Journal of Health and Social Sciences Advance Publication Online
Published Online May 15, 2020 doi10.19204/2020/srvv3
The Italian Journal for Interdisciplinary Health and Social Development

ORIGINAL ARTICLE IN GLOBAL PUBLIC HEALTH

Survival status and determinants of under-five mortality in Sudan: Evidence from the Multiple Indicator Cluster Survey 2014

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Abstract

Introduction: Under-five mortality in Sudan declined in the last decade, but the reduction was well below the goal set by the Sudan Health Sector Strategic Plan developed for 2012-2016. This study investigated the risk factors of under-five mortality in Sudan.

Methods: Data by the Multiple Indicator Cluster Survey conducted in 2014 by the Central Bureau of Statistics (CBS) and the Federal Ministry of Health, Sudan, were collected. Non-parametric methods such as Kaplan–Meier survival function and log-rank were used to assess the effect of socioeconomic and demographic variables on under-five mortality. Cox hazard proportional and frailty models were carried out to examine predictors of under-five mortality.

Results: Our research showed that the risk of death among under-five children vary by states in Sudan. Moreover, Cox proportional and frailty models showed that type of birth (Hazard Ratio (HR) twin birth vs. single birth = 2.7, (95% Confidential Interval [CI] 1.8 to 4.1, P = 0.000), household wealth index (HR rich vs. poor = 0.42, (95% CI 0.20 to 0.87, P = 0.021), previous birth interval less than 2 years (HR vs. first birth = 2.3, (95% CI 1.6 – 3.4, *P* = 0.000), and region of residence (HR Northern region vs. Khartoum) = 0.33, (95% CI 0.12 – 0.92, *P* = 0.035) were statistically significant determinant of under-five mortality in Sudan.

Discussion: Based on our findings, all intervention plans targeted to reduce child mortality in Sudan should consider specific determinants of risk. Furthermore, the Cox proportional model jointly with frailty models could be useful for further studies on determinants of under-five mortality.

Keywords: Cox hazard proportional; frailty model; global health, Sudan; under-five mortality.

Riassunto

Introduzione: La mortalità nei bambini con meno di 5 anni in Sudan è diminuita nell'ultimo decennio, ma la riduzione è stata ben al di sotto dell'obiettivo fissato dal Piano Strategico per la Salute del Sudan sviluppato per gli anni 2012-2016. Questo studio ha indagato i fattori di rischio della mortalità ni bambini sotto i 5 anni in Sudan.

Metodi: Sono stati raccolti i dati dal Multiple Indicator Cluster Survey condotto nel 2014 dal Central Bureau of Statistics (CBS) e dal Ministero della Salute del Sudan. Metodi non parametrici come la funzione di sopravvivenza di Kaplan–Meier ed il log-rank sono stati usati per valutare l'effetto delle variabili socio-economiche e demografiche sulla mortalità. Un modello a effetti casuali ed il modello di rischio proporzionale di Cox sono stati utilizzati per esaminare i predittori di mortalità.

Risultati: La nostra ricerca ha evidenziato che il rischio di morte tra i bambini con meno di 5 anni varia in base agli stati del Sudan. Il modello di Cox insieme al modello ad effetti casuali ha mostrato che il tipo di nascita (Hazard Ratio (HR) gemellare rispetto alla nascita di singoli = 2,7, Intervallo Confidenziale (IC) al 95% 1,8-4,1, *P* = 0.000), la ricchezza della famiglia (HR dei ricchi rispetto ai poveri = 0,42, IC 95% 0,20-0,87, *P* = 0.021), l'intervallo dalla precedente nascita inferiore a 2 anni (HR rispetto alla nascita di un solo figlio = 2,3, IC 95% 1,6-3,4, *P* = 0.000) e la regione di residenza (HR regione del Nord rispetto a Khartoum = 0,33, IC 95% 0,12-0.92, *P* = 0.035) erano tutti determinanti statisticamente significativi di mortalità nei bambini con meno di 5 anni in Sudan.

Discussione: Sulla base dei nostri risultati, tutti i piani di intervento mirati a ridurre la mortalità dei bambini in Sudan dovrebbero considerare specifici determinanti di rischio. Inoltre, il modello proporzionale di Cox usato insieme con modelli ad effetti casuali potrebbe essere utile per ulteriori studi sui determinanti di mortalità nei bambini con meno di 5 anni.

TAKE-HOME MESSAGE:

In Sudan, under-five mortality is associated with specific determinants of risk. Twin birth, household wealth, previous birth interval less than 2 years, and residing in Northern region are all significant factors for under-five mortality in Sudan. Policymakers should consider them for developing targeted interventions.

Competing interests: none

Cite this article as: Ahmed HMM, Elkarib HAO, Digna MFMO. Survival status and determinants of under-five mortality in Sudan: Evidence from the Multiple Indicator Cluster Survey (2014). Published online ahead of print May 15, 2020]. J Health Soc Sci. doi10.19204/2020/srvv3

DOI 10.19204/2020/srvv3

Received: 5 Jan 2020 **Accepted:** 23 March 2020 **Published Online:** 15 May 2020

INTRODUCTION

Under-five child mortality reflects the socioeconomic and environmental status of children as well as the overall health system performance of a nation. It is a global issue, because about 10 million children under age five die throughout the world every year [1]. This problem received sufficient attention from the international communities, and reducing the current rates was included among International Development Goals, adopted by United Nations Member States, namely the Millennium Development Goal 4 for reducing the under-five mortality rates by two-thirds between 1990 and 2015, and the Sustainable Development Goal 3 aimed to reduce them to at least as low as 25 deaths per 1,000 live births, in all countries of the world. Different measures were implemented by local governments and global agencies to meet this goal. As a result, the global under-five deaths fell from 93 deaths per 1,000 live births in 1990 to 39 deaths in 2017, with a total of about 58% reduction of cases [2]. Despite the remarkable reduction in the global under-five mortality rate, about 5.4 million under-five deaths were estimated in 2018, and around half of them took place in South Asia and sub–Saharan African countries. A comparison between rich and developing countries shows that under-five child mortality estimates vary from over 110 per 1,000 live births in some of the poorest countries to less than 3 per 1,000 live births in some of the richest ones. Most developing countries are located in Sub-Saharan Africa. For example, the estimates for 2018 show 127 deaths per 1,000 live births in Somalia, 111 in Sierra Leone, 106 in Mali, 100 in Nigeria and 96 in South Sudan [2]. It is obvious that under-five mortality involves a developmental dimension that needs to be considered while examining the determinants of under-five child mortality.

