

1 **Abstract**

2 **Background:** Low-and Medium-Income Countries (LMIC) continue to record high burden of
3 under-five deaths (U5D). There is a gap in knowledge of the factors contributing to housing
4 materials inequalities in U5D. This study examined the contributions of the individual- and
5 neighbourhood-level factors to housing materials inequalities in influencing U5D in LMIC.

6 **Methods:** We pooled data from the most recent Demographic and Health Surveys for 56 LMIC
7 conducted between 2010 and 2018. In all, we analysed the data of 798,796 children living in
8 59,791 neighbourhoods. The outcome variable was U5D among live births within 0 to 59
9 months of birth. The main determinate variable was housing material types, categorised as
10 unimproved housing materials (UHM) and improved housing materials (IHM) while the
11 individual-level and neighbourhood-level factors are the independent variables. Data were
12 analysed using Fairlie decomposition analysis at $\alpha=0.05$.

13 **Results:** The overall U5D rate was 53 per 1000 children, 61 among children from houses built
14 with UHM, and 41 among children from houses built with IHM ($p<0.001$). This rate was higher
15 among children from houses that were built with UHM in all countries except in Malawi,
16 Zambia, Lesotho, Gambia, Liberia, Sierra Leone, Indonesia, Maldives, Jordan, and Albania.
17 None of these countries had significant pro-IHM inequality. The factors explaining housing
18 inequalities in U5D include household wealth status, residence location, source of drinking
19 water, media access, paternal employment, birth interval, and toilet type.

20 **Conclusions:** There are variations in individual- and neighbourhood-level factors driving
21 housing materials inequalities as it influences U5D in LMIC. Interventions focusing on
22 reducing the burden of U5D in households built with UHM are urgently needed.

23 **Keywords:** Under-five deaths, Housing material inequality, Low-and middle-income
24 countries

1 **Background**

2 The implementation of the adopted international framework of the United Nations Convention
3 on the Rights of the Child and other global interventions including the Global Strategy for
4 Women's, Children's and Adolescent's Health, the Millennium Development Goals, and the
5 Sustainable Development Goals (SDGs) (1) by the global community, have led to a significant
6 reduction in childhood deaths worldwide. Globally, there has been a decline in under-five
7 deaths (U5D) from 93 deaths per 1000 live births in 1990 to 38 deaths per 1000 live births in
8 2019 (2). A reduction in U5D by more than two-thirds were recorded in more than 80 countries
9 inclusive of 31 Low- and lower-middle-income countries in 2019 (LMIC) (3).

10 Despite these achieved level of U5D reduction worldwide, U5D remains unacceptably high
11 across certain countries and regions of the world (Figure 1) (4). Some of these countries are
12 found in Africa, Asia and to some extent in Latin America. Countries with the highest U5D
13 include the Democratic Republic of Congo, Ethiopia, India, Nigeria, and Pakistan (2,3). In
14 2019, 5.2 million children under age five died globally representing 14,000 deaths daily (5).
15 More than half of these deaths occurred in sub-Saharan Africa. The under-five mortality rate
16 was 41 deaths per 1000 live births in LMIC as compared to 5 deaths per 1000 live births in
17 high-income countries in 2019 (3).

18 Studies have shown that infectious diseases, including acute respiratory infections, measles,
19 malaria and diarrhoea are leading direct causes of U5D, while the indirect causes are most
20 especially the socio-economic, environmental and behavioural factors (6). Difficulties
21 associated with accessing fundamental lifesaving care such as the skill of birth attendant,
22 postnatal care, adequate dietary intake, and vaccinations against common childhood diseases
23 also predispose children to the risk of dying before the age of five years. Other factors that have
24 been linked with U5D include the child gender, weight at birth, birth interval, and birth order,

1 multiple births, maternal education, maternal age, marital status, maternal and paternal
2 occupation, sex of the head of the household, access to media, sources of drinking water, toilet
3 type, type of cooking fuel, household wealth index, place of residence and the type of housing
4 materials with which a house is built (2,7). The wellbeing of household occupants is also a
5 reflection of the building materials with which the house is built (8,9).

6 Children's homes are a key determinant of their environment (10). It is also one of the major
7 determining factors in their health outcome (11). Poor housing conditions are one of the ways
8 through which social and environmental inequalities lead to health inequality (11). Poor
9 housing conditions can elicit a range of diseases including respiratory infections, mental and
10 behavioural dysfunction and neurological disorders which impact negatively on children's
11 health (12). It is also a risk factor for U5D. Previous study have established the fact that the
12 probability of a child dying before the age of 5 years was likely to be higher among children
13 who lived in houses built with unimproved materials than those living in houses built with
14 improved materials (9).

15 Literature is replete that inequality exists in the proportion of U5D and housing type (9).
16 However, there is a gap in the literature on what factors contributes to this inequality.
17 Understanding these factors that contribute to housing materials inequalities in USD can
18 provide useful information needed to further reduce the burden of U5D in LMIC. This study is
19 therefore designed to identify and quantify the contributions of the factors that determine the
20 inequalities in U5D among children from houses built with improved housing materials and
21 unimproved housing materials.

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1 **Methods**

2 **Study design and data**

3 Data for this cross-sectional study were obtained from ICF, the primary owner and implementer
4 of Demographic and Health Surveys (DHS) across countries worldwide. These surveys are
5 nationally representative household surveys conducted in LMIC. This study used data from 56
6 recent DHS conducted between 2010 and 2018 and available in the public domain as at 15th of
7 September 2020 when the data were harvested from dhsprogram.com. The DHS uses a multi-
8 stage, clustered and stratified sampling design with households as the sampling frame using an
9 individual country's most recent census as a sampling frame. Typically, the upper stages
10 include states or districts, or regions depending on country-specific administrative
11 nomenclatures. The last stage of the multi-stage sampling is the selection of clusters from
12 which households are selected. The clusters are referred to as the primary sampling units
13 (PSUs) (13,14). All eligible women (aged 15 to 49 years) and men (aged 15-65 years) within
14 each sampled household were interviewed. The surveys were not self-weighting. Therefore,
15 sampling weights were calculated for all participants to account for unequal selection
16 probabilities as well as for non-response. The application of the sampling weights ensures that
17 survey findings represent the full target population. The DHS data include household data,
18 women's data, birth recode data and children recode data and men's data. However, the present
19 study made use of the children recode data. Further details of the sampling methodologies are
20 available at dhsprogram.com. In all, we pooled the data of 798,796 children, living in 59,791
21 neighbourhoods nested within 56 countries.

