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ORIGINAL ARTICLE

Inequalities in cause-specific mortality in children and adolescents in the Moramanga health survey, Madagascar

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Abstract

Objectives One child or young adolescent dies every 10 min in Madagascar and large disparities in survival persist. We estimated cause-specific mortality in a cohort of children aged 0–14 in the Moramanga district and explored how causes of death shape these inequalities.

Methods Children were followed prospectively between 2012 and 2017. Causes of death were established based on verbal autopsies. Incidence rate ratios were estimated in Poisson regression models.

Results The risk of dying before age 15 was 68.1 per thousand live births. Risks of dying were highest in the first year of life (31.2‰) and lowest in children aged 10–14 (6.4‰). The male-to-female sex ratios of mortality increased with age and reached 2.3 among adolescents aged 10–14. Communicable, nutritional and neonatal causes accounted for 79.5% of deaths below age 5 and 47.0% above age 5. Mortality was positively associated with household poverty, lack of education of the household head, and rural residence.

Conclusions Interventions should be designed with an equity lens to reduce large disparities in survival and be tailored to the needs of each age-group.

Keywords Madagascar · Low-income countries · Child mortality · Verbal autopsy · Rural area · Urban area

Introduction

Remarkable progress in preventing child mortality has been made in Madagascar, in a context characterized by political instability, limited economic growth, and high rates of chronic undernutrition (World Bank 2019). Madagascar was among the 62 countries that met the target set in the Millennium Development Goals (MGDs) to reduce the under-five mortality rate (U5MR) by two-thirds between 1990 and 2015 (IGME 2015). In the Sustainable Development Goals (SDGs) agenda, the new target is to reduce U5MR to less than 25 deaths before age 5 per 1,000 live births. In Madagascar, U5MR had already declined to 54‰ in 2018 (IGME 2019). Immunization could have contributed to this reduction, despite important gaps in the immunization coverage. According to WHO and UNICEF estimates, the immunization coverage was still below 80%

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in 2018 for many vaccines (World Health Organization and UNICEF 2019). If the rate of reduction in U5MR observed in 1990–2018 is kept constant in the future, the country should achieve the U5MR target around 2038. The decline in mortality is also impressive above age 5; the risk of dying of older children and young adolescents aged 5–14 was reduced by 70% from 41‰ in 1990 to 12‰ in 2018 (IGME 2019).

Despite these achievements, 45 000 children died under age 5 in 2018, in addition to 8 000 deaths that occurred in the age-group 5–14 (IGME 2019). This represents one death of a child or young adolescent every 10 min. Huge disparities in mortality rates also persist between segments of the population; according to the 2008–09 Demographic and Health Survey (DHS), U5MR was more than twice higher in households from the poorest quintile (106 ‰) than in households from the richest quintile (48 ‰) (Institut National de la Statistique and ICF Macro 2010). Significant within-county inequalities in child survival were observed according to maternal education and type of residence. The 2008–2009 survey also shed light on social inequalities in vaccination uptake. Herd immunity for diphtheria, pertussis, tuberculosis, measles, and polio was only achieved in a small number of districts near the capital, and increased household wealth and parental education were strongly associated with improved vaccination in children (Clouston et al. 2014).

Accelerating progress in child survival and reducing inequities requires a better understanding of the underlying diseases that contribute most directly to the deaths. However, the system of registration and medical certification of deaths is not sufficiently complete in Madagascar to generate nationally-representative estimates of cause-specific mortality. In the capital and other major cities, deaths are notified to the health sector, and physicians assign a cause of death (CoD) based on interviews with relatives or medical information, allowing a detailed assessment of the burden of disease (Masquelier et al. 2019). But a large proportion of the population of children and adolescents in Madagascar is concentrated in rural areas, where evidence on the leading CoD is scant. All-cause mortality can be estimated with relative precision, because Madagascar has conducted several demographic surveys with birth histories in the last decades, including a DHS in 2008–09 and a survey tracking progress towards the MDGs in 2012–2013 (Institut National des Statistiques 2013). In 2018, the third population census was conducted, after a long intercensal period (25 years). These surveys and census have collected information on mortality, but no data on CoD in children. When deaths go uncounted and CoD are not recorded, the government has limited capacity to design effective public health policies and to measure their impact (Jha 2012).

