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Development of a multidimensional deprivation index for emerging municipalities and cities in Uganda

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Abstract

This study advances the measurement of urban living standards deprivation by developing a context-specific multidimensional deprivation index and estimating the extent of deprivation in Uganda's newly gazetted municipalities and cities. The analysis draws on household listing data collected in November 2021 from 5987 households in Jinja City and Iganga Municipality. Exploratory and confirmatory factor analyses were used to identify latent deprivation dimensions and to validate the measurement structure. Using a factor loading threshold of 0.50, six interrelated dimensions of urban deprivation were identified, jointly explaining 70% of the total variance: access to electricity, financial and communication access, adequate dwelling occupancy, improved sanitation facilities, clean water access, and housing structural quality. Sampling adequacy was confirmed (Kaiser–Meyer–Olkin statistic = 0.75; Bartlett's test of sphericity, $p < 0.001$), and the confirmatory factor analysis demonstrated excellent model fit (Tucker–Lewis Index = 0.959; Root Mean Square Error of Approximation = 0.037). Overall, 97% and 93% of households were deprived in at least two and three dimensions, respectively. The multidimensional deprivation index was 17%, with 32% of the population classified as multidimensionally deprived and an average deprivation intensity of 52%. Substantial intra-urban variation was observed, with Jinja City recording a markedly higher level of deprivation than Iganga Municipality. Multidimensionally deprived households were predominantly characterized by residence in single-room dwellings, reliance on highly shared and unimproved sanitation facilities, substandard housing materials, and lack of electricity access. These findings reveal pervasive and overlapping deprivations in Uganda's emerging urban centers and challenge assumptions of uniform urban advantage. They underscore the need for integrated, multisectoral, and data-driven urban development strategies to ensure equitable access to essential services as urbanization accelerates, particularly in rapidly growing secondary cities.

Keywords Deprivation dimensions, Urban, Municipalities, Secondary cities, Uganda

1 Introduction

The role of the social determinants of health in the development and eradication of diseases, including mental health conditions, has been well studied [1, 5, 18, 29]. This growing body of evidence has informed the development of Social Determinants of Health (SDH) frameworks by the World Health Organization, which emphasize the structural conditions influencing health across the life course [15]. These frameworks align closely with the Sustainable Development Goals (SDGs), which explicitly link health, poverty, housing, and urban development [52]. Among SDG indicators, target 11.1.1 measures the proportion of the urban population living in slums, informal settlements, or inadequate housing, while target 1.2 measures the proportion of people of all ages living in poverty in all its dimensions.

Widening inequalities in the distribution of resources fundamentally shape individuals' ability to attain acceptable standards of well-being. In sub-Saharan Africa, empirical evidence on material and public-service deprivation has historically concentrated on rural settings, informing policies and interventions aimed primarily at rural development. However, the rapid expansion of secondary cities and capital-city suburbs—often outpacing infrastructure and service provision—has received comparatively limited analytical and policy attention [32, 54]. As a result, significant forms of deprivation persist within urban areas, particularly in emerging cities and peri-urban settlements.

Uganda exemplifies these dynamics. With an annual urban growth rate of approximately 5.2%, nearly one-fifth of the population now resides in urban areas. Yet living conditions in many cities remain precarious: an estimated 67% of households in the Kampala metropolitan area live under slum-like conditions, nearly half of urban households occupy single-room dwellings, and substantial proportions lack access to improved sanitation and safe cooking facilities [21, 33]. The expansion of emerging towns—ranging from Kampala's suburban periphery to newly designated secondary cities—has largely occurred without adequate planning, environmental management, or long-term economic strategies [13]. Decentralization reforms and the creation of new administrative units have further accelerated this unregulated urban growth [12, 13]. Despite these trends, urban deprivation remains weakly integrated into national poverty monitoring systems and poverty-reduction strategies, limiting the visibility of intra-urban inequalities.