22 **Outcome variable**

23 The outcome variable in this study is under-five death (U5D). Under-5 deaths is death among
24 live births within the first five years of life. It is defined as all deaths within 0 to 59 months of
25 birth (ICF International Inc., 2012; Kenya National Bureau of Statistics & ICF International,

1 2015; National Population Commission (NPC)[Nigeria] & ICF International, 2019). To ensure
2 the completeness and correctness of this variable, mothers were asked to name all their
3 livebirths within five years preceding the date of the study. They were then asked if each of
4 those children were alive or dead. The dates of death, the ages at death for the dead children
5 and survival status were then used to determine U5D. Under-5 death was coded as a
6 dichotomous variable: Alive or Died before 5th birthday.

7 **Main determinant variable**

8 The main determinate variable is the quality of the materials used to build houses where
9 children under 5 years of age live. It was derived from the three sub-variables. These are the
10 materials used for the house floor, wall and roof. During the survey, the enumerators personally
11 observed these housing materials. The DHS provided a guideline for the classification of
12 materials used for any of these three parts of the house as either improved or not. The
13 classifications are (i) the improved floor materials are cement, ceramic tiles, vinyl asphalt
14 strips, parquet and polished wood while the unimproved floor materials are earth, sand, dung,
15 rudimentary, wood planks, palm, bamboo, and others; (ii) the improved wall materials include
16 cement, stone with lime/cement, cement blocks and bricks while the unimproved wall materials
17 are no wall, cane/palm/trunks, dirt, rudimentary, bamboo with mud, stone with mud, uncovered
18 adobe, plywood, and others (iii) the improved roof materials are cement and roofing shingles
19 while the unimproved materials consist of no roof, thatch/palm leaf, sod, rudimentary, rustic
20 mat, palm/bamboo, wood planks, cardboard, wood, and others (15–18). Each of the improved
21 floor, wall and roof materials were scored "1" while unimproved materials were scored "0".
22 We then summed these scores. Houses with ≥ 2 scores out of the maximum obtainable 3
23 scores were classified as houses built with improved housing materials (IHM) while houses
24 with <2 scores were categorized as houses built with unimproved housing materials (UHM).

1 **Independent variables**

2 The independent variables consist of individual-level and neighbourhood-level factors
3 identified in the literature to be associated with childhood deaths.

4 *Individual-level factors*

5 The children characteristics, mothers' characteristics and the households' characteristics
6 constitute the individual-level factors. The children characteristics are sex (male, female),
7 weight at birth (average+, small and very small), birth interval (firstborn, <36 months and ≥36
8 months) and birth order (1, 2, 3 and 4+), a child is a twin (single, multiple (2+)). The maternal
9 characteristics: maternal education (none, primary or secondary plus), maternal age (15 to 24,
10 25 to 34, 35 to 49), marital status (never, currently and formerly married), maternal and paternal
11 employment status (working or not working), health insurance (yes /no). The household
12 characteristics include the sex of the head of the household (male or female), access to media
13 (at least one of radio, television, or newspaper), sources of drinking water (improved or
14 unimproved), toilet type (improved or unimproved), cooking fuel (clean fuel or biomass),
15 housing materials (improved or unimproved) and household wealth index (poorest, poorer,
16 middle, richer and richest), place of residence (rural or urban).

17 *Neighbourhood-level factors*

18 Neighbourhood was operationalized as the clustering of children. The DHS uses "clusters" as
19 the PSU. People of the same cluster are very likely to share similar contextual factors (13,14).
20 We regard children as "neighbours" if they belong to the same cluster. In this study, we
21 computed neighbourhood socioeconomic status (SES) as a neighbourhood-level from the
22 proportion of mothers within the same clusters without education, belonging to a household in
23 two lowest wealth quintiles, no media access and unemployed using the principal component
24 factor method.

1 **Statistical analyses**

2 The analytical approach for this study included descriptive statistics, bivariable analysis and
3 multivariable decomposition analysis. Descriptive statistics to show the distribution of the
4 children's background characteristics as well as the distribution of USD among the children
5 from houses with IHM and UHM by countries and characteristics. The bivariable analysis was
6 conducted using the Z-test to determine the equality of proportions of USD among the children
7 from houses with IHM and UHM within each country and region (Table 1). Charts were used
8 for visualization. The spatial distribution of under-five deaths per 1000 livebirths among
9 children in houses with improved and unimproved housing materials are shown in Figure 1.
10 The maps were built in Microsoft Projects 2020.

11 We calculated the risk differences (RD) in U5D among the children from houses with IHM and
12 UHM. A risk difference greater than 0 suggests that U5D are higher among the children from
13 houses built with UHM than those from IHM (pro-unimproved housing material). Conversely,
14 a negative RD indicates under-5 deaths are higher among the children from houses with IHM
15 than those from UHM (pro-improved housing material). We carried out country-level meta-
16 analysis of the prevalence of U5D in each of the countries by computing the risk difference in
17 the development of U5D between U5C from houses with improved and unimproved housing
18 materials and presented the results in Figure 2. A random-effects meta-analysis was used on
19 the assumption that each country is estimating a study-specific true effect. We implemented
20 the meta-analysis in R software by specifying the summary measure (SM) as risk difference
21 (RD), the number of deaths in houses with improved and unimproved housing materials as well
22 as the numbers of participants for each country, grouped by regions using the “metabin”
23 command in R. We built a 95% confidence interval (CI) around the RDs to determine their
24 significance.

1 The Mantel-Haenszel (MH) Odds Ratio (OR) and tests of heterogeneity of ORs were conducted
2 to ascertain that the countries are different with regards to the odds ratio of USD among
3 children from houses with IHM and UHM and a test of homogeneity of ORs among all the
4 countries with a significant odds ratio of USD to determine if the odds of having USD death in
5 those countries are homogenous. Finally, the Fairlie decomposition analysis (FDA) techniques
6 using logistic models was applied.