In 2012, a cohort of a geographically-defined population of Moramanga, known as the MHURAM cohort (Moramanga Health survey in Urban and Rural areas in Madagascar), was set up by the Institut Pasteur of Madagascar to fill data gaps on mortality and the burden of disease (Ratovoson et al. 2019). Moramanga is a district located at 112 km from Antananarivo. About 78 000 individuals were enumerated in the second wave of data collection (2016–2017), representing about a fourth of the population of the district.

In this study, we describe mortality rates and CoD patterns in children aged under 15 years of age, based on prospective data collected between the first census (conducted between 2012 and 2014) and the follow-up (2016–2017). Information on the CoD was determined by verbal autopsies (VA) (Nichols et al. 2018). VA is an indirect method to determine CoD based on an interview with the caretakers of the deceased using a standardized questionnaire on symptoms preceding the death. We report here on the main CoD in children aged less than 15, explore socio-demographic determinants of mortality and analyse how various CoD shape inequalities in survival chances.

Methods

Study site

The Moramanga district is located in the Alaotra Mangoro region of Madagascar (latitude 18°57′S, longitude 48°13′E), straddled between the central highlands (where Antananarivo is located) and the East coast with the seaport of Toamasina. The MHURAM cohort was established in this district, building on a longitudinal community-based study on diarrheal diseases in children under 5 years of age (Randremanana et al. 2014). This survey was extended to cover the entire population in 3 communes: the Urban commune of Moramanga and the rural communes of Ambohibary and Ampasimpotsy. The initial census, conducted in 2012–2014, registered 16,789 households with 71,587 inhabitants. According to administrative boundaries, 56% of the population resided in areas considered as urban and 46% in rural areas. The population is served by 15 primary health care centers, one referral district hospital and one private confessional hospital. A substantial proportion of the population lives in poverty. In the urban commune, the daily household income varies from 1000 to 2000 ariary per day, or about US$1 (UN Habitat 2012). Rural household incomes are likely to be lower. Children are chronically food insecure: the prevalence of stunting was estimated at 53% in children aged less than 5 years in 2014–2015 (Remonja et al. 2017). Basic services are also

limited; less than 30% of households have improved sanitation facilities (Ratovoson et al. 2019). There are important disparities between the urban and rural communes: 49% of households in the urban commune have access to improved drinking water (bottled water, private or public tap), against less than 1% in the rural communes. About 63% of urban households have access to electricity, against only 7% in rural areas.

Data collection

This study is based on the data collected on children living in households enumerated both at the initial census and during the follow-up. The following data were collected during the first census: type of residence, household assets, educational attainment of all household members aged 6 and above, religion of the head of household, number of household members and their date of birth and sex. In the follow-up, all previously registered and new households were visited by the local fieldworkers, who had been trained to use the same procedures as those of the initial census. They interviewed again the heads of households or other adults living in the household. All households where a death was reported to have taken place between the initial census and the follow-up were revisited to conduct a VA interview.

VAs and interpretation of CoD data

Trained fieldworkers conducted the VA interviews using World Health Organization instruments (Nichols et al. 2018), translated into Malagasy. Further details on the VA process are provided in the "Appendix". Underlying CoD were coded using the International Classification of Diseases, 10th revision (ICD-10) and categorized into four groups based on categories used by the Maternal and Child Epidemiology Estimation (MCEE) group (World Health Organization 2018). The first group consisted of communicable, perinatal, and nutritional conditions, and was further divided into diarrhoeal diseases, meningitis, malaria, acute respiratory infections (ARI), prematurity, intrapartum-related complications, sepsis and other infections of the newborn, nutritional deficiencies, and other causes. The second group consisted of non-communicable diseases (NCDs) and we distinguished between congenital anomalies and other causes. The third and fourth groups were respectively injuries and ill-defined or unknown CoD. The full list of corresponding ICD codes is provided in "Appendix".

Socio-demographic characteristics

A composite measure of household's living standards was constructed based on Multiple Correspondence Analysis (MCA) ("Appendix"). The data collected on educational levels were of poor quality, with many values missing, probably due to some reluctance on the part of interviewees to report their educational level and too much precision required in the degree levels. We, therefore, chose to identify adults who had never been to school from a question on current or past school attendance. As children do not always live with their father or mother, we retained the educational level of the head of household in the covariates.