Being one of the developing countries in Sub-Saharan Africa, Sudan faces the challenges of under-five child mortality. In 1990, the under-five mortality rate was 131 per 1,000 live births. During the period 1995-2000 and 2010-2014, the mortality rates were estimated at 104 and 68 per 1,000 live births, respectively. Despite the 35 percentage points decline in two decades, the goal of 'The Sudan Health Sector Strategic Plan' (HSSP 2012-2016) of reducing the rate to 53 deaths per 1,000 live births has not yet achieved. The main goal of the HSSP was to reduce under-five mortality by improving the health status and outcomes of the population, with special considerations for the poor, underserved people in remote areas and vulnerable groups. The available data, however, revealed that likelihood of dying differs by the mode of living, wealth quintiles, and geographical locations. According to the Multiple Indicator Cluster Survey in 2014, under-five mortality rates in urban and rural areas were 56.5 and 72.8 per 1,000 live births, respectively. Geographically, the death rate ranged from 111.7 in East Darfur to 29.9 in Northern State. This paper is, therefore, motivated by the belief that the first step for reducing child mortality is to know the risk factors associated with it.

Literature review about models to assess under-five mortality

Child mortality is a significant public health issue that reflects the socioeconomic development and measures the efficiency of health systems of various countries. Therefore, it draws the attention of researchers, and many studies were conducted to examine the factors behind the child and infant mortality, and then a vast literature has grown up during the last three decades.

According to Mosley and Chen [3], background social, economic, cultural, and health system variables determine child survival in developing countries. According to previous studies conducted in Ethiopia, India, Zambia, Bangladesh, and Sub-Saharan Africa, there are common factors determining child mortality in these countries, albeit with some slight differences. For example, Gebretsadik and Gabreyohannes found socioeconomic factors as the main determinants of child mortality in Ethiopia [4], while Mani et al. found biological factors are decisive factors in India [5].

Traditionally, social science research on child mortality has focused on the association between socioeconomic status and levels and patterns of mortality in the population [6–9]. In contrast, medical research focused primarily on the biological processes of diseases [10, 11], while nutrition research focused on breastfeeding, dietary practices, and food availability [12, 13].

In the early 1980s, a new framework including maternal factors, environmental contamination, nutrient deficiency, injury, and personal illness control was set up for developing countries by Mosley and Chen [3]. Based on Mosley's model, several studies have investigated the determinants of child mortality, though research was limited by the unavailability of all required data.

In India, Mani et al. used the Cox proportional hazard and frailty models to examine the risk factors associated with under-five child mortality and to account for the unmeasured familial effect [5]. They found that mother's age at birth, place of delivery, sex of the child, the composite variable of birth order and birth interval, as well as baby size at birth, and breastfeeding were significant determinants of under-five mortality. Their findings also revealed the presence of a significant unobserved familial effect on child deaths. In Bangladesh, father's education, place of residence, region of residence, number of children under five years of age, previous death of siblings, mother's age, and breastfeeding were the most important determinants of under-five child mortality [14].

In Zamibia, Mulenga, et al. utilized cross-sectional data from the Demographic and Health Survey (2013-2014) and used a logistic regression model [15]. Their findings exhibited that mother's age at birth, child's sex, number of children under-five, level of wealth, mother's level of education, the region in which a mother resides; smoking cigarettes and use of contraception were significant determinants of under-five mortality. Most of these variables were also reported in a study conducted in Sub-Saharan Africa [16].

In Ethiopia, Getachew and Bekele used the Cox proportional hazard model and stratified Cox regression to compare the hazard of under-five mortality for different covariates [17]. This was done by comparing the hazard of each covariate levels with one level of the same covariate taken as reference. Their findings suggested that covariates such as geographical region, mother's education, sex of child, mother's age at first birth, preceding birth interval, contraceptive use, breastfeeding, place of delivery, number of antenatal visits, father's occupation were all risk factors of under-five deaths and could influence child's survival time. Some studies extended Cox proportional model to test the correlation between clusters and accounts for the unobservable random effect by using frailty models. They revealed the existence of unobserved heterogeneity of under-five death at regional level [18, 19].

In Uganda, Nasejje et al. [20] fitted the Cox-proportional hazard model with frailty effects to draw inference using both the frequentist and Bayesian approaches. They showed an unobserved heterogeneity at household level, but not at community level. Sex of the household head, sex of the child, and number of births in the past year, were all found to be significant risk factors of child mortality.

In Sudan, household income and mother's education were recognized as primary factors of child mortality [21, 22]. Farah and Preston added an important risk factor known as 'cousin marriages'. Though marriage of first cousins was common in Sudan in the last three decades, it is now diminishing. Using the logistic regression model, Fawzi et al. examined the relationship between malnutrition and mortality among Sudanese children [23]. A cohort of 28,753 children between the ages of 6 months and six years were examined every six months for 18 months. Two hundred and thirty-two children died during 18 months of follow-up (480,624 child-months). The findings showed that weight-for height was statistically associated with an increased risk of mortality. The risk of death among the children with Z-score of weight-for-age between -2 and -1 was 50% higher compared to those whose z-score was >-1. Also, stunting and higher risk of child mortality were significantly associated (P-value for trend < 0.0001). This study also revealed strong and significant interactions between infection and wasting or stunting as predictors of child mortality. The study concluded that children with low weight-for-height in developing countries were more likely to die before their fifth birthday, compared to their counterparts.