7 Sampling weights were applied in all the analysis in this study to adjust for unequal cluster
8 sizes, stratifications and to ensure that our findings adequately represent the target population.

9 Multicollinearity among the independent variables was tested using the "colin" command in
10 Stata version 16. The command provided the variance inflation factor (VIF). The VIF is an
11 approximate of $1/(1-R^2)$ ranging from 1 to infinity. The R^2 -value is obtained by regressing t_j^{th}
12 independent variable on other independent variables. All variables with $VIF > 2.5$ were removed
13 from the regression analysis. Literature has shown concerns about $VIF > 2.5$ (19).

14 The FDA technique is an offshoot of the well-known Blinder-Oaxaca decomposition analysis
15 technique that was originally developed for linear models (20–22). FDA was developed
16 following the inefficiency of the Blinder-Oaxaca decomposition analysis technique in handling
17 non-linear outcomes such as logit or probit models (23–27). The FDA was developed for non-
18 linear regression models and used in the quantification of the contributions to differences in
19 the prediction of an outcome of interest between two groups (28). This technique is a
20 counterfactual method with an assumption that "what the probability of under-5 death would
21 be if children from houses built with UHM had the same characteristics as the children whose
22 houses are built with IHM?".

23 The FDA allows for the decomposition of the difference in an outcome variable between 2
24 groups (children from houses with IHM and UHM) into 2 components. The first component is

1 the "explained" (also referred to as the "compositional" or "endowments") portion of that gap
2 that captures differences in the distributions of the measurable characteristics. The explained
3 part is the portion of the gap in USD attributable to the differences in observable, measurable
4 characteristics between children from houses with IHM and UHM. This method helps to
5 quantify how much of the gap between the children from houses with UHM and the children
6 from houses with IHM is attributable to these differences in specific measurable characteristics.
7 The second component of the model is the "unexplained" (also referred to as the "structural"
8 component or the "coefficient") part. The unexplained part is the portion of the gap due to the
9 differences in the estimated regression coefficients and the unmeasured variables between the
10 two groups.

11 The Fairlie decomposition technique works by constraining the predicted probability between
12 0 and 1 as available in a logit model. The coefficients (β) estimated by the logit regression
13 technique with the probability of under-5 deaths conditioned on the independent variables (X)
14 is obtained as

15
$$Pr(U5D = 1|X) = \frac{e^{X'\beta}}{1 + e^{X'\beta}} \dots \dots \dots (1)$$

16 We carried out an FDA analysis by calculating the difference between the predicted probability
17 for Group A (children from houses with UHM) using the Group B (children from houses with
18 UHM) regression coefficients and the predicted probability for under-5 deaths among Group
19 B using its regression coefficients (24).

20 Fairlie et al. showed that the decomposition for a nonlinear equation $Y = F(X)$, can be
21 expressed as:

$$1 \quad \bar{Y}^A - \bar{Y}^B = \left[\sum_{i=1}^{N^A} \frac{F(X_i^A \hat{\beta}^A)}{N^A} - \sum_{i=1}^{N^B} \frac{F(X_i^B \hat{\beta}^A)}{N^B} \right] + \left[\sum_{i=1}^{N^B} \frac{F(X_i^B \hat{\beta}^A)}{N^B} - \sum_{i=1}^{N^B} \frac{F(X_i^B \hat{\beta}^B)}{N^B} \right] \dots \dots \dots (2)$$

2 Where N^A is the sample size for group J (29). In equation (1), \bar{Y} is not necessarily the same as
3 $F(\bar{X} \hat{\beta})$, unlike in BODA where $F(X_i \beta) = X_i \beta$. The 1st term (explained) is the part of the gap
4 in the binary outcome variable that is due to group differences in distributions of X , and the
5 2nd term (unexplained) is the part due to differences in the group processes determining levels
6 of Y (under-5 deaths). The 2nd term also captures the portion of the binary outcome variable
7 gap due to group differences in unmeasurable or unobserved endowments.

8 The estimation of the total contribution is the difference between the average values of the
9 predicted probabilities. Using coefficient estimates from a logit regression model for a pooled
10 sample, $\hat{\beta}^*$, the independent contribution of X_1 and X_2 to the group, the gap can be written as

$$11 \quad \frac{1}{N^B} \times \sum_{i=1}^{N^B} F(\hat{\alpha}^* + X_{1i}^A \hat{\beta}_1^* + X_{2i}^A \hat{\beta}_2^*) - F(\hat{\alpha}^* + X_{1i}^B \hat{\beta}_1^* + X_{2i}^A \hat{\beta}_2^*) \dots \dots \dots (3)$$

12 and

$$13 \quad \frac{1}{N^B} \times \sum_{i=1}^{N^B} F(\hat{\alpha}^* + X_{1i}^B \hat{\beta}_1^* + X_{2i}^A \hat{\beta}_2^*) - F(\hat{\alpha}^* + X_{1i}^B \hat{\beta}_1^* + X_{2i}^B \hat{\beta}_2^*) \dots \dots \dots (4)$$

14 respectively. The contribution of each variable to the gap is thus equal to the change in the
15 average predicted probability from replacing the group B distribution with the group A
16 distribution of that variable while holding other variables constant. Other detailed numerical of
17 this approach have been reported in the literature (24,25,27,29,30). We implemented the FDA
18 in STATA 16 (StataCorp, College Station, Texas, United States of America) using the "Fairlie"
19 command.