Statistical analysis

Using the reported dates of birth, dates of death of deceased children and dates of survey rounds, we tabulated deaths and person-years of follow-up time into different age-groups: infants (less than 1 year), children (1–4 years), older children (5–9 years) and young adolescents (10–14 years). Central death rates were estimated and converted into risks of dying expressed as probabilities ($_nq_x$) (Swanson et al. 2004). Standard errors for the life table probabilities were obtained from Chiang's formula (Chiang 1984). Poisson regression models were used to estimate incidence rate ratios (IRR). The number of deaths from all causes was assumed to follow a Poisson distribution, with the log of exposure time introduced as an offset parameter. A scale parameter was allowed to vary to account for possible overdispersion. Variable selection was based on comparing Akaike Information Criterion (AIC) values in a stepwise algorithm. The full model included as covariates the age-group and sex of children, educational attainment and religion of the household head, wealth index, household size and type of residence. Based on the AIC values, we excluded the religion of the household head and the household size. The model selected for all age-groups and all CoD combined was reused for each age-group separately, to compare IRRs across age-groups for all-cause mortality, and then used again for each category of causes separately, adjusting for age-groups. All analyses were conducted using the R statistical software (version 3.5.2) (Hlavac 2018; R Core Team 2018).

Results

In total, 31,078 children were included; 90.1% of them had less than 15 years at the time of the initial census while 9.9% were born between the census and the follow-up;

47.1% of the children resided in the urban commune (Table 1). Two-thirds of them lived in households with more than 4 members. One child out of 15 (6.6%) had a household head who had never attended school. Between the two rounds of data collection, 301 children died before reaching age 15. Gender, type of residence, household wealth and size and educational attainment of the household head were all significantly associated in bivariate analyses with the occurrence of death.

Table 2 presents the summary indices of mortality for each sex. The risk of dying before age 15 was 58.4‰ among girls (95%CI: 57.7–59.0) and 77.6‰ among boys (76.9–78.4). Risks of dying were highest in the first year of life, at 31.2‰ (25.5–37.0) and lowest in children aged 10–14, at 6.4‰ (5.9–6.8). Mortality in older children and young adolescents ($_{10}q_5$) represented about a third of the risk of dying in the first 5 years of life.

The male-to-female sex ratios of mortality increased with age and ranged from 1.1 in infants to 2.3 among adolescents aged 10–14. The difference between male and female mortality was statistically significant in all age-groups after the first birthday.

Increasing sex differences in survival reflect the changing patterns of CoD as children get older. Cause-specific mortality fractions (CSMFs) obtained from the VA are presented in Fig. 1. Unknown causes or ill-defined conditions were distributed proportionately across categories of the Groups I and II. They represented 7.8% of infant deaths, 18.8% of deaths in children aged 1–4, 14.5% in the age-group 5–9 and 13.3% in young adolescents. In infants, the leading CoD were sepsis and other infectious conditions of the newborn (30.2%), prematurity (16.1%), ARI (14.1%) and intrapartum-related complications (13.2%). In children aged 1–4, four categories of infectious diseases (ARI, meningitis, diarrhoeal diseases and malaria)

Table 1 Socio-demographic characteristics of the children aged under 15 years old at the initial census or at birth

Characteristics	Alive N = 30,777		Deceased N = 301		Total N = 31,078		p
	n	%	n	%	n	%	
Age at the start of the observation period							< 0.01
Born during the follow-up	2981	9.7	83	27.6	3064	9.9	
0–4 years	9814	31.9	152	50.5	9966	32.1	
5–9 years	9407	30.6	46	15.3	9453	30.4	
10–14 years	8575	27.9	20	6.6	8595	27.7	
Gender							< 0.01
Male	15,425	50.1	174	57.8	15,599	50.2	
Female	15,352	49.9	127	42.2	15,479	49.8	
Type of residence							< 0.01
Rural	16,197	52.6	231	76.7	16,428	52.9	
Urban	14,580	47.4	70	23.3	14,650	47.1	
Wealth index							< 0.01
Lowest	10,695	34.7	126	41.9	10,821	34.8	
Middle	10,687	34.7	123	40.9	10,810	34.8	
Highest	9395	30.5	52	17.3	9447	30.4	
Number of household members							< 0.01
4 or less	10,350	33.6	135	44.9	10,466	33.7	
More than 4	20,427	66.4	166	55.1	20,612	66.3	
Educational attainment of the household head							< 0.01
Never attended school	2003	6.5	46	15.3	2049	6.6	
Attended school	28,774	93.5	255	84.7	29,029	93.4	
Religion of the head of the household							0.07
Christian	30,088	97.7	289	96.0	30,371	97.7	
Non-christian	689	2.2	12	4.0	707	2.3	