Bashir et al. analyzed data from the Sudan Household Health Survey (2nd round) that was carried out in 2010 [24]. A total number of 6,198 live-born infants delivered within the two years preceding the survey was the study population. Multivariate logistic regression was used to model neonatal mortality as a function of maternal health factors, socioeconomic indicators, and demographic variables. The findings revealed 189 neonatal deaths out of 6,198 live births (3.0%) and multiple logistic regression estimates showed that maternal age, household wealth index, type of birth delivery, and delivery complications were determining factors of neonatal mortality.

Based on the information available in the literature and methods of analysis used in past research this study aims to identify the risk factors associated with under-five child mortality in Sudan, using data collected by Multiple Indicators Cluster Survey (MICS) (2014), in order to provide some guidance for policymakers in designing evidence-based policies.

METHODS

Data collection and study variables

Data used for this study was extracted from the Multiple Indicator Cluster Survey conducted in 2014 by the Central Bureau of Statistics (CBS) and the Federal Ministry of Health in Sudan. The sample was designed to provide estimates for a large number of indicators at national, state, rural and urban levels. Thus, urban and rural areas within each state were identified as the main sampling strata. A two-stage cluster sample design was adopted; in the first stage, 40 clusters were selected with probability proportional to size from each of the 18 States; in a second stage, 25 households were systematically selected from each cluster. Thus, the primary sampling units were the clusters and sampling element was the household.

The Sudan MICS 2014 sample is not self-weighting, and by allocating equal numbers of households to each of the states, different sampling fractions were used in each state since the sizes of the states vary. For this reason, sample weights were calculated in the early stage of sampling design and considered in data analysis.

Data was collected by three questionnaires (household questionnaire, women questionnaire, and under-five questionnaire). Each questionnaire consisted of 10 to 13 modules. The Household Questionnaire involved ten modules including; household information panel, selection of one child for child labor, child discipline, child labor, household characteristics, water and sanitation, hand washing, food consumption and sources, coping strategies, and salt iodization. Women's Questionnaire involved eleven modules including women's information panel, women's background, fertility and birth history, desire of last birth, maternal and new born health, postnatal health checks, contraception use, unmet needs, female genital mutilation, attitude towards domestic violence and HIV. According to the UNICEF, questionnaire modules for MICS were developed and validated to collect internationally comparable data [25].

As stated from the final report of the Sudan MICS 2014, "For quality assurance purposes, all questionnaires were double-entered and internal consistency checks were performed. Procedures and standard programs developed under the global MICS programs and adapted to the Sudan questionnaires were used throughout" (CBS and UNICEF, 2016-Final Report) [25].

The respondent for the household questionnaire was the head of the household; women aged 15-49 were the respondents of women's questionnaire, whereas mothers or caregivers were the respondents of under-five questionnaire. Data was further split into many files. Two files were merged to include the needed data, namely the file of birth history and the household file. All information on sampling were borrowed from the final report released by the Central Bureau of Statistics and its partners. The reference period of the study were five years prior to the survey.

The dependent variable in hazard analysis was a combination of two parts: An event indicator and a measure of time from baseline to the event or censoring. In this study, the dependent variables were the survival time of a child (measured in years from birth until death/censor of children aged less than or equal 5 years) and the event indicator (given the value 1 if the child was dead within the reference period and 0 if censored, or stay alive within the reference period).

The independent variables were 16 and consisted of socioeconomic, demographic, and environmental variables. Most variables were qualitative variables, and some of them were dichotomous variables: Type of birth (single = 0, twins =1), sex of child (male = 0, female =1), gender of household head (male = 0, female =1), residential areas (urban = 0, rural = 1), household with electricity (no = 0, yes = 1), main source of drinking water (unprotected = 0, protected = 1), and whether household owns animals (no = 0, yes = 1). Other variables were ordinal including; order of the child (first birth = 1, 2nd -3^{ird} birth = 2, 4th -6th birth = 3 and 7th birth or more = 4) previous birth interval (first birth (0 interval) = 0, interval less than 2 years = 1, interval of 2 years = 2, interval of 3 years = 3 , and interval of 4 years or more = 4), mother's age at birth (less than 20 years = 1, 20-34 = 2, and 35 or above = 3), mother's education (no education = 0, primary = 1, secondary and above = 2), head of household level of education (no education = 0, primary = 1, secondary and above = 2), household wealth index quintiles (poorest = 1, second poor = 2, middle = 3, fourth = 4, and richest = 5). Moreover, residential region (Khartoum = 0, Northern = 1, Eastern = 2, Central = 3, Kordufan = 4, and Darfur = 5), sanitation facilities (no facility = 0, pit latrine = 1, and flushing = 2), and method of disposing garbage (transported by garbage dumpsters = 1, received away from residential areas = 2, by incineration or burial = 3, and others = 4) were nominal, but coded for comparison. The variable 'region' was created from the 18 States, by collecting two or more neighboring states into one region. Northern region was created from the state of the north, Darfur and Kordufan regions from the western states, Eastern region out of the eastern states, Central region out of central states, while Khartoum state remained as Khartoum region and was used as reference in regression analysis. Household wealth index was calculated by the Central Bureau of Statistics (CBS) out of household's assets and characteristics such as accessibility to clean drinking water and building materials of the house. The 'household wealth index' was computed using the principle component method, and then the distribution of the scores of wealth index was divided into five quintiles, ranging from the poorest quintile to the richest quintile. Each household was assigned to its corresponding quintile.

Statistical analysis

Survival time refers to a variable which measures the time from a particular starting point of time to a particular endpoint of interest. Survival analysis is concerned with studying the time between entry to a study and a subsequent event and becomes one of the most important fields in statistics used in engineering, physical, biological, and social sciences [26]. In this study, we focused on the time to a single event for each of the under-five children included in the study.

