
Household size					< 0.001[b]
Median (Q1, Q3)	4.00 (3.00, 5.00)	4.00 (3.00, 6.00)	4.00 (3.00, 6.00)	4.00 (3.00, 6.00)	

[a] Pearson's Chi-squared test, [b]Linear Model ANOVA

had a primary level of education but the proportion declined between periods 1 and 3. Only 4.3% and 40.2% of mothers were engaged in income-generating activities during the second and third analysis periods, respectively. Fewer mothers had multiple births for each period.

Regarding household-level factors, the summarized results revealed that the sample had a higher number of children from Viwandani compared to Korogocho throughout the different periods. The median age of household heads was 29, 32, and 33 years in the first, second, and third analysis periods, respectively, with most households being led by males over the periods. Wealth status of household heads improved over time. In the first period, the majority belonged to the Luo ethnic group (25.1%), followed by Kamba (24.3%), Kikuyu (20.2%), Luhya (17.7%), and others (12.7%). In the subsequent periods, the majority were Kikuyu (27.5% in period 2 and 26.2% in period 3), followed by Kamba (21.6% in period 2 and 22.8% in period 3). For household size, the median remained four (4) across all three analysis periods.

Bivariate association between survival status and risk factors

The next phase of descriptive analysis aimed to evaluate the bivariate association between survival status and various risk factors at a significance level of 0.05, as depicted in Table 2. Across the three periods, Sex of the child and mother's educational level did not exhibit a significant association with survival status. The indicators for multiple births, Sex of the head of the household, and household size were found to be associated with survival status only from 2002 to 2006. A notable association was observed between BCG vaccination and survival status throughout all three analysis periods, indicating a higher proportion of deaths among the unvaccinated compared to the vaccinated. Marital status, wealth status, ethnicity, and age of the household head were statistically significant in the first and second periods. From 2002 to 2006, a higher proportion of child deaths was recorded among currently married individuals (9.5% versus 7.0%). Conversely, from 2007 to 2011, the mortality rate was higher for currently unmarried mothers (3.0% versus 4.4%). Regarding wealth status, the highest mortality occurred among the higher wealth tertiles (7.9% and 10.5% in the middle and highest wealth tertile, respectively) in the first period. However, this trend reversed in the second period, with lower mortality rates in the middle and highest wealth tertiles (3.4% and 2.8%, respectively).

Association between child mortality and associated factors

Figures 1 and 2 shows the Kaplan-Meier survival curves over the entire period and by the different periods, respectively. From these graphs, we observed that overall survival rate was still quite high at year 5 (96.8% [96.5%, 97.0%]). In Fig. 2, we observed that child survival improved overtime; from 82.6% (2002-2006) to 95% (2007-2012) and 98.4% (2012-2018).

A global test for Cox proportional hazard assumption was assessed and found to be plausible (χ^2 =91.245, $df = 585.34$, p-value $= 1.0000$). The hazard ratios along with their 95% confidence intervals and corresponding p-values for each risk factor in the models are presented in Table 3.

Based on our findings, no statistically significant associations were observed between the risk of death and some factors, including sex, mother's highest level of education, wealth status, and household size, across all analyzed periods. However, a significant reduction in the risk of death was identified for children who received BCG vaccination. Specifically, the risk of death was 81%, 78%, 68%, and 71% lower for vaccinated children compared to their unvaccinated counterparts in the first, second, third periods, and across all periods combined, respectively.

Child mortality risk exhibited variability based on different maternal and other factors. For instance, the risk of child mortality was 70% higher among children whose mothers were currently married from 2002 to 2006. However, this risk was found to be 50% lower from 2007 to 2011 compared to children born to unmarried mothers. Having a single birth also led to a reduced risk by 83% in the period 2002 to 2006 and 44% in the period 2002 to 2018. Additionally, from 2007 to 2011, children born to mothers who did not engage in income-generating activities had a 58% lower risk of death compared to those whose mothers were involved in such activities.

