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Determinants of transitions in water and sanitation services in two urban slums of Nairobi: A multi-state modeling approach

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ABSTRACT

Access to improved water, sanitation, and hygiene (WASH) services at the household level remains a good strategy to improve the health and well-being of individuals. Informal settlements, such as urban slums, are at risk of the spread of diseases due to the relative lack of access to safe, clean drinking water and basic sanitation, as well as poor hygiene. Global initiatives, such as the Sustainable Development Goals (SDGs) adopted by the United Nations, are aimed at transitioning households and communities from unimproved to sustained improved states of WASH services. To deepen understanding of the time dynamics between states of WASH services in the Nairobi Urban and Demographic Surveillance System (NUHDSS), this study employs the multi-state transition model to assess the influence of potential risk factors on these transitions. Results indicated that study sites, wealth tertile, age of household head, poverty status, the ethnicity of household head, household ownership, and food security were associated with household transitions of WASH services. There was a lower probability for households to transition from unimproved to improved toilet services than the reverse transition, but a higher chance for households to transition from unimproved to improved water and garbage services. The estimated average time that households spent in the unimproved and improved states before transitioning were, respectively, 35 months and 9 months for toilet services, 7 months and 66 months for water services, and 16 months and 19 months for garbage services. Thus, households tend to remain longer in the unimproved state of toilet and garbage services, and when in the improved states, they transition back relatively faster compared to water services. In conclusion, sanitation services in Nairobi informal settings remain largely unsatisfactory as transitions to improved services are not sustained. It is therefore important for governments, policy-makers, and stakeholders to put in place policies and interventions targeting vulnerable households for improved and sustained WASH services.

Introduction

The lack of access to water, sanitation, and hygiene (WASH) services mostly affects people living in extreme poverty, who are often vulnerable and marginalized. Mostly, these groups of people are localized in rural and informal urban settlements [1,2]. In 2014, the percentage of the urban population in sub-Saharan Africa (SSA) who were living in slums was estimated to be 55% [3]. Several African countries, including Kenya, have witnessed a rapid growth of slum populations with the majority of these slums located in urban settings. This rapid growth of slums has created water and sanitation challenges [4]. In Kenya, nearly 60% of Nairobi's population lives in informal settlements and is circumstantially compelled to live in inadequate housing with little access to clean water and sanitation services [5,6].

The consequences and health risks brought about by lack of access to improved water and sanitation services are dire, especially for children. Unimproved drinking water and sanitation are the world's second-biggest killer of children, and people who are deprived of access to improved water and sanitation services face diminished opportunities to realize their potential [7–9]. Universally, over 61 million disability-adjusted life-years (DALYs) are attributed to the use of unimproved water and 40 million DALYs to a lack of basic sanitation services. Children in resource-poor areas under five years of age contribute the most towards these numbers [1,10].

Ensuring the availability and sustainable management of WASH services for all is one of the Sustainable Development Goals (SDGs)

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[1] Data used in the preparation of this article were obtained from Nairobi Urban Health and Demographic Surveillance System. As such, the investigators within the NUHDSS contributed to the design and implementation of NUHDSS and/or provided data but did not participate in the analysis or writing of this manuscript. A complete listing of NUHDSS investigators can be found at http://aphrc.org

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adopted by the United Nations in 2015. SDG Targets 6.1 and 6.2 aim to achieve universal and equitable access to safe drinking water, sanitation, hygiene, and end open defecation by 2030. The strategies of the WASH initiatives are based on access to improved water supply, improved sanitation, and good hygiene practice which are essential to reducing environmental health risks for the population's well-being at the global level.

The World Health Organisation (WHO)/ United Nations Children's Fund (UNICEF)'s Joint Monitoring Program (JMP) estimates that as of 2015, 2.4 billion people still lacked access to safely managed sanitation [11]. Although access to improved water and sanitation services is a fundamental human right and necessary for the health of every person, over 2.1 billion people around the world do not have access to these basic needs [12]. Notably, despite the great need for access to improved water and sanitation services in urban informal settlements, there has been little progress. For instance, between 1990 and 2010, there was very minimal change in access to improved sanitation in urban SSA, which stagnated at 43% of the population [13]. In 2015, about 70% of the SSA population was using unimproved sanitation facilities and 32% was relying on unimproved drinking water sources. This is particularly pronounced among slum dwellers living in precarious settlements in impoverished urban areas [14].

Given the rapid urbanization rates and poor access to improved WASH services in urban areas in SSA, the examination of the driving factors on WASH indicators is increasingly critical, particularly for urban informal settlements. Chikozho et al. [15] identified risk factors associated with the probability of households' access to improved water and sanitation services using longitudinally collected data from the Nairobi Urban and Demographic Surveillance System (NUHDSS) in two settlements, Korogocho and Viwandani. However, their approach did not consider transitions and back transitions between improved and unimproved states of WASH services, and the duration of stay by households within a given state. The aims of this present study were to 1) examine the influence of the risk factors (social, economic, and demographic) on the transitions and back transitions between improved and unimproved states of the WASH services and 2) gain insight into the time dynamics between states of WASH services in the NUHDSS. The results obtained from this study will help decision-makers to create sustainable solutions for improved WASH services in informal urban settlements.

Data description

Data source and study settings

The longitudinal data used in this study was obtained from the Nairobi Urban Health and Demographic Surveillance System (NUHDSS) collected between 2006 and 2015. The NUHDSS monitors and tracks demographic events, health, and socio-economic outcomes in two Nairobi slums, namely Korogocho and Viwandani. Since 2002, the platform has collected relevant data to generate evidence about the living situations of the urban poor in Nairobi. Korogocho is one of the largest slums in Nairobi, located in Kasarani District, with an estimated population of about 34,152. The slum settlement is to the northeast of Nairobi city about 12 km from the central business district (CBD). Viwandani, on the other hand, is in the industrial zone of the city. It lies about seven kilometers from the city center and is home to a youthful, more educated, and highly mobile population seeking employment in industries. Korogocho's population is older and less educated, and the majority have lived in the slum longer compared with Viwandani's residents. Although these slums are not homogenous with regard to age distribution, both face a shared challenge of poverty and exclusion especially with regard to access to water and sanitation services [16].

The analysis in this study was based on data from 37,630 unique households interviewed during the period between 2006 and 2015. The number of households and households interviewed for each year for the WASH variables have been described in a study by Chikozho and colleagues [15] and have been seen to vary from year to year. Households with only one measurement were removed as they do not produce transitions. A detailed description of the general design, variables, and data collected in the NUHDSS are available elsewhere [17].