By survival status at the end of the observation period in Moramanga Health survey in Urban and Rural Areas in Madagascar (2012–2017)

17 children were enumerated in the area during the first census in the age-group 10–14. They reached their fifteen birthday and later died before the first round of data collection. They are classified in this table as "alive" because they were still alive at their fifteen birthday

Table 2 Age-specific mortality rates among children aged less than 15 in the Moramanga Health survey in Urban and Rural Areas in Madagascar cohort (2012–2017)

	Boys ‰ (CI 95%)	Girls ‰ (CI 95%)	Both sexes ‰ (CI 95%)	Male-to-female sex ratio
Infant mortality rate ($_1q_0$)	33.0 (24.6–41.4)	29.5 (21.6–37.4)	31.2 (25.5–37.0)	1.12
Child mortality rate ($_4q_1$)	23.6 (22.1–25.2)	19.0 (17.6–20.4)	21.3 (20.3–22.3)	1.24
Under-five mortality rate ($_5q_0$)	55.8 (53.9–57.8)	48.0 (46.2–49.7)	51.9 (50.6–53.2)	1.16
Risk of dying between ages 5 and 10 ($_5q_5$)	14.4 (13.5–15.3)	7.1 (6.5–7.8)	10.8 (10.2–11.4)	2.03
Risk of dying between ages 10 and 15 ($_5q_{10}$)	8.8 (8.1–9.6)	3.9 (3.4–4.4)	6.4 (5.9–6.8)	2.28
Risk of dying before age 15 ($_{15}q_0$)	77.6 (76.9–78.4)	58.4 (57.7–59.0)	68.1 (67.6–68.6)	1.33

Infant mortality rate ($_1q_0$): probability at birth of dying before reaching the first birthday

Child mortality rate ($_4q_1$): probability of dying before reaching the 5th birthday in children aged one year

Under-five mortality rate ($_5q_0$): probability at birth of dying before reaching the 5th birthday