Geographical differences played a role in child mortality risk. From the period 2007 to 2011, children from Viwandani had a 32% reduced risk of mortality compared to those from Korogocho. However, no significant association was observed for the other periods. Additional factors influencing child mortality risk included the Sex of household heads. Children from households headed by males had a 50% lower risk of death from 2002 to 2006, but this risk was 88% higher from 2007 to 2011. Ethnicity also demonstrated significant differences in the risk of mortality across all analyzed periods. Notably, from 2007 to 2011, a unit increase in the age of the head of the household led to a reduced risk of mortality by 3%. However, this association was not significant for the other periods.

Discussions and conclusions

In this paper, using data from two informal settlements in Nairobi, Kenya, we have shown that overall under-five child survival improved during the 2002-2018 period. Mortality risk was lower among children

Table 2 Relationship between risk factors and survival status, by period

	2002-2006		2007-2011		2012-2018	
Characteristics	**Dead**	***p*-value**	**Dead**	***p*-value**	**Dead**	***p*-value**
Sex of child		0.425[a]		0.981[a]		0.869[a]
Female	92 (7.8%)		143 (3.3%)		105 (1.3%)	
Male	113 (8.7%)		148 (3.3%)		114 (1.3%)	
BCG vaccination		0.001[a]		< 0.001[a]		0.005[a]
No	17 (8.5%)		37 (7.8%)		15 (2.7%)	
Yes	154 (7.5%)		211 (2.7%)		176 (1.2%)	
Dont know	34 (14.3%)		43 (9.1%)		28 (1.7%)	
Mothers marital status		0.023[a]		0.001[a]		0.407[a]
Currently not married	87 (7.0%)		92 (4.4%)		60 (1.5%)	
Currently married	118 (9.5%)		199 (3.0%)		159 (1.3%)	
Mother's highest education		0.705[a]		0.229[a]		0.157[a]
N-Miss	0		3		4	
Primary	142 (8.5%)		187 (3.4%)		125 (1.4%)	
At least secondary	46 (7.5%)		83 (3.6%)		81 (1.3%)	
Dont know	17 (8.4%)		18 (2.3%)		9 (0.8%)	
Multiple births		0.002[a]		0.293[a]		0.167[a]
N-Miss	0		1		0	
Multiple	9 (20.9%)		6 (5.0%)		6 (2.3%)	
Single	196 (8.0%)		284 (3.3%)		213 (1.3%)	
Dont know	205 (8.2%)					
Mom has income generation activity				< 0.001[a]		0.009[a]
Yes			57 (14.9%)		107 (1.6%)	
No			48 (6.3%)		72 (1.3%)	
Dont know			186 (2.4%)		40 (0.9%)	
Slum area		< 0.001[a]		0.010[a]		0.672[a]
Korogocho	129 (11.5%)		157 (3.8%)		95 (1.4%)	
Viwandani	76 (5.6%)		134 (2.9%)		124 (1.3%)	
Sex of HH		0.012[a]		0.811[a]		0.432[a]
N-Miss	2		4		1	
Female	41 (11.6%)		53 (3.2%)		53 (1.5%)	
Male	162 (7.6%)		234 (3.3%)		165 (1.3%)	
Wealth status of HH		0.046[a]		0.035[a]		0.092[a]
N-Miss	1		1		2	
Lowest	71 (7.2%)		93 (4.0%)		73 (1.7%)	
Middle	58 (7.9%)		100 (3.4%)		59 (1.2%)	
Highest	75 (10.5%)		97 (2.8%)		85 (1.5%)	
Ethnicity of HH		< 0.001[a]		0.027[a]		0.104[a]
Kamba	21 (3.5%)		53 (2.8%)		44 (1.2%)	
Kikuyu	44 (8.7%)		80 (3.3%)		58 (1.3%)	
Luhya	42 (9.5%)		53 (3.8%)		35 (1.2%)	
Luo	76 (12.2%)		70 (4.3%)		44 (1.9%)	
Others	22 (7.0%)		35 (2.4%)		38 (1.2%)	
Age of HH		0.032[b]		0.002[b]		0.987[b]
N-Miss	2		4		1	
Median (Q1, Q3)	30.00 (26.00, 37.00)		30.00 (25.00, 36.50)		32.00 (28.00, 38.75)	
Household size		< 0.001[b]		0.8002		0.787[b]
Median (Q1, Q3)	5.00 (3.00, 6.00)		4.00 (3.00, 5.00)		4.00 (3.50, 6.00)	