A multidimensional understanding of deprivation, grounded in the capability approach, is therefore essential for identifying the structural constraints that limit individuals' freedoms and for informing inclusive urban policy, infrastructure investment, and equitable resource allocation. The relative scarcity of empirical research on living standards in secondary cities and their surrounding suburbs obscures important pockets of deprivation in these rapidly transforming urban spaces. This study draws on data from 5,987 households in two newly gazetted municipalities, Iganga and Jinja, to pursue three objectives:

1. to identify the latent dimensions of urban living standards deprivation using confirmatory factor analysis;
2. to construct a context-specific Multidimensional Deprivation Index; and.
3. to examine inequalities in living standards among residents of these secondary cities.

Methodologically, the study contributes to multidimensional deprivation research by developing and validating an empirically grounded framework tailored to the realities of urbanization in sub-Saharan Africa. Substantively, it advances understanding of urban living standards in Uganda by providing a policy-relevant diagnostic tool capable of informing urban planning, service delivery, and poverty-reduction strategies in emerging cities.

The remainder of the paper is organized as follows. Section 2 presents the conceptual framework and a concise literature review on multidimensional deprivation. Section 3 outlines the methodology, including data sources, indicator selection, and the application of factor-analytic techniques to identify deprivation dimensions. Section 4 reports the empirical findings—the structure, distribution, and key correlates of the MDI. Section 5 interprets these findings through the capability approach, highlighting how deprivation dimensions constrain or enable substantive freedoms. Section 6 discusses methodological strengths and limitations. Finally, Sect. 7 concludes with implications for urban governance, spatial planning, and pro-poor policy interventions in Uganda and comparable sub-Saharan African contexts.

2 Conceptual framework and literature review

2.1 Theoretical framework: the capability approach

The capability approach, advanced by Sen [47], provides a robust theoretical foundation for this expanded poverty concept [9, 23]. Rather than assessing poverty by income or wealth alone, the approach centers on what individuals are free to do and be—their real opportunities (capabilities) and achieved states (functionings). Functionings are valuable doings and beings (e.g., good health, education), while capabilities are the substantive freedoms to achieve those functionings.

The capability approach distinguishes poverty as structural barriers to essential capabilities, and deprivation as the specific lack of functioning and opportunities experienced by individuals, reflecting a shift away from income- or consumption-based definitions [14, 39, 44]. Poverty is a multidimensional phenomenon of interlocking deprivations that constrain individuals' capabilities and the opportunities necessary for a life of dignity and value. Within this framework, a critical distinction can be made between intrinsic and instrumental deprivation.

Intrinsic deprivation refers to the direct absence of basic functionings that are constitutive of well-being, such as adequate shelter, safe sanitation, clean drinking water, and sufficient living space. These forms of deprivation are inherently undesirable because they directly undermine individuals' ability to live a life with dignity, health, and personal security. In this study, indicators related to inadequate housing conditions, poor sanitation, overcrowding, and unsafe drinking water capture intrinsic deprivation by reflecting immediate exposure to health risks, loss of privacy, and compromised physical well-being—outcomes that represent direct failures in achieving essential human functionings. For example, residence in overcrowded dwellings or communities lacking safe water and sanitation substantially increases exposure to infectious diseases such as diarrhoeal illnesses and upper respiratory infections [41, 56].

Instrumental deprivation, by contrast, captures deficits in resources or conditions that indirectly constrain capabilities by limiting the means through which functionings can be achieved. Examples include lack of electricity, restricted access to financial services,

or poor housing materials, which may not be ends in themselves but are essential inputs for achieving health, safety, productivity, and social participation. Financial deprivation illustrates this instrumental role clearly. Beyond low income, it includes limited access to credit, lack of savings, and reliance on informal borrowing systems, all of which reduce households' resilience to economic and health shocks and constrain their capacity to plan, invest, or cope with risk [14, 26, 46]. Lack of access to electricity restricts children's ability to study at night, impedes safe and efficient food preparation, restricts self-employment opportunities, and limits overall quality of life [48, 55]. Similarly, material deprivation—manifested through poor housing quality, overcrowding, and limited access to essential household assets—functions instrumentally, by mediating access to education, employment, and social participation. For instance, deprivation in access to basic household assets, such as radios, mobile phones, or means of transportation, not only signals material lack but also constrains the household members capabilities to lead a secure, connected, and economically active life [55].