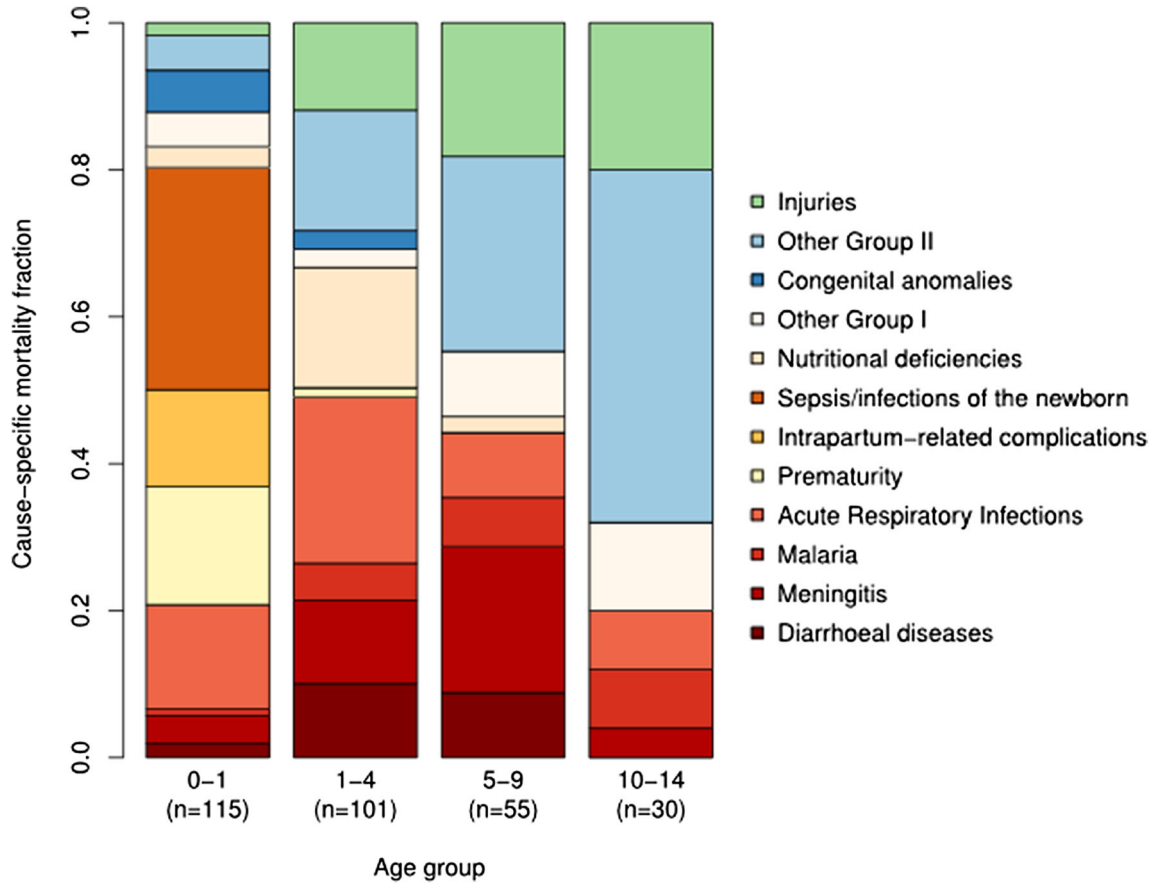

Fig. 1 Cause-specific mortality fractions, by age-group, among children aged 0–14 in the Moramanga Health survey in Urban and Rural Areas in Madagascar cohort (2012–2017)

accounted for about half of deaths (49%), while nutritional deficiencies caused about one death out of six (16.4%). In children aged 5–9, the CoD profile was still dominated by infectious diseases and nutritional deficiencies. In particular, meningitis accounted for 19.9% of deaths in this age-group. The burden of NCDs increased steadily with age, to reach 26.5% in children aged 5–9 and 48.0% in young adolescents. Deaths in this category were caused by epilepsy, cardiovascular diseases and tumours of the hematopoietic and lymphoid tissues. The share of violent deaths also increased with age, from 1.7% in infants, to 11.9% in children aged 1–4, 18.2% in children aged 5–9 and 20.0% in young adolescents. Drownings, road accidents, and burns were the top three causes in this category.

Table 3 presents the IRRs for the final model for all-cause mortality, with age-groups included among the covariates (model 1) and used as a stratification variable in the subsequent models (models 2–5).

When considering all age-groups combined, IRRs reveal a large female advantage, estimated at 0.72 (95%CI: 0.55–0.94) after controlling for other covariates, but this advantage is only significant in older children and young adolescents in the age-stratified models. Having as head of household an adult who had been to school benefited children and this advantage was significant in the global model and the stratified models below age 5. Children born in households in the highest tercile faced lower mortality rates, and this was significant in the global model [IRR: 0.66 (0.44–0.96)] and for infant mortality [IRR: 0.669 (0.379, 0.960)]. Children from the urban commune had much higher survival outcomes than their rural counterparts. This urban advantage was significant in all age-stratified models. The IRRs suggest that children gain more advantage from living in an urban setting as they get older.

IRRs obtained for cause-specific mortality are presented in Table 4, along with IRRs for all-cause mortality (column 1). In all categories of causes, mortality rates decline as children get older, but this decline is the steepest in mortality rates from causes associated with group I (communicable, neonatal and nutritional conditions). Mortality rates from such causes in young adolescents are about 70 times lower than in infants, reflecting the high burden of neonatal conditions in this group of causes. By contrast, the IRRs for age-groups are not statistically significant when considering external deaths (Group III). As noted earlier, males are at higher risk of dying, but the disaggregation by categories of causes indicates that this is mostly due to NCDs (Group II) and unknown or ill-defined causes. The IRR for sex was the lowest for violent deaths, but it was not significant, presumably due to the low number of deaths.