[a] Pearson's Chi-squared test, [b]Linear Model ANOVA

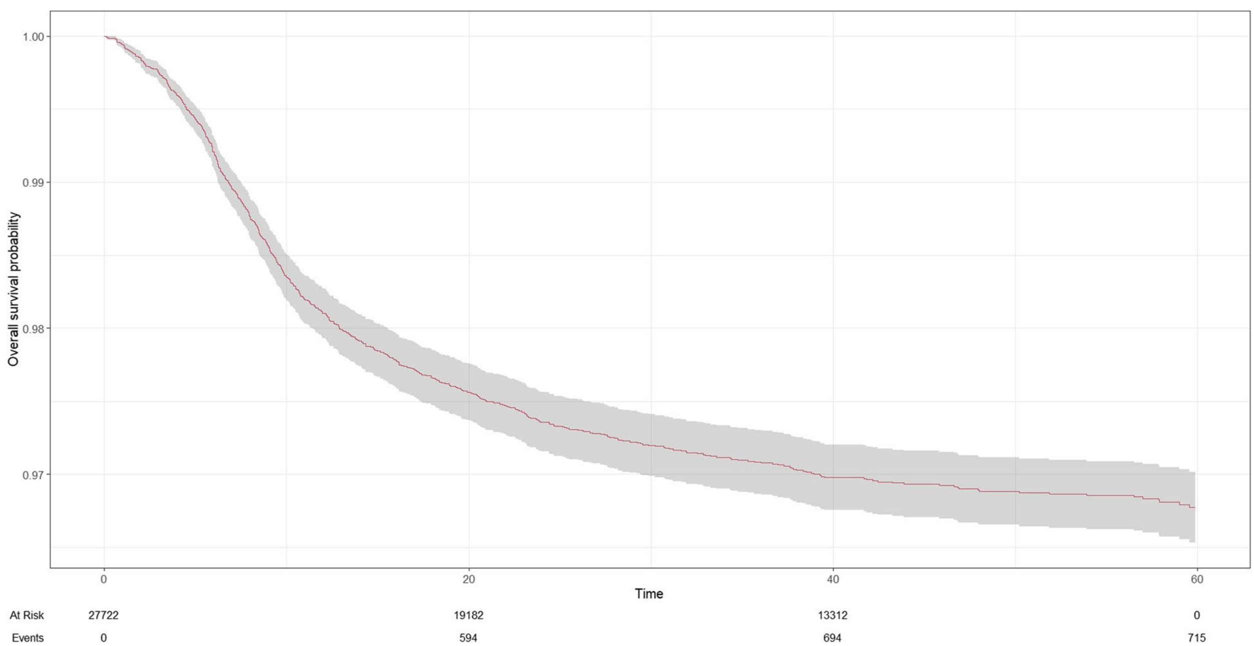

Fig. 1 Overall survival from 2002 to 2018

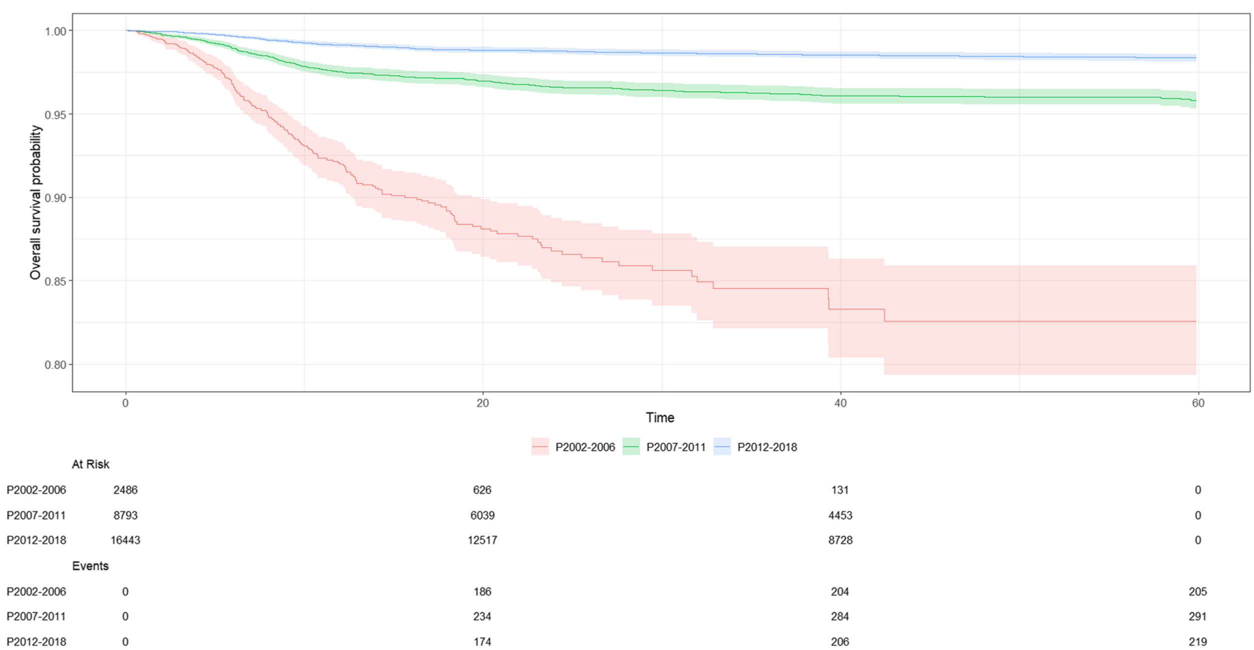

Fig. 2 Survival curves for the three period; 2002-2006, 2007-2011 and 2012-2018

who received BCG vaccination, were born to a married mother or whose mother did not engage in any income-generating activity. Furthermore, Mortality risk was lower among children from singleton pregnancy, and children born in Viwandani (compared to Korogocho, the other informal settlement).

This study highlights a noteworthy and significant decline in the mortality rate over the observed period. This positive trend could be attributed to the potential impact of targeted public health initiatives - improved access to healthcare (antenatal care, increase number of health facilities), health education programs (on

Table 3 Estimated harzard ratio (HR) and corresponding 95% confidence interval (CI) for the frailty model for each period