To calculate the mean and median of the survival time, we first estimated the survival distribution function (SDF). T was assumed as a continuous random variable representing survival time of subjects in the population, with a probability density function of f(t). The cumulative distribution function gives the probability that the event (child death) has occurred by duration t, and is denoted as:

$$F(t) = P(T < t),\ t > 0 \qquad \text{1}$$

The complement of the F(t) gives the survival function, $S(t)$ gives the probability of being alive just before duration ***t***. In other words, it represents the probability that the child lives longer than the duration t**.** The survival function is given by:

$$S(t) = p(T > t) = 1 - F(t) = \int_t^{\infty} f(x)dx \qquad \text{2}$$

Hazard function gives the probability that a child dies at time t, given that it was a live till time t; and is shown by the following formula:

$$h(t) = \text{limit}_{\Delta t \to 0} \frac{1}{\Delta t} \mathrm{P}(t \leq T < t + \Delta t \,|\, T \geq t) \quad \ldots\ldots 3$$

$$= \frac{f(t)}{S(t)} \quad \ldots\ldots$$

4

The instantaneous rate of occurrence given by equation (3) was obtained by dividing the conditional probability that an event will occur (death here) in the interval (t, t+ dt) given that it has not yet occurred by the width of the interval [27]. Kaplan-Meier product-limit estimate is the standard estimator of the survival function, developed by Kaplan and Meier [28].

Cox proportional hazard regression model

The Cox proportional hazards model introduced by Cox (1972), as cited by Fox (2002) [29], is a widely used approach to model covariate effects on survival time analysis. In a Cox model, the hazard function for individual i, is defined as:

$$h_i(t \,|\, x_i) = h_0(t) \exp(x_i' \beta) \quad \ldots\ldots 5$$

Where $h_0(t)$ is the baseline hazard rate, which is an unknown function giving the hazard function when the set of conditions $x_i = \mathbf{0}$, and $\boldsymbol{\beta}$ is a p x 1 vector of unknown parameters. The factor $\exp(x_i\beta)$ describes the hazard for an individual with covariates x relative to the hazard at a standard x = **0**. The Cox model is called a proportional hazards model since the ratio of the hazard rates of two individuals with covariate values **X** and **X*** were not depending on **t** as shown below:

$$h(t \mid \mathbf{X}) / h(t \mid \mathbf{X^*}) = \exp(\mathbf{X} - \mathbf{X^*})\, \beta,$$

The 'Frailty model'

The conventional Cox model may not fit the data well all the time, and may leads to incorrect inferences when relevant covariates are omitted because they have not been observed [30]. In recent literature, frailty models were developed to analyze more complex survival data by Vaupel et al (1997), Wienke (2010) and Hanagal (2011) [31–33]. The concept of frailty was developed by Vaupel et al in 1979 [31] to show that some individuals are more at risk than others, though they are similar on the basis of the observed variables. Cox model can be modified as follows:

Given a covariate vector represented as X, the frailty model is given by:

$$h(t|U,X) = U h_0(t)\exp(\beta X) \qquad \ldots 6$$

$h_0(t)$ is again the baseline hazard function, β is a vector of regression coefficients, X is the vector of covariates, and U is the frailty, random variable that varies over the population. Individual's risk factor increases/decreases if the value of $U > 1$ or $U < 1$, respectively. This model is based on the individual level and has to be modified at a population level.

To estimate the hazard of under-five mortality between groups of the covariates (independent variables), we used the log-rank test. The groups of the covariates are found in the definition of independent variables. As an example the two groups of 'Type of birth' are single and twins.

The result of the log-rank test facilitates the inclusion of significant covariates in the Cox hazard proportional model. For multivariate model, we retained all variables that were found to have a p-value <= 0.2. To select the most appropriate model for multivariate analysis, we compared parametric models (exponential and Weibull) and semi-parametric models (Cox hazard models). The estimated coefficients for the three models were almost the same; therefore, we selected the

Cox proportional hazard model (CPH). After the Cox proportional hazard model was estimated, it was necessary to verify for the violation of the proportional hazard of Cox's assumption. The assumption of hazard ratio indicates that the hazard of predicators does not change over time, thus we test proportionality by different methods, including adding time interaction term in the model.

RESULTS

Out of the total of 13,450 under-five children born during the reference period (within five years by the 2014 MICS), 383 children were dead, with a rate of 0.028 percent, a total risk time of 31,432.75 years and a survival median time of 2.3 years. Kaplan Meier survival estimates and the proportion surviving to age five suggest that most child deaths occurred at an earlier age, and then gradually decline to the age of 5 years (Figure 1). Results of Log-rank test are presented in Table 1.

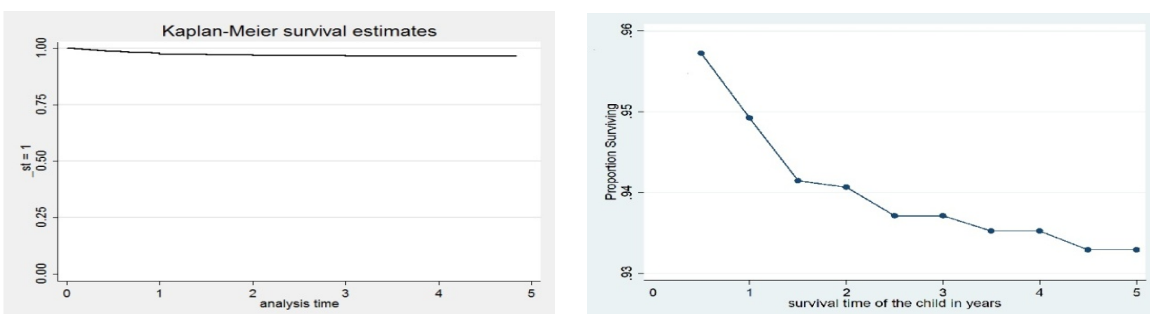


Figure 1. Kaplan-Meier survival estimates: The left lane represents Kaplan-Meier survival estimates, and the right lane shows the proportion surviving to age 5. (Source: Compiled by the authors from MICS, 2014 [25].

Table 1. Log-rank test for equality of survival time among the different groups of covariates for under-five mortality.