1 **Results**

2 Table 1 shows the distribution of U5D across children from houses built with UHM and IHM
3 by countries and regions. The overall prevalence of houses with UHM was 58.8%. The highest
4 proportion of children from houses built with UHM was found in Papua New Guinea (99.2%)
5 and least in Albania at 2.4%. The overall weighted prevalence of U5D was 53 per 1000
6 children, 61 among children from houses built with UHM and 41 among children from houses
7 built with IHM ($p < 0.001$). The prevalence of U5D among children from houses built with
8 UHM ranged from 3 per 1000 children in Albania to 120 in Nigeria, while it ranged from 4 in
9 Albania to 119 in Sierra Leone among children from houses built with IHM. The z-test of
10 equality of prevalence among children from houses built with UHM and IHM was statistically
11 significant ($p < 0.05$) in Afghanistan, Angola, Bangladesh, Benin, Burkina Faso, Burundi,
12 Cambodia, Cameroon, Congo DR, Cote d'Ivoire, Dominican Rep, Ethiopia, Guatemala,
13 Guinea, India, Kenya, Mali, Mozambique, Myanmar, Niger, Nigeria, Pakistan, Peru, Senegal,
14 South Africa, Timor Leste, and Togo. The spatial distribution of U5D per 1000 livebirths
15 among children in houses with improved housing materials are shown in Figure 2(a) and 2(b)
16 respectively.

17 Table 2 shows the descriptive statistics of the characteristics of the children across the 56 LMIC
18 and prevalence of U5D by the quality of housing materials. The overall U5D was highest
19 among multiple births compared with singletons (20.3% vs 5.6%). These rates were 23.3% vs
20 5.6% among children from houses built with UHM and 15.8% vs 3.8% among children from
21 houses built with IHM. Also, the prevalence of U5D was highest among females than males
22 (59.2% vs 58.5%), among children using unimproved water sources (80.8%) and unimproved
23 toilets (77.1%).

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1 **Risk Differences in U5D among children from UHM and IHM**

2 The risk differences of U5D among children from houses built with UHM and IHM across the
3 countries studied are presented in Figures 3, 4 and 5. A meta-analysis of the prevalence of U5D
4 among children from houses built with UHM and IHM in each of the countries was carried out
5 and presented the results in Figure 3. The prevalence of U5D was generally higher ($RD > 0$)
6 among children from houses built with UHM in all the countries (pro-UHM inequality) except
7 in Malawi, Zambia, Lesotho, Gambia, Liberia, Sierra Leone, Indonesia, Maldives, Jordan and
8 Albania with $RD < 0$. None of these countries had significant pro-IHM inequality. The
9 heterogeneity of the RDs was 88% ($p < 0.01$).

10 Irrespective of regions, the fixed effects of pro-UHM differences in U5D were largest in
11 Nigeria (46.5/1000 children) while the fixed effects of pro-IHM RD were largest for Lesotho
12 (-9.9/1000). The random effect, which is the RD of U5D irrespective of country of residence
13 was 11.8/1000 children (95% CI: 8.4-15.3). The greatest contribution to the weight of the
14 random effect was found in India at 2.3% while the least was in Papua New Guinea at 0.6% as
15 shown in Figure 3.

16 **Risk difference and prevalence of under-5 deaths and magnitude of housing material** 17 **inequality**

18 In Figures 4 and 5, we used red and orange colours to depict the countries with significant pro-
19 UHM inequality and insignificant inequality respectively. There was no statistically significant
20 pro-IHM inequality in any of the countries. Figures 4 and 5 showed that four of the nine
21 countries in Eastern Africa, three of the six countries in Middle Africa, only South Africa in
22 Southern Africa and nine of the 13 countries in West Africa, four of the seven countries in
23 Southern Asia and three countries in the Caribbean showed statistically significant pro-UHM
24 inequality. No country in South-Eastern Asia and Oceania, one country each in Central Asia,

1 Western Asia, Central America, and South America showed statistically significant pro-UHM
2 inequality (Figures 3, 4 and 5).

3 **Relationship between the prevalence of U5D and magnitude of inequality**

4 The relationships between the prevalence of U5D and the magnitude of the inequality by the
5 differences in the houses, where the children's lives were built of improved or unimproved
6 materials in the 56 countries involved in this study, are presented in Figure 4. We categorised
7 the countries into four distinct categories based on their prevalence of U5D and sizes of the
8 inequalities in each country: (i) High U5D and high pro-UHM inequality countries such as
9 Cote D'Ivoire, Nigeria, Mali, Niger and Burkina Faso (ii) High U5D and high pro-IHM
10 inequality countries such as Sierra Leone, Liberia and Lesotho (iii) Low U5D and high pro-
11 UHM inequality countries such as Dominican Republic, India, Cambodia, and South Africa
12 (iv) Low U5D and high pro-IHM inequality countries such as Jordan and Gamb

13

14 **Decomposition of factors in the prevalence of U5D by inequalities in the improvement of** 15 **housing materials**

16 The Mantel-Haenszel (MH) pooled estimate of the odds ratio (OR) of having U5D controlling
17 for the countries of the children. We estimated MH-OR = 1.33 (95% CI: 1.30-1.36) and tested
18 a null hypothesis: OR=1; and obtained $z = 23.8$ ($p < 0.001$) and (ii) Test of heterogeneity: $X^2 =$
19 207.3 , degree of freedom (d.f.) = 55 ($p < 0.001$), I-squared (variation in odds ratio (OR)
20 attributable to heterogeneity) = 73.5%. Of the 56 countries, statistically significant pro-UHM
21 was found in only 26 countries. The countries are Afghanistan ($p = 0.001$), Angola ($p < 0.0001$),
22 Bangladesh ($p = 0.010$), Benin ($p = 0.001$), Burkina Faso ($p < 0.0001$), Burundi ($p = 0.005$),
23 Cambodia ($p < 0.0001$), Cameroon ($p = 0.048$), Congo DR ($p = 0.001$), Cote d'Ivoire ($p = 0.010$),
24 Dominican Rep ($p < 0.0001$), Ethiopia ($p = 0.000$), Guatemala ($p < 0.0001$), Guinea ($p < 0.0001$),
25 India ($p < 0.0001$), Kenya ($p = 0.000$), Mali($p = 0.006$), Mozambique ($p < 0.0001$), Niger

1 (p=0.004), Nigeria (p<0.0001), Pakistan (p<0.0001), Peru (p<0.0001), Senegal (p<0.0001),
2 South Africa (p<0.0001), Timor Leste (p<0.0001), and Togo (p=0.005).

3 The test of homogeneity of the odds of U5D among the children from the pro-UHM countries
4 showed that ORs: $X^2 = 95.10$, d.f. = 25, and $p = 0.001$. We then computed the Mantel-Haenszel
5 pooled estimate of the odds ratio (OR) of having U5D among the children in the 26 countries
6 with pro-UHM inequalities while controlling for the countries. We had MH-OR= 1.42 (95%
7 CI: 1.38-1.46).