Outcome and explanatory variables

The main outcomes of this study were the status of access to toilet, water, and garbage collection and disposal services in a household. We followed the WHO guidelines to classify these services into 'improved' and 'unimproved'. Table 1 provides information on the categorization scheme [15,18]. It is important to note that, although garbage/solid wastes are not typically defined as part of WASH, in Kenya they frequently are. For example, solid waste is included within the scope of the Kenya Environmental Sanitation and Hygiene Strategic Framework (KESSF) [19]. Also, the service level classification used for sanitation did not follow the revised JMP sanitation ladder [41] mainly because the majority of households in our sample had access to two main categories of sanitation services (Limited/Basic and Unimproved). Households with improved facilities which are not shared with other households were combined with those shared between two or more households and classified as 'improved' facilities in this study. The potential risk factors considered for this study were the study site (Korogocho and Viwandani) - which is included to compare transitions in WASH outcomes between the two settlements, whether or not the household is below or above the poverty line, and the household wealth tertile. Others include the gender of the household head, ethnicity of the head of the household (Kikuyu, Luhya, Luo, Kamba, Kisii, and others), size of household, ownership type of the household (owned, rented, other), and food security status.

The wealth status variable was created by the managers of the NUHDSS data following similar steps used in computing the Demographic and Health Survey (DHS) wealth index [20]. The index was created on a full list of household amenities variables such as type of floor, wall, and roof materials, agricultural land, farm animals, etc. [21]. Before creating the index, items with 20% of missing values were first removed, while others were imputed for a given year using data up to 3 years

Table 1
Overview of the classification of WASH indicators in the NUHDSS.

	Improved	Unimproved
Drinking water source	• Piped water into dwelling, plot or yard • Public tap/standpipe • Tube well / borehole • Protected dug well with hand pump • Protected spring • Rainwater collection from the roof	• Unprotected dug well • Unprotected spring • Small water vendor (cart with small tank or drum) • Bottled water Tanker truck • Rainwater collection from surface run off. • Surface water (river, dam, lake, pond, stream, canal, irrigation channels) • Protected dug well with bucket
Toilet facility type	• Flush / pour flush to piped sewer system or septic tank or pit latrine • VIP latrine • Pit latrine with slab • Composting toilet	• Flush/pour flush to elsewhere e.g. to open drain • Pit latrine without slab (slab with holes) / open pit • Bucket • Hanging toilet/hanging latrine • No facilities or bush or field
Garbage disposal method	• Garbage dump • Private pits • Public pits • Proper garbage disposal services • Other organized groups such as the national youth service	• In the river • On the road, railway line/-station • In drainage/sewage/trench • Vacant/abandoned house/plot/-field • No designated place/all over • Street boys/urchins • Burning • Other

Note: Adapted from Yu et al. [18].

forward or backward. Items with no variations were also removed. The remaining indicators were checked for internal consistency using Cronbach's alpha. Items with alpha coefficients between 0.65 and 0.80 were retained and factor analysis with principal components extraction on the selected variables was performed. For each of the years, the proportion of the variability explained by the first-factor score used as the wealth index was above 80%. The index is created for each slum area per year and merged into the household dataset. This index is then grouped into the lowest, middle, and highest household tertiles. For the household ownership variable, 'owned' households are households purchased, constructed, or inherited by the head of household, while 'rented' households comprise households rented by an individual, government, local authority, parastatal and private companies. 'Other' household ownership type includes those belonging to or rented by caretakers/security, religious entity, relatives/friends, or by an employer. The food security status was obtained from a composite score which was generated yearly by summing items that captured domains of food access as described by the Radimer Framework [22]. The items are a list of questions in the NUHDSS module for food production and consumption. These questions contained a checklist of ordinal and dichotomous items. Some of the questions posed to households included whether or not (i) they had enough food during the last 30 days, (ii) they had money to get more if the food they bought was completely consumed during the last 30 days, (iii) children in the household failed to eat for a whole day or slept hungry because there was not enough food during the past 30 days, and (iv) adults in the household failed to eat for a whole day because there was not enough food during the past 30 days, etc. [23,24]. The composite scores were categorized as food secure (score of 0); mildly food insecure (score of 1); moderately food insecure (score of 2), and severely food insecure (score of more than 2).

Statistical methodology

A time-homogeneous continuous-time Markov model [25,26] was used to explore the association between explanatory factors and transition between two states of WASH services, namely the 'Unimproved' (state 1) and 'Improved' (state 2) states. A brief description of the model is given as follows. Let $Y(t)$, $0 \le t \le \tau$ be a stochastic process that represents the WASH states of a household at time t and $S = \{1,2\}$ denote the finite state space. Transitional intensity, $\lambda_{r,s}$ between states is defined as the instantaneous risk of moving from state r to state s. That is,

$$\lambda_{r,s}(t|F(t)) = \lim_{\delta t \to 0} \frac{P(Y(t+\delta t) = s | Y(t) = r, F(t))}{\delta t}, r, s \in S$$

where $F(t)$ is the event history preceding time t. The intensities $\lambda_{r,s}$ form a matrix, Λ called the Intensity Matrix. Each row of the intensity matrix must sum to 0 and therefore the diagonal entries are simply obtained by $\lambda_{r,r} = -\sum_{s \neq r} \lambda_{r,s}$. It is assumed that a single period occupancy (sojourn time) in state r follows an exponential distribution with rate, $-\lambda_{r,r}$. This implies that the mean sojourn time in state r is given by $-1/\lambda_{r,r}$. The probability that an individual move from state r to state s is given by $-\lambda_{r,s}/\lambda_{r,r}$. Dependencies between events were assumed to be governed by the Markov assumption, which states that the trajectory of the process depends only on the current state and time. That is $\lambda_{r,s}(t, F(t)) = \lambda_{r,s}(t)$. Covariate information, $\boldsymbol{X}(t)$ were incorporated into the model by allowing the transition intensities to be expressed as a function of both time-dependent and time-invariant factors. The proportional hazards model approach by Marshall and Jones [27], is given as follows:

$$\lambda_{r,s}(X(t)) = \lambda_{r,s0} \exp\left(\boldsymbol{X}'(t)\boldsymbol{\beta}_{r,s}\right)$$

where $\boldsymbol{\beta}_{r,s}$ is the coefficient of the covariates on each transition intensity and $\lambda_{r,s0}$ is the baseline transition intensity. The hazard ratio for transition corresponding to a given covariate is obtained by exponentiating the covariate effect, $\boldsymbol{\beta}_{r,s}$. Specifically, study site, age, gender, and ethnicity of household heads were included in each of the transition models for water, toilet, and garbage services. Other factors included were household size, household ownership, poverty, wealth, and food security status of households.