Covariates	Chi-Squared	Degree of Freedom	P-values

Type of birth	19.27	1	0.000
Sex of child	3.34	1	0.067
Birth order	14.41	3	0.002
Previous birth interval	91.04	4	0.000
Mother’s age at birth	15.55	2	0.004
Gender of household’s head	0.00	1	0.986
Mother’s education	18.38	3	0.000
Head of household’s education	15.25	3	0.001
Household’s Wealth Index	38.36	4	0.000
Have electricity	22.42	1	0.000
Region of residence	35.27	5	0.000
Residential areas	7.19	1	0.007
Main source of drinking water	0.94	1	0.331
Sanitation facility	14.48	2	0.000
Methods of disposing of garbage	15.07	5	0.010
Household own animals	0.25	1	0.618

Source: Estimated from MICS, 2014 [25]

As shown in Table 1, the event of death differs significantly between groups of the following covariates: being twins or a single child, birth order, previous birth interval, mother’s education, head of household’s education, household accessibility to electricity, wealth index quintiles, residential areas, and waste disposal practices. Sex of child was only significant with a 10% significance level. Conversely, main sources of drinking water, gender of the head of household, and whether the household owns animals or not were not statistically significant.

Table 2 shows the estimates of the Cox proportional hazard model. The findings showed that the overall model was highly significant with a p-value of 0.000, indicating that at least one of the covariates exerts effects on under-five mortality in Sudan. According to our results, under-five mortality was 1.6 times higher for twin children compared to a single one; and the covariate was highly significant with a p-value of 0.000. This indicates that a twin child is more likely to die before his 5th birthday compared to a single child.

Sex of child and residential areas were not statistically significant, but they indicated the expected relationship with under-five mortality. The signs of the coefficients indicate that females had a lower hazard rate and longer survival time, as well as children from urban areas compared to those from the rural ones. The results also showed that the hazard rate of under-five child mortality was 2.4 times higher for children born with previous birth interval less than 2 years, compared to first born children (0 interval), whereas the hazard rates for other groups were not statistically significant. The hazard of under-five mortality was much lower (61%) for children from the richest group compared to their counterparts from the poorest group. This result indicates that poor children are more likely to die; however, with the only Cox proportional model, this variable was significant at 10% level of significance.

Cox proportional hazard model failed to detect the appropriate hazard of some covariates, such as the hazard rate for children born by mothers with secondary (or above) education and for children delivered by mothers aged 20-34 at birth, compared to their references. Our results also showed that the hazard of death for children living in the Northern region was lower than their counterparts in Khartoum region. The hazard rate was significant with a p-value of 0.021; this is expected because most the socioeconomic indicators of Northern region are better than that of all regions including Khartoum. The unexpected result is that the hazard rates of child mortality in regions of Eastern and Kordufan were lower than that of Khartoum, where health services were comparatively better and timely access. Therefore, we needed to check for the model's adequacy and the existence of frailty.

Table 2. Cox proportional hazard model on risk factors effect of under-five mortality in Sudan, 2014.

Variables	Marginal Effect of Variables (B)	Standard Errors B (SE)	P-value	Hazard Ratio [Confidence intervals] HR [95% CI]
Type of birth:				
Single: (Ref.)				
Twins:	0.9725	0.2503	0.000	2.644 [1.617 - 4.322]
Sex of the child:				
Male: (Ref.)				
Female:	-0.216	0.1426	0.131	0.805 [0.609 - 1.006]
Residential areas:				
Urban: (Ref.)				
Rural:	0.2600	0.2181	0.234	1.297 [0.845 - 1.990]
Mother's Age at Birth:				
<20 years (Ref)				
20-34	0.0683	0.1997	0.732	1.070 [0.723-1.585]
>=35	0.1173	0.2464	0.634	1.124 [0.693-1.824]
Previous Birth Interval:				
First birth(0 interval ref)				
<2 Years:	0.8833	0.2515	0.000	2. 419 [1.476 - 3.964]
2 Years:	0.3442	0.2814	0.222	1.410 [0.811 - 2.451]
3 Years:	-0.2308	0.3444	0.503	0.793 [0.403 - 1.561]
≥ 4 Years:	-0.2618	0.3228	0.418	0.769 [0.408 - 1.450]
Mother's Education:				
Not educated (Ref):				
Primary:	-0.0135	0.1879	0.943	0.986 [0.679 -1.432]

Variables	Marginal Effect of Variables (B)	Standard Errors B (SE)	P-value	Hazard Ratio [Confidence intervals] HR [95% CI]
Secondary and above:	0.0467	0.3496	0.894	1.047 [0.527-2.081]
Region of Residence:				
Khartoum: (Ref)				
Northern:	-1.2899	0.5594	0.021	0.275 [0.091- 0.825]
Eastern:	- 0.1689	0.4675	0.718	0.844 [0.337 - 2.115]
Central:	-0.3694	0.4775	0.437	0.691[0.271 - 1.1756]
Kordufan:	-0.1018	0.4656	0.827	0.903 [0.362 - 2.253]
Darfur:	0.0738	0.4507	0.870	1.076[0.444 - 2.608]
Wealth index quintiles:				
Poorest (Ref)				
Second poor:	0.0083	0.1974	0.966	1.008 [0.684 - 1.485]
Middle:	0.0166	0.2589	0.949	1.016 [0.611 - 1.690]
Fourth:	-0.0755	0.3258	0.817	0.927[0.489 - 1.758]
Richest:	-0.9373	0.4806	0.052	0.391[0.152 - 1.006]
Number of observations = 13,450, F (20,683) = 5.92, Prob>F= 0.000				

Source: Estimated from MICS, 2014 data [25]

Table 3 shows the estimates of time interaction with covariates. All time-dependent covariates were insignificant (collectively or individually) with p-values > 0.05, indicating that there was no violation of the proportionality assumption for that specific predictor.

Table 3. Time interaction with covariates in Cox proportional hazard.

Covariates	Coefficients	Standard Error	P-values
Child Twins*Time	0.3084	0.2185	0.158
Sex of Child*Time	-0.2018	0.1055	0.056
Residential Areas *Time	-0.0319	0.1478	0.829

Mother's Age at Birth *Time	0.1037	0.1033	0.316
Previous Birth Interval*Time	-0.0931	0.0550	0.091
Mother's Education *Time	-0.0487	0.0600	0.417
Region of Residence*Time	0.0109	0.0454	0.810
Household's Wealth*Time	0.0517	0.0641	0.419

Source: Estimated from MICS, 2014 data [25]

Statistical test based on Schoenfeld and Scaled Schoenfeld

Table 4 shows the statistical test based on Schoenfeld and Scaled Schoenfeld. We cannot reject Cox hazard proportionality since that both the individual covariate test and the global test were not significant.