The survival advantage of children born in the highest wealth tercile, observed in all-cause mortality, is driven by neonatal, infectious and nutritional conditions (perhaps reflecting lower access to health services) and also by unknown and ill-defined conditions. Finally, the survival

Table 3 Incidence rate ratios (IRR) with confidence intervals (CI 95%) according to the socio-demographics characteristics included in the model for all-cause mortality in children aged less than 15 years in Moramanga Health survey in Urban and Rural Areas in Madagascar cohort (2012–2017)

	(1) All age-groups	(2) 0–1	(3) 1–4	(4) 5–9	(5) 10–14
Child (1–4 years)	0.170***				
	(0.124, 0.231)				
Older children (5–9 years)	0.070***				
	(0.048, 0.101)				
Young adolescent (10–14 years)	0.043***				
	(0.026, 0.067)				
Sex (= females)	0.725**	0.903	0.797	0.487**	0.440*
	(0.555, 0.944)	(0.676, 1.204)	(0.487, 1.293)	(0.271, 0.842)	(0.153, 1.111)
Household head ever been to school	0.542***	0.550**	0.542*	0.564	0.488
	(0.379, 0.800)	(0.367, 0.856)	(0.289, 1.112)	(0.275, 0.842)	(0.162, 2.001)
Middle wealth tercile	1.033	1.208	0.963	0.609	1.787
	(0.773, 1.379)	(0.882, 1.658)	(0.563, 1.633)	(0.320, 1.126)	(0.655, 5.577)
Highest wealth tercile	0.660**	0.669*	0.617	0.703	0.695
	(0.445, 0.960)	(0.379, 0.960)	(0.285, 1.233)	(0.345, 1.368)	(0.149, 2.794)
Type of residence (= Urban)	0.503***	0.652**	0.470**	0.463**	0.239**
	(0.363, 0.687)	(0.462, 0.906)	(0.251, 0.833)	(0.236, 0.855)	(0.048, 0.772)
Constant	0.085***	0.067***	0.015***	0.008***	0.004***
	(0.056, 0.126)	(0.043, 0.101)	(0.007, 0.027)	(0.004, 0.016)	(0.001, 0.013)
Nb. of deaths	301	113	103	55	30
Nb. of person-years	71,340	3519	19,079	25,371	23,420

Explanatory note for co-variates: Reference

Age-group: Infant (less than 1 years), Sex: Male, Educational attainment of the household head: Attended school, Wealth index: Lowest wealth tercile, Type of residence: Rural (the 2 rural communes: Ambohibary and Ampasimpotsy)

*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$

Table 4 Incidence rate ratios (IRR) with confidence intervals (CI 95%) according to the socio-demographics characteristics included in the model for cause-specific mortality in children aged less than 15 years in Moramanga Health survey in Urban and Rural Areas in Madagascar cohort (2012–2017)

	(1) All causes	(2) Grp I	(3) Grp II	(4) Grp III	(5) Unknown & ill-defined
Child (1–4 years)	0.170***	0.114***	0.297***	1.097	0.396***
	(0.124, 0.231)	(0.085, 0.151)	(0.132, 0.705)	(0.103, 129.1)	(0.222, 0.736)
Older children (5–9 years)	0.070***	0.039***	0.168***	0.711	0.131***
	(0.048, 0.101)	(0.026, 0.057)	(0.070, 0.414)	(0.060, 85.07)	(0.063, 0.267)
Young adolescent (10–14 years)	0.043***	0.014***	0.182***	0.488	0.075***
	(0.026, 0.067)	(0.007, 0.025)	(0.075, 0.450)	(0.027, 61.74)	(0.029, 0.176)
Sex (= females)	0.725**	0.898	0.515**	0.429	0.597**
	(0.555, 0.944)	(0.696, 1.157)	(0.272, 0.935)	(0.073, 1.825)	(0.365, 0.956)
Household head ever been to school	0.542***	0.547***	0.509	0.432	0.659
	(0.379, 0.800)	(0.387, 0.795)	(0.230, 1.321)	(0.077, 5.326)	(0.354, 1.349)
Middle wealth tercile	1.033	1.092	1.554	0.867	0.576**
	(0.773, 1.379)	(0.827, 1.444)	(0.793, 3.147)	(0.171, 4.133)	(0.334, 0.967)
Highest wealth tercile	0.660**	0.682**	1.113	0.368	0.462**
	(0.445, 0.960)	(0.463, 0.984)	(0.483, 2.512)	(0.020, 2.698)	(0.221, 0.888)
Type of residence (= Urban)	0.503***	0.449***	0.657	1.019	0.287***
	(0.363, 0.687)	(0.323, 0.984)	(0.332, 1.239)	(0.129, 4.576)	(0.140, 0.534)
Constant	0.085***	0.062***	0.006***	0.002***	0.009***
	(0.056, 0.126)	(0.042, 0.090)	(0.002, 0.017)	(0.000, 0.025)	(0.004, 0.018)
Nb. of deaths	301	181	50	30	40
Nb. of person-years	71,340	71,340	71,340	71,340	71,340