Another important concept is the transition probability between state r at time t_0 and state s at time t_1. Equivalently, this represents the probability of being in state s at time t_1 in the future given that an individual is state r at time t_0. Mathematically, this is expressed as

$$P_{r,s}(t_0 t_1) = P(Y(t_1) = s | Y(t_0) = r).$$

These transition probabilities also form a transition probability matrix, $P(t)$. For a time-homogeneous process, the transition probability matrix is the matrix exponential of the scaled transition intensity matrix, Λ. That is, $P(t) = \exp(t\Lambda)$.

The estimates of the parameters of the model were obtained using the maximum likelihood procedure. The estimation is carried out using the specialized msm() function in the R software package, msm [28].

Empirical results

The conceptual framework of this study is depicted in Fig. 1 and demonstrates the time-dynamics and transition between various states of WASH services. We assumed that there were two states in which households may advance, from unimproved to improved, back-transition (i.e., improved to unimproved), or remain in a given state between each observation time.

Descriptive analysis

Table 2 summarizes the demographic and socio-economic status of the study communities for the first, middle two, and final year for ease in the presentation. In 2006, the proportion of households in Korogocho was higher than in Viwandani (53% versus 47%). This shifted from 2010 to 2015, and the proportion of the households was consistently higher in Viwandani compared to Korogocho. Disaggregated by gender, the proportion of male-headed households was consistently higher compared to female-headed households from 2006 to 2015 (78% versus 21% in 2006 and 76% versus 24% in 2015). There were five main ethnic groups in the study area: Kikuyu, Luhya, Luo, Kamba, and Kisii. Out of these main ethnic groups, the majority were Kikuyu (31%), followed by Kamba (23%), Luo (16%), Luyha (14%), and the least were Kisii (5%) in 2006. A similar pattern was observed in 2015, where Kikuyu made up 29%, Kamba 27%, Luyha 16%, Luo 12%, and Kisii 8%. The majority of the households in the study area lived in rented houses compared to those who owned their houses (87% versus 10% in 2006 and 85% versus 11% in 2015). The median age of household heads was 33, 34, 34, and 37 years in 2006, 2010, 2011, and 2015, respectively. Overall, the percentage of households who lived below the poverty line was observed to increase from 57% in 2006 to 73% in the year 2015. In terms of the size of the household, the median household size is 3 across all years.

Fig. 2 shows the general trends of toilet, water, and garbage services in the study area. We observed a higher percentage of unimproved toilet services which slightly declined in the later years. Also, unimproved water services were generally low but rose sharply in the later years.

Unimproved access to garbage collection services decreased sharply but the decline slowed towards 2015. The bivariate relationship

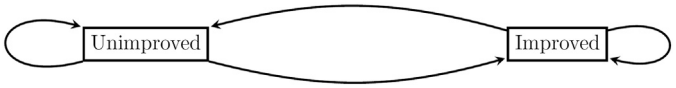


Fig. 1. The 2-state model.

Table 2
Study household characteristics by year ($N = 66,385$).

Factors	*N*	2006	2010	2011	2015
		$N = 12,858$	$N = 20,806$	$N = 21,533$	$N = 11,188$
Slum area	66,385				
Korogocho		53%	41%	40%	42%
Viwandani		47%	59%	60%	58%
Gender of HH	66,385				
Female		21%	22%	22%	24%
Male		78%	77%	78%	76%
N-Miss		2%	0%	0%	0%
Ethnicity of HH	66,385				
Kikuyu		31%	32%	31%	29%
Luhya		14%	14%	14%	16%
Luo		16%	11%	11%	12%
Kamba		23%	28%	29%	27%
Kisii		5%	5%	6%	8%
Others		9%	8%	8%	8%
N-Miss		2%	1%	1%	0%
Age of HH (continuous)	65,994				
Median (IQR)		33 (27–42)	34(27–42)	34(27–43)	37(29–46)
Below poverty line	66,385				
No		43%	52%	53%	27%
Yes		57%	48%	47%	73%
Wealth tertile of household	66,385				
Lowest		33%	28%	30%	20%
Middle		30%	33%	33%	37%
Highest		37%	39%	37%	42%
Size of household (continuous)	66,341				
Median(IQR)		3 (2–6)	3 (2–5)	3 (2–5)	3 (2–5)
Ownership	66,385				
Owned		10%	8%	8%	11%
Rented		87%	88%	89%	85%
Others		4%	3%	3%	4%
Food security status	64,376				
Food secure		50%	36%	36%	54%
Mildly food insecure		6%	16%	13%	11%
Moderately food insecure		14%	17%	15%	12%
Severely food insecure		31%	31%	35%	23%

N is the number of non-missing values, *N*-Miss is the number of missing values and HH is household head.

between various risk factors and WASH outcomes are presented in Table 3. For both slum areas, the percentage of unimproved toilet services was higher than improved services and also when disaggregated by other explanatory factors. Improved water services were generally higher in both slum areas. For garbage, the percentage of unimproved services was only slightly higher in both slums than improved services.

Table 4 shows the one-step transition between states of water and sanitation services. We observed that about 16% of households transitioned from having unimproved to improved toilet services and about 64% back-transitioned from improved to unimproved state. Also, 84% and 36% of households remained in the unimproved and improved state of toilet services, respectively. About 66% and 9% of households made unimproved-improved and improved-unimproved transitions in water services, respectively. For garbage services, we observed that about 39% and 34% of households made one-step transitions from unimproved-improved and improved-unimproved, respectively.