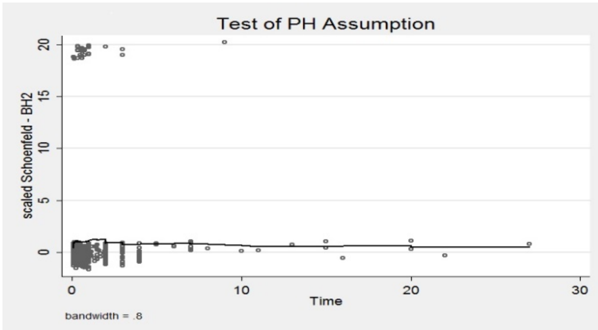
Table 4. Statistical test based on Schoenfeld and Scaled Schoenfeld.

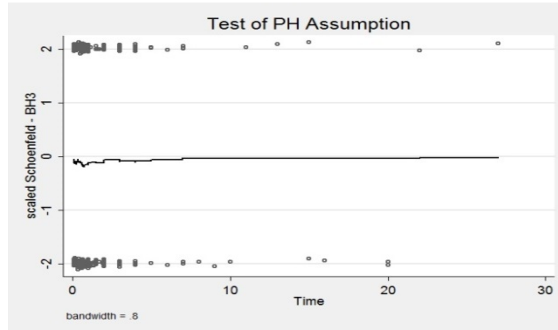
Covariates	**Rho**	**chi2**	**df**	**Prob>chi2**
Child Twins	0.0305	0.36	1	0.5504
Sex of Child	-0.0377	0.54	1	0.4621
Residential Areas	0.0110	0.05	1	0.8285
Mother's Age at Birth	0.0180	0.13	1	0.7175
Previous Birth Interval	-0.0670	1.47	1	0.2251
Mother's Education	-0.0247	0.26	1	0.6104
Region of Residence	-0.0072	0.02	1	0.8848
Household's Wealth	-0.0121	0.05	1	0.8148
Global test		3.05	8	0.9580

Source: Estimated from MICS, 2014 data [25]

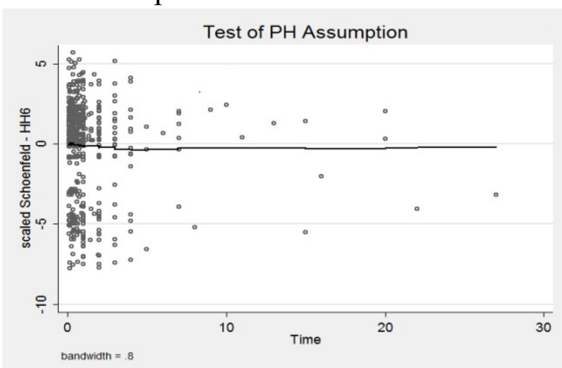
2. Residual plots for type of birth

3. Residual plots for sex of child

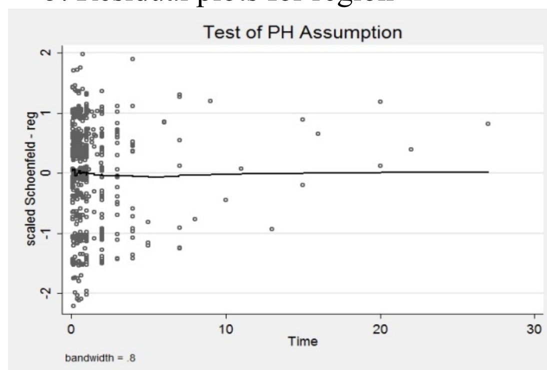




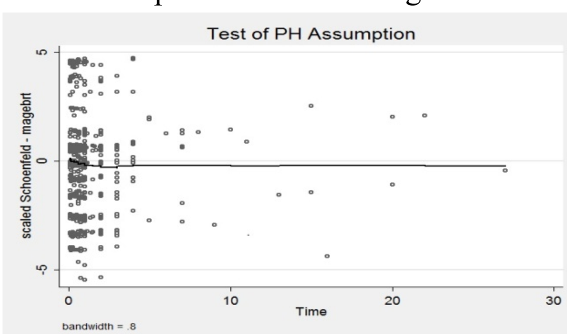
4. Residual plots for residential areas



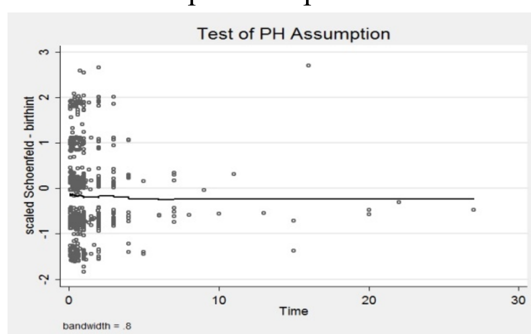
5. Residual plots for region



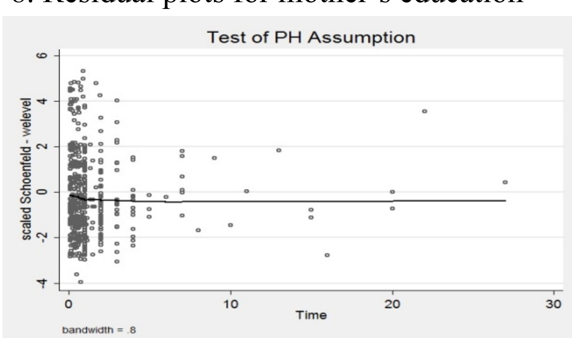
6. Residual plots for mother's age at birth



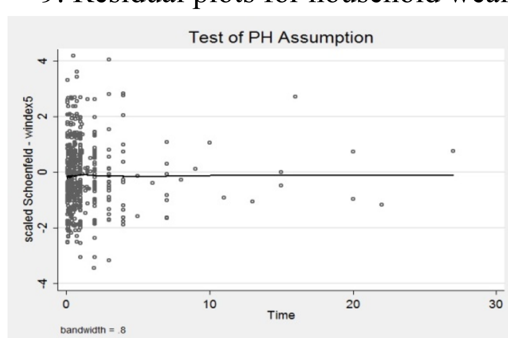
7. Residual plots for previous birth interval



8. Residual plots for mother's education



9. Residual plots for household wealth



Figures 2-9. Test of the proportional hazard assumption, based on Schoenfeld and Scaled Schoenfeld Residuals. Source: All compiled by the authors from MICS, 2014 [25].