8 The 26 LMIC with pro-U5H inequality in U5D were included in the Fairlie decomposition
9 analysis. Figure 6 shows the detailed decomposition of the part of the pro-UHM inequality
10 caused by compositional and structural effects of the factors associated with U5D. The red
11 boxes in the heat map are the "explained" (compositional component) while the "unexplained"
12 (structural component) portions of the pro-UHM inequalities are depicted in blue boxes as
13 shown in Figure 5. The lighter the red colour, the lower the percentage contribution of the
14 "explained" portion and the lighter the blue colour, the lower the percentage contribution of the
15 "unexplained" portion.

16 We found wide variations in the factors associated with the pro-U5H inequalities across the
17 countries. There was clustering among household wealth status, residence location, source of
18 drinking water, media access, paternal employment, birth interval and toilet type while
19 maternal education, neighbourhood SES, birth order and cooking fuel formed another cluster.
20 All these factors contributed mostly to the inequalities. Also, Ethiopia, Bangladesh, Cameroun,
21 Afghanistan and Niger formed a cluster of countries with similar associated factors with U5D
22 while India, Congo DR, Cambodia and Cote d'Ivoire formed another cluster.

23 Different factors had the largest association with U5D in different countries. In Ethiopia, the
24 greatest contributions to pro-UHM equalities are household wealth status (1728% - 17 times

1 higher odds of death among children from the richest household compared with those from
2 poorest households), residence location (752%), drinking water sources (450%), maternal
3 education (307%) and cooking fuel (135%). Neighbourhood SES (236%), household wealth
4 status (288%), cooking fuel (233%), media access (201%) and residence location (174%)
5 contributed most to pro-UHM in Bangladesh. In Cote d'Ivoire, the largest contributions to pro-
6 UHM inequality in U5D were household wealth status (132%), residence location (119%), and
7 neighbourhood SES (99%).

8 **Discussions**

9 This study identified factors that contributed to housing material inequality in U5D in 56
10 LMIC, on which limited research has previously been conducted. The most salient findings
11 show that (1) higher prevalence of U5D was recorded among children living in houses built
12 with UHM in 46 out of 56 countries studied (2) there was no statistically significant pro-IHM
13 inequality in any of the countries but significant pro-UHM was recorded in only 26 countries
14 (3) factors associated with the pro-UHM and pro-IHM inequalities in U5D differ widely across
15 countries.

16 The highest U5D was recorded among twin births compared with singletons. The rates were
17 23.3% vs 5.6% among children from houses built with UHM and 15.8% vs 3.8% among
18 children from houses built with IHM. A startling one-fifth of twins died before attaining age
19 5 years in sub-Saharan Africa. The risk of dying is three times higher among multiple births
20 compared to singletons (31). The rate of U5D is two to five times higher among twin birth
21 compared to singletons in regions known for low childhood deaths (31) and in sub-Saharan
22 countries where the highest global U5D has been observed in the recent times (32,33). There
23 is a higher probability of U5D among twins than singletons in households sourcing water from
24 unimproved sources. Since twins start complimentary food much earlier than singletons, the
25 use of unimproved water in the preparation of complementary foods could contaminate such

1 foods with gastroenteritis which are risk factors for communicable diseases and malnutrition
2 (34,35). This may explain the higher U5D recorded among twin births. Our study showed
3 evidence of higher U5D among children from households with unimproved water sources and
4 unimproved toilet. Drinking water from unimproved sources and the use of unimproved toilet
5 make children more vulnerable to diarrhoea, parasitic and helminthic infections which may
6 compromise their nutritional status and make them susceptible to poor health outcomes (36–
7 38).

8
9 Moreover, the proportion of pro-UHM inequality (99.2%) was highest in Papua New Guinea
10 (PNG) and least in Albania (2.4%). Papua New Guinea is a low resource, and
11 socioeconomically diverse country (39,40) with the majority of the people occupying the low
12 socio-economic cadre and thus cannot access quality and affordable housing (41,42). Although,
13 PNG has the highest number of houses built with UHM, it did not translate to high U5D in the
14 country. This might be unconnected with the non-existence of reliable data to measure
15 childhood mortality in PNG. PNG relies mostly on the use of civil registration and routine
16 health data which have been reported to be incomplete, deficient and inaccurate for measuring
17 childhood mortality in the country (43).

18
19 Findings from this study show that Nigeria has the highest rate of U5D among children from
20 houses with UHM. This result gave credence to the study by Adebowale et al. who investigated
21 if housing materials were a predictor of U5D in Nigeria using the DHS 2013 dataset (9). They
22 reported that the hazard of U5D was 1.46 higher among children who lived in houses with
23 UHM than those in IHM. The refined U5D estimates in houses with UHM and IHM was 143.5
24 and 90.8 per 1000 live births, respectively (9). Living in houses built with unimproved
25 materials can predispose children to a range of health morbidities that culminate in deaths. For

1 instance, the odds of malaria infection was significantly higher among under-five children who
2 lived in houses built completely with unimproved materials than those living in improved
3 housing materials in Nigeria (18). In 2018, children under-5 years made up 67% (272 000) of
4 global malaria deaths. Nigeria accounted for 24% of all malaria global deaths (44). In another
5 study conducted among under-five children in Nigeria, more cases (65.2%) than controls
6 (42.4%) who were diagnosed with respiratory infections lived in houses of poor quality (45).
7 Pneumonia, a form of acute respiratory infection, is one of the highest causes of U5D in Nigeria
8 killing more than 140,000 annually (46).