Statistical analysis

We estimated transition intensities and hazard ratios corresponding to predictors of the transition between states using the multi-state model, where states were modeled as a homogeneous continuous-time Markov process. Note that the risk factors wealth status, poverty line, and food security are all likely to depend on income in one way or another, which raises questions about the independence of these risk factors in the analysis. Therefore, before fitting the model with independent variables, we used Cramer's *V* to measure the association between household food security, wealth status, and poverty line. We obtained values of 0.06, 0.2, and 0.14 between poverty line and wealth, poverty line and food security, and wealth status and food security respectively, indicating negligible to weak associations between these variables such that there are unlikely to be multicollinearity issues. Table 5 shows the estimated baseline transitions between states for the three different WASH outcomes without and with covariates. From the assessment of the Akaike Information Criterion (AIC) values (Table 5–6), we observed that the model that allows transitions to depend on risk factors fit well to the data since it produced the smallest value for all the three different outcome models. Thus, we proceed to provide interpretations of the model with covariates. We assessed the effect of potential risk factors on transitions between unimproved and improved states of water and sanitation services using the results from Table 6.

Analysis for toilet service

After adjusting for multiple risk factors (see Table 5), households were 76% less likely to transition from unimproved to improved toilet services (0.03, 95% CI = 0.03–0.03) than to back-transition from improved state to unimproved state (0.12, 95% CI = 0.11–0.12). The average time households spent in the unimproved state before moving to the improved state and in the improved state before moving back to the unimproved state were respectively 35 months and 9 months. Also, from the results in Table 6, we observed that apart from the household size and whether or not a household was below or above the poverty line, all other factors considered had an effect on at least one transition between the states of toilet services.

Specifically, households in Viwandani had a 19% reduction in risk and a 31% increase in risk to transition from unimproved to improved and improved to unimproved transitions of toilet services, respectively, than households in Korogocho. Also, households in the middle and highest wealth tertile had a 14% and 24% increased risk, respectively, of transitioning from improved to unimproved toilet services compared to households in the lowest wealth tertile.

Households headed by a male had a 6.8% higher chance of improving to better toilet services compared to households headed by a female. The Luhya, Luo, Kamba, Kisii, and other ethnic groups have about 7%, 14%, 9%, 31%, and 17% increased chance to transition from unimproved to improved toilet services compared to the Kikuyu ethnic group, respectively. Also, compared to a household headed by a Kikuyu, households headed by Luhya, Luo, Kamba, Kisii, and other ethnic groups had a 20%, 29%, 16%, 22%, and 6% decreased risk of transitioning to the unimproved state. For household ownership, we observed that 'other' household ownership resulted in a 35% reduction in the likelihood of having improved toilet services compared to households that were 'owned'.

In terms of the effect of food security status, we observed that households that were mild food insecure, moderately food insecure, and severely food insecure were 17%, 23%, and 35% at increased risk to transition from improved to unimproved toilet services in comparison to households that were food secure. Also, households with mild food insecurity, moderate food insecurity, and severe food insecurity had a 3%, 21%, and 23% chance of transitioning from unimproved to an improved state of toilet services compared to households that were food secure, respectively. Generally, as food insecurity increased so did the probability of transitioning from unimproved to improved toilet services.

The 50-month transition probabilities are illustrated in Fig. 3a. Considerably higher probabilities were observed for households transitioning from improved to unimproved toilet services compared to probabilities for transitioning from unimproved to improved.

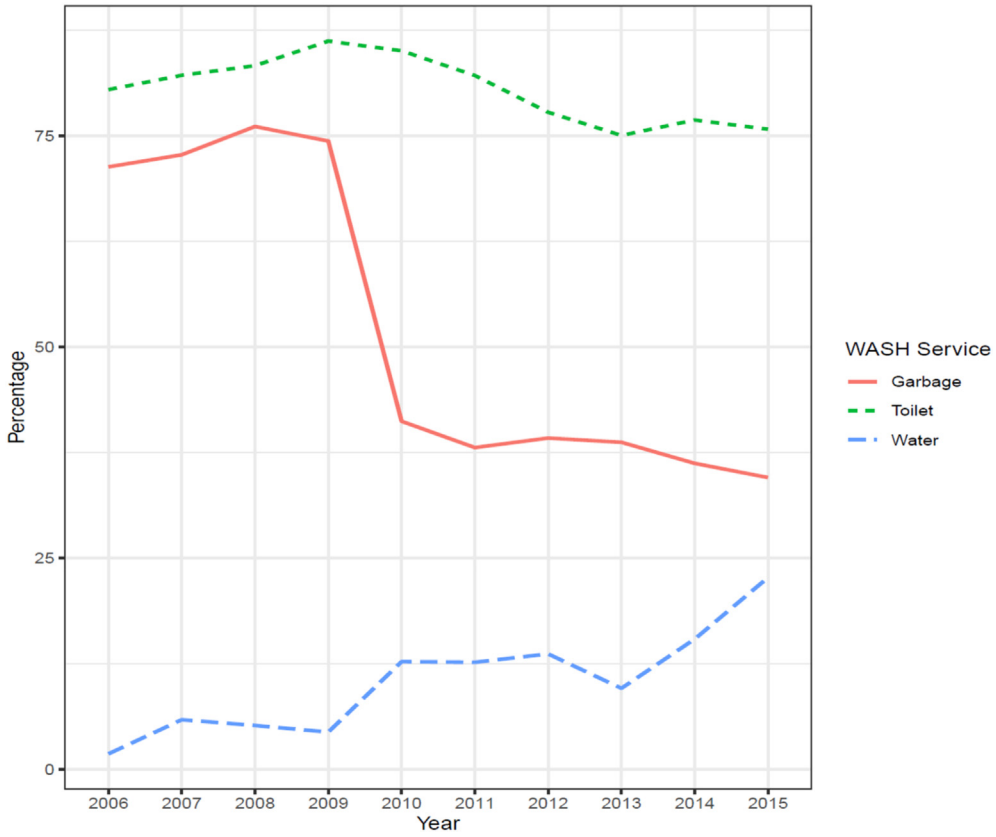


Fig. 2. Trends in the percentage of unimproved water and sanitation situations.

Analysis for water service

Households were 90% less likely to make the transition from improved to an unimproved state of water services (0.15, 95% CI = 0.14–0.15) than the reverse transition (0.02, 95% CI = 0.01–0.02). The mean sojourn time in the unimproved and improved state were, respectively, 7 months and 66 months. Except for gender and household size, all other risk factors were associated with transitioning between states.

The chance for households in Viwandani to transition from unimproved to improved and improved to unimproved water service state was, respectively, 62% lower and 87% higher than households in Korogocho. Also, households below the poverty line have about 11% less risk to transition from an improved to an unimproved state. Households in the middle and highest wealth tertile had, respectively, 11% and 16% reduced likelihood of transitioning from an unimproved state of water service compared to households in the lowest wealth tertile. Generally, as wealth increased, the probability of transitioning from unimproved to improved water services increased.