The third method is to plot Scaled Shoenfeld errors for each covariate against transformed time. Figure 2-8 shows that, for all covariates the smoothed curve was an approximately horizontal line around zero, and the errors were scattered randomly. Therefore, the graphical inspection showed no pattern with time, and the assumption of hazard proportionality was not violated.

Overall assessment of the model

Table 5 presents the goodness-of-fit test for the inclusion of design variables. The goodness of fit was investigated using a Gronnesby and Borgan test using nine groups. The insignificant chi2 suggests the model is good.

Table 5. Gronnesby and Borgan test for goodness of model fit.

Quintile of risk	Observed	Expected	P-Norm	Observations
1	13	15.3	0.593	1495
2	21	22.3	0.777	1496
3	34	27.5	0.221	1493
4	33	33.0	0.996	1500
5	37	38.4	0.818	1506
6	48	45.4	0.700	1534
7	54	49.5	0.532	1439
8	53	62.5	0.225	1509
9	87	85.7	0.890	1478
Total	380	380		13450
Sort test		Chi-2 (8) = 6.971, P> chi2 = 0.5297		
Likelihood- ratio test		Chi-2 (8) = 6.802, P> chi2 = 0.5580		

Source: Estimated from MICS, 2014 data [25]

The frailty model

The CPH model had passed all tests of goodness of model fit; however, there was the problem of unexpected signs and insignificance of some relevant covariates. Therefore, we further examined the model for frailty. We fitted two models, one with households as a group variable and the other with clusters (States) as a group variable. For both models, we used the covariates that passed the Cox proportional hazard assumption. There were 720 clusters selected by the study and 25 households per each cluster. There was no evidence of the existence of frailty at household level. Theta was very small, with a p-value of 0.5000, whereas at state level, frailty was significant with a p-value of 0.000, and the findings were presented in Tables 6.

Table 6 shows that at state level, θ (0.466) was highly statistically significant. This result suggested that some states were more exposed to the risk of under-five mortality than others. Frailty model improved the signs of all variables; mother's age at birth; though was still statistically insignificant with the p-value > 0.05, showed acceptable signs for the covariate levels. The hazard of dying was 7% lower for children born to mothers aged 20-34 than those whose mothers were below 20 years and 7% higher for those whose mothers were 35 and above.

Table 6. Gamma shared frailty with States being group variable.

Covariates	**Hazard Ratio (HR)**	**Standard error (SE)**	**P-values**	**Confidence Intervals (95% CI)**
Child Twins: Single (Reference) Multiple:	2.7711	0.5860	0.000	(1.8308 - 4.1944)
Sex of Child: Male (Ref.) Female:	0.8287	0.0863	0.071	(0.6757 - 1.0164)
Residential Areas: Urban (Ref.) Rural:	1.1441	0.1961	0.432	(0.8175 – 1.6011)

Mother's Age at Birth: <20 (Ref.) 20-34: 35+	 0.9338 1.0776	 0.1607 0.2334	 0.691 0.730	 (0.6663 – 1.3085) (0.7048 – 1.6475)
Previous Birth Interval: First birth (0 interval Ref.) <2 Years: 2 Years: 3 Years: >=4 Years:	 2.3683 1.3636 0.6774 0.7281	 0.4510 0.2730 0.1736 0.2015	 0.000 0.121 0.129 0.252	 (1.6305 – 3.4400) (0.9209 – 2.0190) (0.4099 – 1.1197) (0.4232 – 1.2524)
Mother's Education: No Education (Ref.) Primary level: Secondary or above:	 0.9239 0.8975	 0.1161 0.1708	 0.529 0.570	 (0.7221 – 1.1820) (0.6180 -1.3035)
Region of Residence: Khartoum: (Ref.) Northern: Eastern: Central: Kordufan: Darfur:	 0.3357 1.0509 0.8396 1.1846 1.2349	 0.1735 0.4007 0.3102 0.4464 0.4574	 0.035 0.896 0.636 0.653 0.569	 (0.1219 – 0.9244) (0.4977 – 2.2191) (0.4070 – 1.7322) (0.5659– 2.4796) (0.5974 – 2.5524)
Household's Wealth: Poorest: (Ref.) Second: Middle: Fourth: Richest:	 1.0446 1.1244 1.0506 0.4268	 0.1518 0.2096 0.2605 0.1572	 0.764 0.529 0.842 0.021	 (0.7856 – 1.3889) (0.7802 – 1.6205) (0.64 61- 1.7082) (0.2073 – 0.8787)
theta	0.4685915	0.1366876		
Likelihood-ratio test of theta = 0:	Chibar2 (01)	= 20.81		Prob> chibar2 = 0.000

Source: Estimated from MICS, 2014 data [25]

The signs of mother's education were also improved, indicating that the risk of dying before the fifth birthday was lower for the children with educated mothers compared to children with uneducated mothers. Our findings also revealed that the risk of death for children belonging to the richest quintile was 58% lower compared to those belonging to the poorest quintile. In the Cox hazard proportional model, the sex of the child was not significant, with a p-value of 0.131, whereas in the frailty model, it became significant at a 10% level of significance. In conclusion, the frailty model improved the results obtained with the Cox hazard proportional model.