9 The RD in U5D between houses built with UHM and those built with IHM was obvious across
10 countries. Forty-six countries recorded higher U5D ($RD > 0$) in houses with pro-UHM
11 inequality than the ten countries with pro-IHM inequality ($RD < 0$). In the regions, statistically
12 significant pro-UHM inequality in U5D was found in four Eastern countries (Burundi,
13 Ethiopia, Kenya, Mozambique), nine Western African countries (Benin, Burkina Faso, Cote
14 D'Ivoire, Guinea, Mali, Niger, Nigeria, Senegal, Togo), four Southern Asian countries
15 (Afghanistan, Bangladesh, India, Indonesia), three in Caribbean countries (Dominican,
16 Myanmar, Timor-Leste). Countries in South-Eastern Asia (Cambodia, Philippines), Oceania
17 (Papua New Guinea), Central Asia (Kyrgyz Rep, Tajikistan), Western Asia (Armenia, Yemen,
18 Jordan), Central America (Honduras), and South America (Peru) had no statistically significant
19 pro-UHM inequality. An RD of 12 per 1000 children observed among countries with
20 significant pro-UHM inequality suggests that more deaths will be recorded among children
21 whose mothers lived in houses with UHM than those from houses with IHM. One probable
22 reason for the differences in the housing materials inequalities can be attributed to country-
23 level factors which cut across individual, household and neighbourhood factors and varies
24 across LMIC (47–49). There is the need for urgent intervention in LMIC by the government
25 and relevant stakeholders through the provision of low-cost and sustainable housing, and the

1 enforcement or initiation of policies and programmes that encourage the maintenance of
2 existing housing units.

3

4 Moreover, our findings show the relationship between the prevalence of U5D and the
5 magnitude of housing material inequality. Countries such as Maldives, Armenia, Jordan and
6 Albania have USD of less than 25 per 1000 births which were what the SDG is targeting. The
7 WHO had reported an 80% reduction in the prevalence of U5D in Eastern and South-Eastern
8 Asia countries (50). This achievement was attributed to the political will of the government of
9 these countries to implement primary health care and universal health coverage through
10 improved access to quality care, free health services for mothers and children, family planning
11 support and capacity building of health workers (50).

12

13 However, countries such as Nigeria, Mali, Niger, Burkina Faso and Guinea have high U5D and
14 high-risk differences between children living in houses from UHM and IHM. A weak health
15 system, political and economic instability among other factors that prevent mothers and their
16 children from accessing quality lifesaving healthcare services have been identified as the cause
17 of high U5D in Cote D'Ivoire, Nigeria, Mali, Niger and Burkina Faso. Countries such as
18 Nigeria, Mali, Niger, Burkina Faso and Guinea should learn from other countries (Maldives,
19 Armenia, Jordan and Albania) with low U5D and low-risk differences between living in houses
20 from UHM and IHM, by taking urgent steps towards the realization of target 3.2 of the SDGs.
21 It is interesting to note that there was no statistically significant pro-IHM inequality in any of
22 the countries. This further shows the link between good housing quality and improved health
23 and wellbeing of its inhabitants (8,9,51).

24

1 We found wide variations in the factors explaining the housing material differentials in the
2 prevalence of U5D in LMIC. Children from households with poor wealth quintile, who resides
3 in rural areas, drink water from unimproved sources, uses unimproved toilet types, have poor
4 access to media, have short birth interval and fathers that are unemployed have a higher
5 probability of having pro-UHM inequality in experiencing U5D. These findings are consistent
6 with previous studies (7,52,53).

7

8 An individual choice of housing type, features, size and quality are dependent on several factors
9 including socio-economic factors (54). In LMIC, households with poor wealth quintile have
10 limited choices and are more likely to live in houses built with inferior materials, and have less
11 to spend on maintenance and repairs (54,55) which invariably increases the likelihood of child
12 death. The outcome of lengthy non-maintenance of buildings includes dilapidated structures,
13 leaking ceiling and pipes, peeling off of paints and cracks and holes in walls and floors. Cracks
14 on walls and floors provide a conducive environment for mites, respiratory viruses and
15 cockroaches to breed; all of which elicit respiratory morbidity (9,51,56). Also, housing
16 disrepair can act as stressors thus compromising the human immune system (54).

17 .

18 Moreover, poverty is also a predictor of unclean fuel use in LMIC (57,58). When unclean fuel
19 is burnt, it releases harmful pollutants such as respirable particulate matter and carbon
20 monoxide into the atmosphere (59). A child's exposure to fumes from unclean fuel can suppress
21 the functioning of the immune system while increasing bronchial reactivity, which promotes
22 susceptibility to bacterial and viral pathogens (60,61). Respiratory infections from unclean fuel
23 is a major cause of deaths among children (59,62).

24

1 Nonetheless, the use of unimproved toilet facilities hinders safer disposal of faeces and
2 promotes the risk of contact between diarrhoea causative organism and human host (Aziz et
3 al., 2018). Diarrhoea is a major cause of U5D in LMICs (63–65). Conversely, having an
4 educated mother, living in a neighbourhood of high SES, high birth order and cooking with
5 clean fuel reduces the probability of U5D and influenced the housing material inequalities in
6 U5D across LMIC. This position has been reported in the literature (66,67).

7 We found wide variations across countries in the factors associated with the pro-under five
8 housing inequalities. The highest contributors to pro-UHM equalities in Ethiopia are household
9 wealth status, residence location, drinking water sources, maternal education and cooking fuel.
10 Neighbourhood SES, household wealth status, cooking fuel, media access and residence
11 location contributed most to pro-UHM in Bangladesh while in Cote d'Ivoire, the largest
12 contributions to pro-UHM inequality in U5D were household wealth status, residence location,
13 and neighbourhood SES. The findings from our study bring to the fore the importance of
14 enhancing the compositional and structural factors if housing materials inequalities in U5D are
15 to be reduced. Integrated geographically specific interventions may be a better approach to
16 tackling the housing materials inequalities in U5D in LMIC with policies and programmes
17 tailored to country-specific needs.

18 **Study strengths and limitations**

19 This study is one of the first to demystify the factors associated with housing materials
20 inequality in LMIC. The representative nature of data from 59 DHS, their large sample size
21 and high response rate makes the quality of findings from the study useful for international
22 comparison. The causal relationship between housing materials and U5D could not be
23 determined because of the cross-sectional nature of this study. Also, the measure of child
24 mortality using information obtained from mothers may underestimate the actual rate as a result

1 of recall bias. The Fairlie decomposition analysis used in this study has some advantages over
2 the Blinder-Oaxaca decomposition analysis technique in handling non-linear outcomes such as
3 logit or probit model. It can effectively handle non-linear regression models and quantification
4 of the contributions to an outcome of interest between two groups.