Furthermore, the risk of transitioning from improved to unimproved water service for households headed by Luhya, Kamba, Kisii, and other ethnicities versus Kikuyu was decreased by 19%, 10%, 42%, and 33%, respectively. Conversely, Luhya- and Luo- headed households had 15% and 27% reduction in risk, respectively, of transitioning to an improved state from an unimproved state of service compared to Kikuyu headed households. For the Kisii ethnic household, the risk was 20% greater compared to Kikuyu households for the same transition.

With regards to food security status, households that were mildly food insecure, moderately food insecure, and severely food insecure had about 47%, 14%, and 26% less risk, respectively, of moving from the improved to unimproved water service compared with food secured households. Severely food insecure households had a 12% less chance to transition from an unimproved water service to an improved water service.

We found from the 50-month transition probabilities in Fig. 3b that the progression of households from unimproved to improved water services was higher compared to back transitioning from improved to unimproved.

Analysis for garbage service

For garbage services, households were about 12% less likely to transition to an unimproved state from an improved state overall (see Table 5). The mean time spent in the unimproved and improved state of garbage services was about 16 and 19 months, respectively. From the results presented in Table 6, we found that households in Viwandani had a 9.8% higher probability of transitioning from an unimproved to an improved state than households in Korogocho. Households below the poverty line were also found to have 12% and 6% for moving from unimproved to improved and improved to unimproved states, respectively, when compared to households above the poverty line. Also, households in the middle and highest wealth tertiles had about 15% and 25% reductions in risk of transitioning to an unimproved state of garbage service in comparison to households in the lowest wealth tertile. In addition, households in the middle and highest wealth tertile had a 2% and 15% higher probability, respectively, of transitioning to an improved garbage state compared to households in the lowest wealth tertile. Generally, as wealth increased, the probability of transitioning from unimproved to improved garbage services increased.

We also found that households headed by males had a 6% reduced probability of transitioning to an improved garbage state compared to female-headed households. For Luo-headed households, the risk of transitioning from improved to unimproved garbage service was 15% higher than the risk for Kikuyu households. However, the risk was 17% and 18% lower for Kisii and other ethnicities, respectively, compared to Kikuyu-headed households for the improved-unimproved transition.

Table 3
Descriptive statistics of explanatory factors by WASH outcome.

	Toilet		Water source		Garbage	
	Unimproved	Improved	Unimproved	Improved	Unimproved	Improved
Factors	$N = 145,374$	$N = 34,777$	$N = 18,546$	$N = 161,605$	$N = 92,768$	$N = 87,383$
Slum area						
Korogocho	57,176 (77.6%)	16,511 (22.4%)	2598 (3.5%)	71,089 (96.5%)	38,441 (52.2%)	35,246 (47.8%)
Viwandani	88,198 (82.8%)	18,266 (17.2%)	15,948 (15.0%)	90,516 (85.0%)	54,327 (51.0%)	52,137 (49.0%)
Gender of HH						
N-Miss	746	152	64	834	552	346
Female	31,936 (81.0%)	7515 (19.0%)	3637 (9.2%)	35,814 (90.8%)	20,086 (50.9%)	19,365 (49.1%)
Male	112,692 (80.6%)	27,110 (19.4%)	14,845 (10.6%)	124,957 (89.4%)	72,130 (51.6%)	67,672 (48.4%)
Ethnicity of HH						
N-Miss	1272	292	86	1478	902	662
Kikuyu	46,937 (83.7%)	9129 (16.3%)	5372 (9.6%)	50,694 (90.4%)	29,728 (53.0%)	26,338 (47.0%)
Luhya	20,456 (79.1%)	5400 (20.9%)	2313 (8.9%)	23,543 (91.1%)	12,999 (50.3%)	12,857 (49.7%)
Luo	15,569 (73.7%)	5561 (26.3%)	1556 (7.4%)	19,574 (92.6%)	11,305 (53.5%)	9825 (46.5%)
Kamba	41,452 (81.7%)	9256 (18.3%)	7438 (14.7%)	43,270 (85.3%)	26,605 (52.5%)	24,103 (47.5%)
Kisii	8301 (77.9%)	2350 (22.1%)	884 (8.3%)	9767 (91.7%)	5050 (47.4%)	5601 (52.6%)
Others	11,387 (80.3%)	2789 (19.7%)	897 (6.3%)	13,279 (93.7%)	6179 (43.6%)	7997 (56.4%)
Age of HH						
N-Miss		746	152	834	552	346
Median (IQR)	34 (28–43)	34 (27–43)	34 (28–42)	34 (28–43)	34 (27–43)	34(28–43)
Below poverty line						
No	80,132 (82.7%)	16,799 (17.3%)	11,530 (11.9%)	85,401 (88.1%)	49,657 (51.2%)	47,274 (48.8%)
Yes	65,242 (78.4%)	17,978 (21.6%)	7016 (8.4%)	76,204 (91.6%)	43,111 (51.8%)	40,109 (48.2%)
Wealth tertile of household						
Lowest						
	40,132 (76.4%)	12,373 (23.6%)	3237 (6.2%)	49,268 (93.8%)	33,326 (63.5%)	19,179 (36.5%)
Middle	49,713 (83.0%)	10,200 (17.0%)	6748 (11.3%)	53,165 (88.7%)	30,675 (51.2%)	29,238 (48.8%)
Highest	55,529 (82.0%)	12,204 (18.0%)	8561 (12.6%)	59,172 (87.4%)	28,767 (42.5%)	38,966 (57.5%)
Household size						
N-Miss	34	10	0	44	33	11
Median (IQR)	3 (2–5)	3 (2–5)	3 (1–4)	3 (2–5)	3(2–5)	3 (2–5)
Ownership						
N-Miss	9	1	2	8	6	4
owned	13,248 (82.5%)	2812 (17.5%)	1078 (6.7%)	14,982 (93.3%)	8891 (55.4%)	7169 (44.6%)
rented	127,320 (80.3%)	31,183 (19.7%)	17,166 (10.8%)	141,337 (89.2%)	80,455 (50.8%)	78,048 (49.2%)
others	4797 (86.0%)	781 (14.0%)	300 (5.4%)	5278 (94.6%)	3416 (61.2%)	2162 (38.8%)
Food security status						
N-Miss	32	8	6	34	15	25
Food secure	56,175 (86.4%)	8828 (13.6%)	7874 (12.1%)	57,129 (87.9%)	31,000 (47.7%)	34,003 (52.3%)
Mildly food insecure	18,152 (84.3%)	3385 (15.7%)	1478 (6.9%)	20,059 (93.1%)	11,227 (52.1%)	10,310 (47.9%)
Moderately food insecure	25,734 (82.1%)	5617 (17.9%)	4259 (13.6%)	27,092 (86.4%)	13,633 (43.5%)	17,718 (56.5%)
Severely food insecure	42,774 (72.3%)	16,392 (27.7%)	4836 (8.2%)	54,330 (91.8%)	34,730 (58.7%)	24,436 (41.3%)

Table 4
Observed one-step transitions between states of water and sanitation services.