	2002-2006			**2007-2011**			**2012-2018**			**All**		
Characteristic	**HR**	**95% CI**	***p*-value**	**HR**	**95% CI**	***p*-value**	**HR**	**95% CI**	***p*-value**	**HR**	**95% CI**	***p*-value**
Sex of child												
Female												
Male	1.12	0.74, 1.70	0.6	1.00	0.77, 1.30	>0.9	0.95	0.71, 1.25	0.7	1.05	0.90, 1.23	0.5
BCG vaccination												
No												
Yes	0.19	0.08, 0.44	<0.001	0.22	0.14, 0.33	<0.001	0.31	0.17, 0.56	<0.001	0.29	0.22, 0.38	<0.001
Dont know	2.58	0.94, 7.02	0.064	1.44	0.84, 2.48	0.2	0.56	0.28, 1.14	0.11	1.01	0.73, 1.40	>0.9
Marital status												
Currently not married												
Currently married	1.70	1.10, 2.62	0.016	0.50	0.36, 0.69	<0.001	0.85	0.58, 1.25	0.4	0.92	0.77, 1.12	0.4
Mother's highest education												
Primary												
At least secondary	0.98	0.58, 1.66	>0.9	1.15	0.85, 1.55	0.4	0.96	0.70, 1.31	0.8	1.06	0.89, 1.27	0.5
Dont know	0.82	0.38, 1.79	0.6	1.03	0.60, 1.76	>0.9	0.72	0.34, 1.52	0.4	1.05	0.75, 1.46	0.8
Multiple births												
Multiple												
Single	0.17	0.04, 0.67	0.012	0.82	0.31, 2.15	0.7	0.54	0.22, 1.33	0.2	0.56	0.35, 0.90	0.017
Slum area												
Korogocho												
Viwandani	0.68	0.41, 1.11	0.12	0.68	0.50, 0.92	0.013	1.13	0.80, 1.58	0.5	0.84	0.70, 1.01	0.057
Sex of HH												
Female												
Male	0.50	0.28, 0.89	0.019	1.88	1.27, 2.79	0.002	0.97	0.65, 1.45	0.9	1.00	0.81, 1.24	>0.9
Wealth status of HH												
Lowest												
Middle	0.91	0.54, 1.52	0.7	0.95	0.68, 1.31	0.7				0.88	0.72, 1.07	0.2
Highest	1.01	0.61, 1.69	>0.9	0.77	0.55, 1.06	0.11				0.89	0.73, 1.07	0.2
Ethnicity of HH												
Kamba												
Kikuyu	2.68	1.29, 5.55	0.008	1.03	0.69, 1.55	0.9	1.12	0.73, 1.73	0.6	1.26	0.98, 1.61	0.070
Luhya	2.47	1.18, 5.16	0.016	1.13	0.72, 1.77	0.6	1.03	0.63, 1.68	>0.9	1.31	1.00, 1.72	0.048
Luo	3.42	1.65, 7.09	<0.001	1.50	0.96, 2.36	0.074	1.72	1.04, 2.83	0.034	1.73	1.33, 2.26	<0.001
Others	1.42	0.60, 3.36	0.4	0.81	0.49, 1.35	0.4	1.10	0.67, 1.79	0.7	1.05	0.78, 1.41	0.7
Age of HH	0.98	0.95, 1.01	0.3	0.97	0.95, 0.99	<0.001	0.99	0.97, 1.01	0.3	0.98	0.97, 1.0	0.002
Household size	1.13	0.98, 1.29	0.083	1.00	0.92, 1.08	>0.9	1.00	0.92, 1.09	>0.9	1.02	0.98, 1.07	0.3
Mom has income generation activity												
Yes												
No				0.42	0.27, 0.68	<0.001	0.95	0.69, 1.32	0.8	0.84	0.66, 1.08	0.2
Dont know				0.08	0.05, 0.11	<0.001	0.61	0.41, 0.91	0.016	0.19	0.14, 0.25	<0.001
Period												
P2002-2006												
P2007-2011										0.20	0.16, 0.25	<0.001
P2012-2018										0.03	0.02, 0.04	<0.001
Variance of frailty term			7.33			2.39			6.49			0.86

antenatal care, exclusive breastfeeding, immunizations), and proper hygiene practices (provision of clean drinking water) - which have been implemented over time [29, 30].

BCG vaccination was associated with lower mortality risk. This finding is consistent with a study by Nankabirwa et. al. (2015)[31] in Uganda which found that BCG vaccination was associated with a lower rate of childhood mortality. Elsewhere, BCG has also been shown to reduce mortality [32, 33], underscoring the importance of vaccination. In addition to protecting children against tuberculosis, BCG vaccination confers non-specific protective effects against non-related pathogens [33]. For example, it has been shown that BCG vaccination protects against viral infections [34]. By enhancing innate immunity, lowering the risk of respiratory infections and sepsis, protecting against other diseases, BCG vaccination is associated with overall reduction in childhood mortality [35].