5

6 **Conclusions**

7 In this study, we identified a high prevalence of U5D with significant pro-unimproved housing
8 materials inequalities in most LMIC. This showed that the burden of U5D, which is
9 disproportionately higher among children living in houses built with unimproved housing
10 materials compared to those in houses built with improved materials was explained by the
11 individual, household and community-level factors. The decomposition analysis revealed that
12 factors such as wealth quintile, place of residence, drinking water sources, toilet types, media
13 access, birth interval and paternal employment are the major contributors to housing
14 inequalities in most LMIC. These findings can serve as a spur for planning children's country-
15 specific survival programs. Interventions targeted towards the use of good quality materials for
16 the construction of houses and their subsequent maintenance can help reduce the burden of
17 U5D and other related health morbidities, and thus, ensures the wellbeing of their inhabitants.

18

19 **Abbreviations**

20 CI: Confidence Interval;

21 DHS: Demographic and Health Survey;

22 FDA: Fairlie Decomposition Analysis

23 IRB: Institutional Review Board;

24 LMIC: Low- And Middle-Income Countries;

25 PSU: Primary Sample Unit;

26 RD: Risk Difference;

27 SES: Socioeconomic Status;

1 PNG: Papua New Guinea;
2 U5C: Under-Five Children;
3 U5D: Under-five deaths
4 Under-5 Deaths: Under-five deaths
5 UNICEF: United Nations International Children's Emergency Fund;
6 WHO: World Health Organization;

7

8 **Declarations**

9 **Ethics approval and consent to participate**

10 We analysed secondary data collected originally by ICF in conjunction with the participating
11 countries. ICF had received ethical approval to conduct the study from the Institutional Review
12 Board (IRB) of ICF Macro at Fairfax, Virginia in the USA. IRB reviewed and approved the
13 MEASURE DHS Project Phase III. IRB in the USA. ICF granted us access and permission to
14 use the data. There were no need for further ethical approvals. DHS Program has remained
15 consistent with confidentiality and informed consent over the years. ICF ensures compliance
16 with the U.S. Department of Health and Human Services regulations for the respect of human
17 subjects. No further approval was required for this study. Further documentations on ethical
18 issues relating to the surveys are available at dhsprogram.com

19 **Consent for publication**

20 Not applicable.

21 **Availability of data and materials**

22 The datasets generated and/or analysed during the current study are available in the DHS
23 repository, <http://dhsprogram.com> with Accession number 140625.

24 **Competing interests**

25 The authors declare that they have no competing interests.

26

27

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2 The authors received no funding for this study.

3

4 **Authors' contributions**

5 OMM and AFF conceptualised and designed the study. AFF curated and analysed the data and
6 provided the visualizations. OMM did the literature search and discussions. ASA contributed
7 to the background, methods, and discussion sections. All authors (AFF, OMM and AAS)
8 contributed to data interpretation and writing of the manuscript. All authors have read and
9 approved the manuscript.

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13

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1 Table 1: Distribution of sample characteristics by countries, regions and prevalence of under-
 2 five deaths in LMIC by the quality of housing material, 2010–2018.

Country	Survey Year	Sample	Number of Neighbourhoods	UHM (%)	Under-5 Deaths per 1000 livebirth		
					Overall	UHM	IHM
Overall		798,796	59791	58.8	53	*61	41
Eastern Africa		107,839	6163	81.5	52	*54	45
Burundi	2011	13,134	554	90.3	59	*60	41
Comoros	2012	3,129	250	57.0	42	44	40
Ethiopia	2016	10,508	635	97.6	55	56	32
Kenya	2014	20,464	1544	71.2	44	*46	39
Malawi	2016	17,159	845	82.4	49	49	49
Mozambique	2011	10,950	598	85.1	74	*76	62
Rwanda	2014	7,735	487	92.3	38	38	38
Tanzania	2015	9,736	575	79.5	53	54	48
Uganda	2016	15,024	675	72.3	50	51	47
Middle Africa		74,834	2851	78.1	70	*76	50
Angola	2016	14,177	615	60.7	51	*60	38
Cameroon	2018	9,211	404	61.3	61	*65	55
Chad	2015	18,359	620	95.3	98	99	83
Congo	2012	8,858	366	52.9	50	52	48
Congo DR	2014	18,455	529	88.6	75	*77	59
Gabon	2012	5,774	317	95.0	53	53	46
Southern Africa		26,797	2447	51.1	50	51	49
Lesotho	2014	2,896	370	50.1	69	64	74
Namibia	2013	4,902	517	65.3	44	47	38
South Africa	2016	3,397	643	33.1	36	*55	26
Zambia	2018	9,733	531	63.5	49	46	53
Zimbabwe	2015	5,869	386	31.3	57	63	54
Western Africa		145,850	6021	61.4	81	*91	64
Benin	2018	13,349	551	52.7	70	*78	61
Burkina Faso	2010	14,887	569	85.4	89	*95	54
Cote d'Ivoire	2013	7,585	344	42.5	82	*93	75
Gambia	2013	7,961	278	55.5	41	40	42
Ghana	2014	5,757	416	48.0	47	48	46
Guinea	2018	7,839	396	50.2	87	*106	68
Liberia	2013	7,438	315	64.8	70	68	73
Mali	2018	9,883	344	77.6	72	*82	36
Niger	2012	12,511	475	94.5	81	*83	48
Nigeria	2018	33,480	1370	51.0	97	*120	73
Senegal	2018	6,492	208	19.8	39	*52	36
Sierra Leone	2013	11,842	432	69.5	114	111	119
Togo	2013	6,826	323	57.0	62	*75	46
Central Asia		10,146	652	36.0	29	32	27
Kyrgyz Rep	2012	4,135	300	23.7	26	33	25
Tajikistan	2017	6,011	352	43.5	30	32	28
South-Eastern Asia		17,529	1834	62.9	26	*30	21
Cambodia	2014	7,081	604	85.7	29	*32	10
Philippines	2017	10,448	1230	46.4	24	26	23
Southern Asia		322,711	31390	48.7	44	*52	36
Afghanistan	2015	32,398	945	91.2	47	*48	35
Bangladesh	2014	7,214	552	69.1	41	*45	30
India	2016	245,866	26848	41.3	44	*55	37
Indonesia	2017	17,181	1894	54.6	27	25	28
Maldives	2016	3,082	260	8.0	18	14	19
Nepal	2016	4,674	352	62.8	33	35	30
Pakistan	2018	12,296	539	66.4	66	*74	51
Western Asia		27,617	1986	26.8	33	*45	28
Armenia	2016	1,711	305	7.8	05	05	05