	To					
	Toilet		Water		Garbage	
From	Unimproved	Improved	Unimproved	Improved	Unimproved	Improved
Unimproved	95,128 (84%)	18,012(16%)	4291(34%)	8352(66%)	45,430(61%)	29,200(39%)
Improved	16,847(64%)	9480(36%)	11,502(9%)	115,322(91%)	21,838(34%)	42,999(66%)

For the converse transition, Kisii-headed households were 8% less likely and households headed by other ethnicities were 15% more likely than Kikuyu-headed households.

Additionally, rented households and 'other' household ownership types have, respectively, a 10% and 15% decreased risk of moving from improved to unimproved garbage service in comparison to owned households. Conversely, rented households had about a 41% higher chance of transitioning to an improved state from an unimproved state compared to owned households. Finally, households with mild food insecurity, moderate food insecurity, and severe food insecurity had 20%, 26%, and 28% higher risk, respectively, of making improved-unimproved transitions, and a 28%, 14%, and 24% higher probability, respectively, of making an unimproved-improved transition for garbage services in comparison with households that were food secure.

From Fig. 3c, we observed that the fifty-month transition probability was similar for both transitions for the first 10 months but then increased for the transition from unimproved to improved service in comparison to the reverse transition. For both transitions, the probabilities were above 40% after the first 20 months.

Table 5
Baseline Transition Intensity Estimates and 95% Confidence Intervals for the Multi-state model without and with covariates.

Transition parameter	Toilet	Water	Garbage
	Model without	Covariates	
Unimproved - Unimproved	−0.03 (−0.028,-0.027)	−0.10 (−0.104,-0.098)	−0.06 (−0.060,-0.058)
Unimproved - Improved	0.03 (0.027, 0.028)	0.10 (0.098, 0.104)	0.06 (0.058, 0.060)
Improved - Unimproved	0.11 (0.109, 0.114)	0.01 (0.014, 0.0144)	0.05 (0.050, 0.052)
Improved - Improved	−0.11 (−0.114,-0.109)	−0.01 (−0.014,-0.0137)	−0.05 (−0.052,-0.050)
-2log-lik	134,180	94,101	183,942
# of Parameters	2	2	2
AIC	134,184	94,105	183,946
Baseline intensity estimates for the model with covariates			
Unimproved - Unimproved	−0.03 (−0.029, −0.028)	−0.15 (−0.154, −0.140)	−0.06 (−0.062, −0.060)
Unimproved - Improved	0.03 (0.028, 0.029)	0.15 (0.140, 0.154)	0.06 (0.060, 0.062)
Improved - Unimproved	0.12 (0.113, 0.119)	0.02 (0.015, 0.016)	0.05 (0.053, 0.055)
Improved - Improved	−0.12 (−0.119, −0.114)	−0.02 (−0.016, −0.015)	−0.05 (−0.055, −0.053)

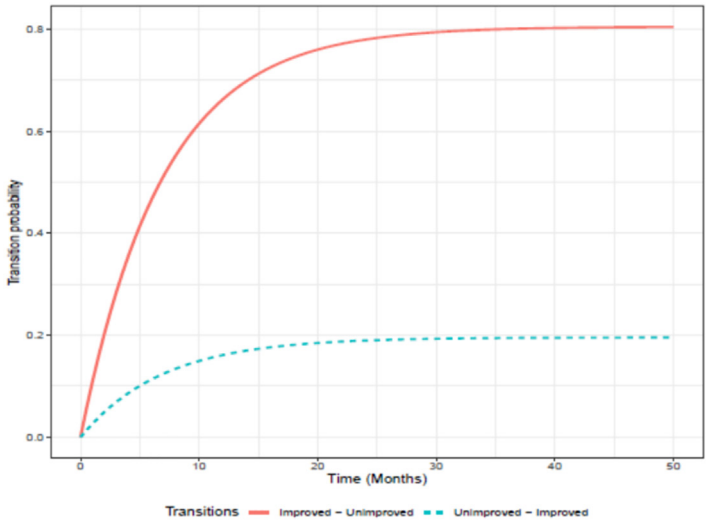
Table 6
Hazard ratios and 95% Confidence Intervals from the Multi-state model with covariates.