DISCUSSION

In line with the Sustainable Development Goal 3, the Sudan Health Sector Strategic Plan (HSSP 2012-2016) was designed to improve health outcomes of the population, especially for the poor, underserved, disadvantaged, and vulnerable people. As a result, the under-five mortality declined, but the targeted progress has not yet achieved. With the hope to help bridge the evidence-policy gap, the present paper was aimed at exploring the risk factors associated with the under-five mortality in Sudan, by using the data drawn by the Multiple Indicators Cluster Survey 2014. We selected the most appropriate models to obtain correct and valid estimates needed for designing evidence-based policies. We first compared exponential, Weibull and Cox hazard models. The coefficients for the three models were similar, therefore we selected the Cox hazard model as the most commonly used model. However, our findings showed some unexpected results and some related variables were found not to be significant. Therefore, we further used the frailty model with the Cox proportional model, achieving better results and showing that twin birth, household wealth, previous birth interval less than 2 years, and residing in Northern region are all significant factors for under-five mortality in Sudan.

In our study, twin children were 2.77 times more likely to die before the age of 5 as compared to single births, in agreement with a study conducted in Ethiopia by Gebretsadik and Gabreyohannes (2016) [4]. Also, Monden and Smits (2017) [34] found that one-fifth of twins in Sub-Saharan countries die before age 5 years, which was three times the mortality rate among singletons. Twins are probably more vulnerable as they have a lower birth weight due to the limited capacity of the human uterus to hold multiple fetuses. In addition, twin births are more likely to be premature and, thus, need more care. Unfortunately, most deliveries in Sudan take place at home and lack the necessary care needed to save twin child's life.

Despite the fact that it was only statistically significant at 10%, our study revealed that females are less exposed to under-five deaths compared to males. This is also consistent with the findings of some previous studies carried out by Mani et al (2012), Nasejje (2015), and Gebretsadik and Gabreyohannes (2016) [4, 5, 20]. Literature does not offer a clear explanation of this association, which, therefore, should be further studied.

In our study, the frailty model as well as the Cox proportional model detected that the hazard of child death in rural areas exceeds that of urban areas, though it was not statistically significant. According to previous studies [14, 35], urban residents have a higher likelihood of access to health care facilities and receive better health care services. Therefore, children could receive a timely and appropriate vaccine and treatment, while most of the rural children depend on traditional practitioners for any treatments.

Another finding of our study, but not statistically significant, was that under-five children born by mothers in the age group 20-34 are less likely to die compared to their counterparts born by mothers below 20 years, while those born by mothers aged above 34 years were found to face the highest risk of death before the age of five. This is because a too young mother is likely to deliver prematurely low weight babies, probably due to mother's biological immaturity, less prenatal care and lack of experience, while mothers older than 35 are likely more affected by health problems such as high blood pressure or diabetes that may lead to serious health problems for both mothers and newborns.

The previous birth interval less than two years compared to 'no interval' significantly increased the risk of under-five child death, while a birth interval of more than three years decreased the risk of death, though this latter was not statistically significant. This finding demarcated the minimum interval between births as three years, which have important policy implications.

Mother's education, though not statistically significant, was negatively associated with under-five mortality. Probably, educated mothers are exposed to better health and nutrition information and have more control over resources and, thus, can make appropriate health-seeking decisions.

In our study household wealth was statistically significantly associated with under-five deaths, as children belonging to the richest quintile were less likely to die before their fifth birthday compared to their counterparts, especially those from the poorest quintile. It is obvious that rich people have better access to early prevention and timely treatment services, as well as enjoy proper nutrition and healthy environment. During the last decade, Sudan witnessed economic hardship after the secession of South Sudan and the loss of oil revenues; as a result, the middle class dropped below the poverty line; thus, we showed no significant differences among wealth quintiles, except for the richest group.

The frailty model revealed that children in some states are more exposed to under-five deaths compared to others, and this is an essential contribution of this study. This finding suggests that different policies and interventions should be probably designed and planned for different states. More specifically, children from some regions of residence such as Eastern, Darfur, and Kordufan were more likely to die before the age of five compared to those living in Khartoum, whereas the likelihood of death was much lower in the Northern region. It is worth noting that people from regions with a higher hazard of child mortality witnessed prolonged periods of civil war, with negative consequences. Many recent studies articulated plainly the inverse impacts of wars, economic hardship, environmental crises and the inequalities between developed and developing countries on children's life and well- beings [9, 36, 37].

Despite the frailty model detects the correct relationships, and previous studies supported our findings, contrary to our expectations, low education of mother, rural areas, age of mothers, and previous birth intervals (except for < 2 years interval) were proved not to be statistically significant determinant of under-five mortality. These unexpected results could be attributed to the exclusion of important covariates from our analyses. This study, indeed, is not without limitations. For example, some important health variables such as vaccination and breastfeeding were collected only for living children and, thus, they were not included in the model. Moreover, data was collected by interviewing surviving women and caretakers; hence, it is more likely that data was subject to recall bias as caretakers were not generally aware of all information. Despite these limitations, the study has some strengths. First of all, the study addresses the issue of model selection, by confirming the availability of the frailty model for similar studies. Moreover, our analysis has important policy implications. Indeed, we showed that poor children are still more likely to die, and children in some regions are more exposed to under-five mortality compared to their counterparts from other regions. Based on these findings, the Federal Ministry of Health should revisit its strategic plans and address, for example, family planning issues to increase the gap between births, develop a plan for giving twin births special care and formulating targeted actions against poverty.

In conclusion, this was one of the few studies that used survival analysis to identify the determinants of under-five mortality in Sudan, and implicitly assessed the existing health plans.

However, further studies are needed to analyze under-five mortality by focusing on socioeconomic, demographic, environmental, and biological data.

Acknowledgments

The authors acknowledge the Central Bureau of Statistics, Sudan, for conducting the Multiple Indicators Cluster Survey and providing data for this study. We also would like to thank Professor Donald B. White and Dr. Chen, Tian, from the Department of Mathematics and Statistics, University of Toledo, Ohio, for their valuable comments and for preparing a seminar to discuss the findings. We also thank Dr. Ahmed E. Ismail for editing the paper.

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