*$p < 0.1$;**$p < 0.05$;***$p < 0.01$

advantage of children living in urban areas is not significant when considering NCDs and external causes.

Discussion

Our study highlights a high burden of mortality among children and young adolescents aged 0–14 in the Moramanga district. The risk of dying in the age-group 0–14 was 68.1 per thousand live births (95%CI: 67.6–68.6). This is roughly equivalent to 1 in 15 children dying before reaching age 15. Mortality rates declined rapidly with age, but the risk of dying between ages 5 and 15 was still 17.1‰ (95%CI: 16.7–17.5). Mortality rates observed in the MHURAM cohort were close to the national estimates from UN IGME (IGME 2019). In 2015, the national estimate of the U5MR was 58.1 (90%CI: 47.1–70.8), against 51.9 (95%CI: 50.6–53.2) in the cohort. The national estimate of the risk of dying in the age-group 5–14 was 13.2 (90%CI: 8.1–20.1), compared with 17.1 (95%CI: 16.7–17.5) in the cohort.

The distribution of CoD is largely dominated by communicable, neonatal and nutritional conditions. This category of cause represents 79.5% of deaths in children under 5 years of age. This figure is consistent with WHO statistics, which put this percentage at 81.2% among deaths under five years of age in 2015 at the national level [17]. However, there are notable differences with WHO estimates when considering subcategories of CoD (Figure S1). In particular, malaria seems to cause a higher proportion of deaths at the national level (8.6%) than in the cohort (2.7%). This is expected, as Moramanga is located on the edge of the central highlands and has a low and unstable level of malaria transmission (Ratsimbasoa et al. 2012). More surprising is the large fraction of deaths attributed to meningitis (7.0%), in contrast with the WHO estimate (2.7%). The distribution of deaths between intrapartum-related complications and sepsis and other newborn infections also differs between the two sources of estimates, although overall these two categories explain a comparable share of under-five deaths (19% in the MHURAM cohort, 25% in WHO estimates). Such deviations from model-based estimates of cause-specific mortality call for additional VAs studies in Madagascar, for example in other cohorts established in the country (Garchitorena et al. 2018). Despite these uncertainties, it is clear that early child mortality remains largely dominated by infectious diseases in Madagascar, and that greater efforts

need to be made to improve immunization coverage. Madagascar has implemented the WHO's expanded program on immunization (EPI) since 1976 and the vaccination schedule follows EPI guidelines. However, lack of infrastructure, fragmentation of the country due to a very poorly developed road network, lack of staff and limited supply of vaccines seem to reduce immunization coverage (Clouston et al. 2014).

Communicable diseases and nutritional problems also account for a significant proportion of deaths beyond the age of 5 (47%). Cost-effective and life-saving interventions are available for most communicable diseases and they should be extended to ensure that they also benefit older children and young adolescents (Masquelier et al. 2018). However, there is also a growing need to address the burden of injuries and NCDs in children aged 5–14. Most violent deaths in this age-group were due to drownings, burns and road accidents. The literature on drownings in low- and middle-income countries suggest that being male, aged less than 17 years old and living in rural environments are the main risk factors (Tyler et al. 2017). Preventive strategies include covering wells, fencing off ditches and ponds, providing swimming lessons in primary schools, and increasing awareness of the risks of drowning.

The observation that NCDs account for a large fraction of deaths in Madagascar is not new. In Antananarivo, NCDs account for more than half of all deaths (Masquelier et al. 2019). Several studies have also highlighted the problems of NCDs in rural areas among adults (Ratovoson et al. 2015; Manus et al. 2018). However, our study is among the first to quantify the burden of NCDs among children in the country. Altogether, the mortality burden from injury and NCDs call for investments in public health strategies beyond those that have historically targeted the major CoD in children aged less than 5 years (Patton et al. 2016).