	Toilet		Water		Garbage	
Covariates	Unimproved-Improved	Improved-Unimproved	Unimproved-Improved	Improved-Unimproved	Unimproved-Improved	Improved-Unimproved
Slum site						
(ref = Korogocho) Viwandani	0.81 (0.766, 0.863)	1.31 (1.234, 1.389)	0.38 (0.337, 0.424)	1.87 (1.672, 2.092)	1.10 (1.052, 1.146)	1.00 (0.958, 1.056)
Below poverty line						
(ref = No) Yes	0.97 (0.922, 1.025)	0.99 (0.941, 1.044)	0.97 (0.902, 1.039)	0.89 (0.829, 0.9469)	0.88 (0.848, 0.916)	0.94 (0.902, 0.982)
Wealth tertile						
(ref = Lowest) Middle	0.99 (0.930, 1.043)	1.14 (1.078, 1.213)	0.89 (0.813, 0.972)	0.99 (0.914, 1.070)	1.02 (0.979, 1.068)	0.85 (0.813, 0.897)
Highest	1.05 (0.985, 1.110)	1.24 (1.163, 1.319)	0.84 (0.772, 0.920)	0.93 (0.860, 1.007)	1.15 (1.098, 1.198)	0.75 (0.711, 0.784)
Age of HH						
(Continuous) Age	0.995 (0.993, 0.997)	0.999(0.997,1.001)	1.00 (0.999, 1.005)	1.00 (1.001, 1.006)	1.00 (1.001, 1.004)	1.00 (0.999, 1.003)
Gender of HH						
(ref = Female) Male	1.07 (1.011, 1.128)	1.05 (0.991, 1.104)	1.01 (0.933, 1.089)	0.10 (0.910, 1.053)	0.94 (0.904, 0.981)	1.03 (0.985, 1.077)
Ethnicity of HH						
(ref = Kikuyu) Luhya	1.07 (0.990, 1.145)	0.80 (0.741, 0.855)	0.85 (0.770, 0.945)	0.81 (0.732, 0.886)	1.05 (0.997, 1.111)	1.05 (0.986, 1.111)
Luo	1.14 (1.054, 1.224)	0.71 (0.663, 0.767)	0.74 (0.650, 0.831)	0.90 (0.803, 1.008)	1.02 (0.958, 1.079)	1.15 (1.078, 1.225)
Kamba	1.09 (1.020, 1.167)	0.84 (0.786, 0.898)	0.93 (0.860, 1.003)	0.90 (0.837, 0.967)	1.00 (0.956, 1.048)	1.05 (0.999, 1.107)
Kisii	1.31 (1.175, 1.454)	0.78 (0.704, 0.869)	1.20 (1.039, 1.389)	0.58 (0.506, 0.664)	0.92 (0.851, 0.987)	0.83 (0.767, 0.905)
Others	1.17 (1.064, 1.283)	0.94 (0.858, 1.035)	1.10 (0.951, 1.267)	0.67 (0.581, 0.769)	1.15 (1.081, 1.229)	0.83 (0.768, 0.887)
Household size						
(Continuous) Size	1.01 (0.999, 1.014)	1.00 (0.994, 1.009)	1.00 (0.994, 1.014)	0.99 (0.983, 1.002)	1.00 (0.998, 1.007)	0.99 (0.989, 1.000)
Ownership						
(ref = Owned) Rented	1.02 (0.943, 1.111)	1.07 (0.983, 1.161)	0.87 (0.761, 0.993)	1.30 (1.141, 1.476)	1.41 (1.323, 1.491)	0.90 (0.845, 0.960)
Others	0.65 (0.557, 0.754)	0.99 (0.847, 1.152)	0.86 (0.636, 1.156)	0.92 (0.692, 1.220)	1.01 (0.913, 1.127)	0.86 (0.760, 0.962)
Food security	re)					
(ref = Food secu Mildly food insecure	1.03 (0.954, 1.115)	1.17 (1.079, 1.276)	1.03 (0.916, 1.152)	0.53 (0.475, 0.590)	1.28 (1.208, 1.351)	1.20 (1.130, 1.284)
Moderately food insecure	1.21 (1.131, 1.296)	1.23 (1.143, 1.320)	0.99 (0.918, 1.0768)	0.86 (0.797, 0.930)	1.14 (1.087, 1.204)	1.26 (1.194, 1.323)
Severely food insecure	1.23 (1.152, 1.305)	1.36 (1.277, 1.443)	0.88 (0.812, 0.952)	0.74 (0.683, 0.796)	1.24 (1.189, 1.300)	1.28 (1.215, 1.347)
Summary of Model fit (Note: the number of parameters includes the 2 baseline intensity estimates in Table 5)						
-2loglike	131,734		87,916.36		180,782.5	
# of Parameters	36		36		36	
AIC	131,806		87,988.36		180,854.5	

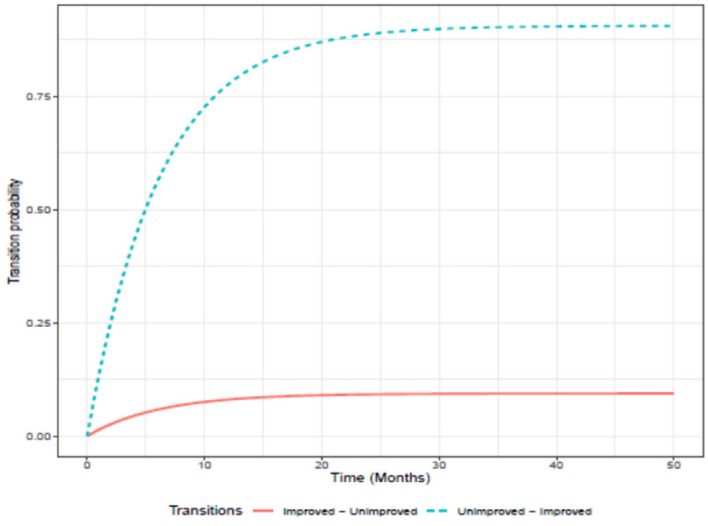
Note: Each covariate listed was adjusted for all other covariates.

Discussion and conclusions

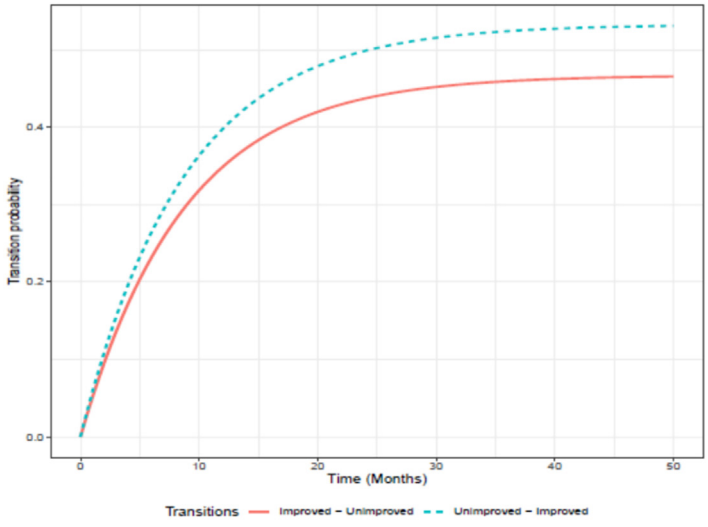
Several African countries, including Kenya, have experienced rapid growth of informal urban settlements such as slums. This poses a strain on existing infrastructure as well as health care and WASH services [4]. Given that populations lacking improved water and sanitation services are concentrated in informal urban settlements, there is the need to gain in-depth insight into the effect of potential risk factors on transitions between unimproved and improved states and the time dynamics between states of water and sanitation services in slums. This study investigated these phenomena in two informal urban settlements in Kenya, namely Korogocho and Viwandani. The results of the study



(a) Toilet



(b) Water



(c) Garbage

Fig. 3. Fifty-month transition probabilities.

showed that there was a lower chance for households to transition from unimproved to improved toilet services than the reverse transition, but a higher chance for households to transition from unimproved to improved water and garbage services. The results also indicated that the estimated average time that households spent in the unimproved and improved states before transitioning were, respectively, 35 months and 9 months for toilet services, 7 months and 66 months for water services, and 16 months and 19 months for garbage services.