Jordan	2017	10,145	918	3.6	18	11	18
Yemen	2013	15,761	763	42.4	45	47	43
Central America		22,747	1948	60.4	28	*32	22
Guatemala	2014	12,252	845	50.8	31	*39	23
Honduras	2011	10,495	1103	72.4	25	27	21
South America		9,022	1318	45.9	17	*21	14
Peru	2012	9,022	1318	45.9	17	*21	14
Southern Europe		2,722	647	2.4	4	3	4
Albania	2018	2,722	647	2.4	4	3	4
Caribbean		21,755	1796	55.6	45	*50	39
Dominican Rep	2013	3,549	491	11.4	28	*51	26
Haiti	2016	6,378	438	45.7	67	73	62
Myanmar	2015	4,684	419	87.2	44	*46	28
Timor Leste	2016	7,144	448	67.1	37	*41	28
Oceania		9,227	738	99.2	40	40	23
Papua NG	2016	9,227	738	99.2	40	40	23
Total		798,796	59791	58.8	53	*61	41

*significant at 5% test of equality of proportions

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1 Table 2: Summary of pooled background characteristics of the studied children and prevalence
 2 of under-five deaths in LMIC by the quality of housing material, 2010–2018

Characteristics	sample	%	UHM (%)	Under-5 Deaths per 1000 livebirth		
				Overall	UHM	IHM
Maternal Current Age						
15-24	233,276	29.2	59.7	54	62	43
25-34	413,113	51.7	56.2	48	57	37
35-49	152,407	19.1	64.5	62	69	49
Maternal Highest Education		0.0				
No Education	283,668	35.5	75.8	70	73	59
Primary	207,148	25.9	70.1	55	57	50
Secondary+	307,980	38.6	36.4	36	43	32
Media		0.0				
No	332,556	41.7	78.2	66	68	59
Yes	465,573	58.3	45.8	44	53	36
Maternal Employment		0.0				
Employed	306,061	54.0	67.5	63	68	51
Unemployed	260,867	46.0	61.3	46	53	35
Paternal Employment		0.0				
Employed	512,803	95.7	64.9	56	63	43
Unemployed	22,993	4.3	65.1	48	53	40
Marital status		0.0				
Never married	25,286	3.2	55.7	54	57	49
Currently married	738,686	92.5	58.6	52	61	40
Formerly	34,822	4.4	65.2	66	70	58
Sex of household head		0.0				
Male	670,970	84.0	58.9	53	61	41
Female	127,826	16.0	58.1	52	58	42
Wealth index combined		0.0				
Poorest	206,972	25.9	89.8	64	65	49
Poorer	180,011	22.5	74	59	63	49
Middle	158,224	19.8	54.6	52	58	45
Richer	138,947	17.4	38.2	46	55	41
Richest	114,642	14.4	21.6	36	46	33
Covered by health insurance		0.0				
No	635,801	87.8	60.4	56	64	44
Yes	88,596	12.2	41.3	34	41	29
Child is twin		0.0				
Single birth	777,993	97.4	58.8	49	56	38
Multiple	20,803	2.6	60.7	203	233	158
Sex of child		0.0				
Female	389,073	48.7	59.2	49	56	38
Male	409,723	51.3	58.5	56	65	44
Weight at birth		0.0				
Average+	633,173	84.0	57.7	45	54	34
Small	87,302	11.6	62.4	68	76	53
Very small	33,169	4.4	66.8	116	113	123
Birth order						
1	219,586	27.5	49.9	50	62	38
2	189,166	23.7	51.5	42	50	33
3	129,778	16.2	59.2	48	53	40
4+	260,266	32.6	72.2	66	70	58
Birth interval						
1st Birth	219,591	27.6	49.9	50	62	38
<36 months	316,485	39.7	65.4	65	73	49
36+ months	260,722	32.7	58.8	39	42	34
Drinking water						
Unimproved sources	186,576	23.4	80.8	67	70	54
Improved source	612,220	76.6	52.8	49	57	40

Toilet type						
Unimproved sources	410,192	51.4	77.1	63	66	54
Improved source	388,378	48.6	40.2	42	51	36
Cooking fuel						
Unclean/biomass	617,796	77.4	70.4	60	64	52
Clean fuel	180,324	22.6	24.6	30	36	28
Place Of Residence						
Urban	235,866	29.5	32.5	42	52	37
Rural	562,930	70.5	70.9	58	63	46
Community SES Disadvantage						
Least	160,002	20.1	27.7	34	43	30
2	159,515	20.0	43.6	47	53	42
3	159,642	20.0	71.1	57	61	48
4	159,251	20.0	74.5	63	67	49
Highest	158,401	19.9	78.8	63	67	53
Total	796,672	100.0	58.8	53	61	41

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1 **Figure Legends**

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3 Figure 1: Distribution of under-five mortality rate worldwide

4 Figure 2a & b: Spatial distribution of under-five deaths among children in houses with
5 improved housing materials and houses with unimproved housing materials poor and non-
6 poor households in the LMIC studied

7 Figure 3: Forest plot of the risk difference in the prevalence of under-five deaths by the
8 improvement of housing materials in LMIC

9 Figure 4: Risk difference between children from houses with improved and unimproved
10 housing materials in the prevalence of under-five deaths by countries in LMIC

11 Figure 5: Scatter plot of rate of under-five deaths and risk difference between children from
12 houses with improved and unimproved housing materials in LMIC

13 Figure 6: Contributions of differences in the distribution 'compositional effect' of the
14 determinants of under-five deaths to the total gap between children from houses with improved
15 and unimproved housing materials among countries with pro-rural inequality

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