Our results show that urban households experience lower child mortality rates than rural households in Moramanga. This covariate was the only one to be significant in all age-stratified models. This urban advantage appeared to get larger as children grew older, and was limited to communicable, perinatal and nutritional conditions or unknown and ill-defined conditions. The urban advantage has been regularly observed in sub-Saharan Africa (Bocquier et al. 2011; Gunther and Harttgen 2012). Because our model was already adjusted for household wealth and education, this advantage presumably reflects better access to health infrastructure. Madagascar currently has one doctor in the public sector for every 10,500 inhabitants and one midwife for every 15,000 inhabitants (Lang et al. 2018). About 90% of basic health centers are run by a single person (Ministère de la Santé Publique 2011). In addition to a significant overload of work, affecting the motivation and quality of care provided by health workers, the lack of equipment and isolation pose additional problems in rural areas.

We also found a positive association between levels of educational attainment of household heads and survival chances. This is consistent with most of the literature showing the protective effects of being raised by educated parents (Caldwell 1979; Fuchs et al. 2010; Lu et al. 2019), although recent work suggests that the role of parental education in child health has attenuated considerably in the last decades (Bado and Sathiya Susuman 2016; Karlsson et al. 2018). In our study, the association between mortality and education of the household head was only significant for communicable, perinatal and nutritional conditions, and was not found above age 5.

Finally, we observed that sex ratios of mortality increased with age, in relation to changes in the relative contribution of underlying CoD. Newborn boys generally have higher birth weights than girls on average, but they are more likely to be born prematurely, they are less resistant to infections, and the burden of congenital malformations and respiratory conditions is heavier in boys (Calu Costa et al. 2017). This explains why U5MR are higher in boys. The UN IGME estimates the male-to-female sex ratio in U5M at 1.18 in Madagascar, a figure consistent with our own estimate in the cohort (1.16). As children get older, the share of deaths due to infections declines, and the percentage of deaths due to accidents increases. As a result, the male-to-female ratios in mortality increase too. In this cohort, rates of mortality from external causes were more than twice higher in males, although the sex ratio was not significant.

Our study had limitations. First, indeterminate or ill-defined causes represented an important fraction of all deaths (13.3%). For this reason, we redistributed them across acceptable CoD for descriptive results but treated them separately in the regressions for cause-specific mortality. Mortality rates from unknown and ill-defined conditions were higher in households from the lowest wealth tercile and in rural areas. This might affect our conclusions, for example, if they come disproportionately from a single group of causes (e.g., NCDs). Another source of imprecision may stem from the validity of VA data. VA relies on information provided by close relatives and their answers are subject to recall or cultural biases. However, VAs are currently the only way to compensate for the lack of systematic medical certification of deaths in Madagascar. A third limitation relates to the poor quality of data on educational levels, which compelled us to use the information about past school attendance of the household head. With the third round of data collection carried out in 2019–2020, more detailed information on educational attainment will be available for further studies. Finally, information about

vaccination was collected during the initial census for all children under the age of 5, but based only on maternal reports. During the follow-up, the health records of all these children were asked to improve data quality, but few households had kept them. For this reason, we did not include immunization status in the covariates.

Despite these limitations, our study adds to the knowledge of CoD patterns and disparities in survival outcomes in Madagascar. In this cohort of children, only 9% of deaths under 15 years of age were reported to the civil registry, and 53% of deaths occurred at home, thus escaping health facility statistics. These proportions indicate that the "scandal of invisibility" (Setel et al. 2007), where people die without entering official statistics, is still a sad reality in Madagascar.

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Author contributions RR, BM, GP and LB conceived this study. RR and BM analyzed data. TA and ZA determined the causes of death. RM coordinated the data management. RR, BM and LB wrote the first draft of the manuscript. All authors reviewed the manuscript and approved its submission.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Data Availability and materials The specific customized data used in this study can be made available upon request to interested researchers.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the national research committee (Comité d'Ethique de la Recherche Biomédicale auprès du Ministère de la Santé Publique) (Approval N°52-CE/MINSAN 02 November 2009 and amendment N°60/MSANP/CE 26 May 2016) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from the head of the household participants included in the study.

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