Toilet services

More specific to toilet services, the results revealed that households were less likely to transition from unimproved to improved toilet services than to back-transition from an improved to an unimproved state. Various factors may have played a crucial role in these transitions. For instance, a mix of social, economic, and behavioral factors such as limited space, household congestion, and expanded family size may contribute to the sharing of sanitation facilities as well as poor sanitation practices like open defecation. Consequently, these influence the transition dynamics between improved and unimproved toilet services. This observation is consistent with findings from other studies [29–31]. Also, apart from the household size and whether or not a household is below or above the poverty line, all other factors considered (location of the household, wealth, household head, and food security status) had an effect on at least one transition between the states of toilet services. Households in Viwandani were found to be less likely to make the unimproved-improved transition and more likely to make the improved-unimproved transition of toilet services than households in Korogocho. This may be because the more youthful Viwandani residents who engage in industrial work are probably more mobile and therefore less likely to invest in permanent structures [16]. Also, although we do not directly attribute the differences in the two sites to a specific causal effect, these differences in transitions in the two sites may have been due to various interventions conducted by Umande Trust and GOAL Ireland conducted in the recent past in Korogocho [30]. For the gender of the household head, the current study revealed that households headed by males were more likely to improve to better toilet services compared to households headed by females. A study by Akpakli et al. [32] revealed a similar finding. However, Njeru and colleagues [33] presented somewhat contrary evidence showing that households headed by women often prioritize sanitation facilities and therefore have an elevated chance of improved sanitation facilities. Whereas the present study focused on informal settlements, the latter study focused on the general Nairobi population. In terms of food security, the present study revealed that households that were mildly to severely food insecure were at an increased risk of transitioning from improved to unimproved toilet services in comparison to households that were food secure. This effect may be due to adequate acquisition of income and thus increased ability to pay for and access improved sanitation services and this is consistent with findings from other studies [34,35]. It was also noted in this study that households in the highest and middle tertiles were at increased risk of transitioning from improved to unimproved toilet services than those in the poorest tertile. This appears counter-intuitive and requires further investigation to understand why this phenomenon is so within the slum settings.

Water services

For water services, households in both slums were more likely to remain in an improved state. Adjusted for covariates, the results revealed that the chance for households in Viwandani to transition from unimproved to improved was lower than for households in Korogocho. This is consistent with what we observed under the analysis of toilet services in section 5.1.

In terms of wealth, households in the middle and highest wealth tertile had a lower risk of transitioning from an unimproved state to an improved state. Although wealth is considered to be positively associated with an increase in access to improved services [34,35], high-income status does not necessarily equate to having a higher probability of transitioning from unimproved to improved water services. This needs to be explored further in future research.

Garbage services

The analysis adjusting for risk factors on transitions of garbage services revealed that households below the poverty line had a lower probability of moving from an unimproved to an improved state compared to households above the poverty line. Furthermore, households in the highest wealth tertile had a higher likelihood of transitioning to an improved garbage state compared to households in the lowest wealth tertile. This suggests that there was a positive impact of high wealth status on improved garbage service in the study communities which is in line with findings from other studies [36–38]. Further, we observed that, in both Viwandani and Korogocho, households occupied by renters had a higher chance of transitioning from unimproved to improved garbage services when compared to owned households. This may likely be attributed to the fact that in Nairobi, garbage services fees are mandatory and are paid as part of the utility fees for most rented properties. This observation collaborates with that of Banga et al. [39].

Conclusion

This research points to the need for policies to recognize that the transition between improved and unimproved services is not unidirectional, especially as seen in the case of sanitation. Various risk factors appear to increase the likelihood of back-transition. The evidence generated from this research can be used in diverse ways. It can be used to inform the targeting of interventions and siting of needed infrastructure for WASH within urban slum settings. It can also be used to inform behavioral change strategies required to support households to gain and sustain access to improved WASH services. For instance, WASH strategies could seek to directly address the underlying poverty-related structural, infrastructural, socio-economic, institutional, and behavioral challenges that continue to limit opportunities for improved health and well-being among slum dwellers [15].

One of the limitations of the present paper is that we have only utilized quantitative research data which can be assumed to lack in-depth and detail to help in understanding or explaining some of the observed findings. This would require qualitative research methods of data collection which are not typically employed in standard HDSS practice, mainly due to cost. For the NUHDSS, there exist limited qualitative studies that seek to answer very focussed qualitative research questions and are limited in their demographic scope [17]. In order to have an in-depth understanding of the results in this paper, a more focused qualitative research study would have to be undertaken in the future to address 'how', 'what' and 'why' questions. Also, a deeper understanding of transitions between states of service provision in the slums can be achieved if causal factors such as nature and scale of interventions by external actors (e.g government entities, utilities, civil society organizations), and how these interventions may impact transitions are comprehensively explored.

To conclude, water, sanitation, and hygiene services in urban informal settlements in SSA remain largely unsatisfactory. This situation is aggravated by increased rates of rural-urban migration, which leads to

the rapid growth of slum populations coupled with unplanned urban informal settlements. It is therefore important for governments, policymakers, and stakeholders to put in place policies and interventions targetting vulnerable urban households for improved and sustained WASH services. For instance, the promotion and/or provision of low-cost WASH technologies at the individual, household, or community-level are seen as workable and strategic solutions in resource-poor settings [40].

Ethical consideration

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

Credit author statement

Samuel Iddi: Conceptualization, Data curation, Methodology, Formal analysis, Writing – original draft, Writing – review & editing.

Dennis Akeyo: Data curation, Writing – original draft, Writing – review & editing.

Moussa Bagayoko: Validation, Writing – review & editing.

Slyvia Kiwuwa-Muyingo: Methodology, Validation, Writing – review & editing.

Claudious Chikozho: Conceptualization, Supervision, Writing – review & editing.

Damazo T. Kadengye: Conceptualization, Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors have no competing interests to declare.

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