Maternal characteristics, such as marital status and engagement in income generating activities, displayed noteworthy impacts on child mortality risk [36–39]. Marital status influences child mortality in numerous ways. Married women are more likely to have more financial stability because of dual income or financial support from the partner. This financial stability translated into better nutrition and access to healthcare. Also, married women are more likely to receive more social and emotional support which is crucial for managing childcare, especially in the early years. Better childcare, nutrition and access to healthcare results in lower child mortality. The finding of lower childhood mortality risk among mothers not engaging in income generating activities was intriguing. This could be attributed to more time dedicated to childcare. There was lower mortality risk among children from singleton pregnancies. Multiple pregnancy is a high-risk pregnancy with associated morbidity and mortality risk to the mother and child [40].

Geographical disparities emerged as an influential factor, with children from Viwandani experiencing a reduced risk of mortality across periods [27]. Furthermore, household dynamics, including the sex of household heads, showcased nuanced effects on child survival, emphasizing the multifaceted nature of the associated risk factors [41].

In conclusion, the reduction in childhood mortality noted is encouraging and the trend bodes well for the overall well-being and health outcomes within the studied population. However, ongoing vigilance and continuous efforts are essential to further advance and sustain these positive trends in mortality reduction. We recommend that policymakers and public health practitioners leverage the study findings to design targeted strategies aimed at reducing child mortality such as vaccination uptake, and special programs for at risk children in informal settlements.

Strengths, limitations and recommendations

The study has various strengths that increase its contribution to the field. First, the research addresses a key public health issue–childhood mortality in urban informal settlements–where data is frequently scarce, making the study especially relevant to poor and middle-income nations. Second, the study uses a rich longitudinal dataset from the Nairobi Urban Health and Demographic Surveillance System (NUHDSS) to effectively investigate patterns in under-five mortality across a 17-year period, providing useful insights into long-term changes. The use of Kaplan-Meier survival curves and Cox proportional hazard models with frailty terms provides a complete evaluation of risk factors, which improves the reliability and validity of the results. Third, the identification of major protective factors, such as BCG vaccination and maternal features, identifies actionable areas for targeted interventions, which may inform policy and public health measures in similar circumstances. Finally, the study offers light on geographical variations within urban slums, providing detailed insights into how various environmental and family factors influence child mortality, which could be critical for designing location-specific interventions.

Despite the many strength, this paper is limited in its scope since it only focused on specific slum settings in Nairobi. Consequently, the observed findings might not be universally applicable to other slums. Conducting additional research across other urban settlements in Nairobi, using a similar methodology, could facilitate a more comprehensive analysis of contextual factors affecting child mortality within the urban poor population. Furthermore, future investigations on child mortality could build upon this study, refining data collection instruments and expanding coverage to include more variables, thereby enhancing the understanding of the complex dynamics of child mortality.

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Authors' contributions

SI: Conceptualization, Data curation, Methodology, Formal analysis, Writing-original draft, Writing-review & editing. DA: Conceptualization, Writing-original draft, Writing -review & editing. RES: Writing-review & editing, Validation. MW: Data curation, Writing-review & editing. GA: Supervision, Methodology, Validation, Writing-review & editing.

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Availability of data and materials
The anonymized dataset used for this study can be obtained from the African Population and Health Research Center (APHRC) microdata portal upon request via this link: https://microdataportal.aphrc.org/index.php/catalog.

Declarations

Ethics approval and consent to participate
The NUHDSS received ethical clearance from the Kenya Medical Research Institute (KEMRI) in 2002 and it's consequently renewed over the years. This study has used pre-existing data from the NUHDSS which had already received ethical clearance. The analysis was based on an anonymized dataset with no identifiable information on the study participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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