2.2 Empirical background: urban poverty and multidimensional indices

Urban poverty in sub-Saharan Africa is increasingly recognized as a complex, multidimensional challenge that cannot be fully captured by income-based measures alone [45, 57]. Empirical research documents diverse forms of deprivation experienced by urban residents, including inadequate housing, overcrowding, poor sanitation, lack of safe drinking water, and limited access to electricity and household assets [9, 23, 24, 27, 45, 57], reflecting broader structures of constraint that impede social mobility and the realization of essential capabilities [9, 23]. Deprivations often concentrate in informal settlements and peripheral urban areas where public infrastructure and services are limited. For instance, several empirical studies demonstrate that multidimensional poverty among urban residents is predominantly characterized by deprivations in housing quality, sanitation, and access to modern energy services, reflecting the central role of the built environment and basic infrastructure in shaping urban well-being [17, 21, 36, 37, 49].

The capability approach is therefore particularly well suited to the analysis of urban deprivation in rapidly urbanizing sub-Saharan African contexts, where informal urbanization, weak infrastructure, and social exclusion systematically constrain people's opportunities and lived experiences [3, 4, 25]. However, the existing literature has largely concentrated on large metropolitan areas or nationally aggregated urban indicators, offering limited insight into secondary cities and newly gazetted municipalities, where rapid population growth often outpaces institutional capacity and service provision. As a result, the capability-restricting conditions faced by residents of these urban spaces remain insufficiently documented.

There are multiple approaches for developing deprivation indices [2, 6, 31, 34, 37]. Methodologically, generating multidimensional deprivation index involves two key tasks: selecting appropriate indicators and determining how to combine them into an index [6]. Indicator selection is typically guided by study objectives and the availability of household or census data. Once indicators are selected, they can be combined through equal-weight additive methods, expert- or normatively weighted aggregation, or data-driven multivariate techniques (e.g., principal component analysis or factor analysis) that derive weights from observed correlations among indicators [2, 6].

The Multidimensional Poverty Index (MPI), developed by Alkire and Santos, has advanced poverty measurement by incorporating multiple indicators across health, education, and living standards [2]. However, the MPI relies on standardized thresholds that may overlook local specificities—particularly in sub-Saharan African urban contexts where infrastructure is often informal, administrative boundaries are dynamic, and access to services is highly variable. These limitations are especially evident in secondary cities and peri-urban areas, where infrastructure often fails to keep pace with population growth and where official data may miss hidden forms of deprivation. Furthermore, the UN-Habitat's slum household definition—based on five dimensions including housing, water, sanitation, crowding, and tenure [53]—has informed the monitoring of SDG Indicator 11.1.1, but may not capture the full complexity of deprivation in urban environments, especially when applied uniformly across diverse contexts. In such contexts, standardized indicators may obscure intra-urban disparities and inadequately account for the structural and institutional determinants of deprivation.

In advancing this effort, the study continues to draw on the capability approach while departing from traditional operationalizations such as the MPI. Whereas the MPI relies on a fixed set of expert-defined dimensions and thresholds [43], this study adopts a data-driven, context-sensitive approach using exploratory and confirmatory factor analysis (CFA) to empirically identify latent dimensions of deprivation. All selected living standards indicators, including, housing quality, sanitation, water access, asset ownership, electricity access, and overcrowding are conceptually aligned with valued capabilities. However, their inclusion is justified not by international consensus, but by empirical evidence of how they cluster within the local context. This approach not only strengthens the internal validity of the index but also enhances its relevance for policy and programmatic use in settings where poverty is both spatially concentrated and structurally embedded.

3 Methodology

3.1 Study Setting

This study utilized household listing data collected from selected parishes within municipalities Iganga and Jinja City (Fig. 1). Jinja, formerly a municipality within the Jinja District (Fig. 1), was designated as a city in 2020. As alluded to earlier, the creation of new cities and municipalities in Uganda, including Jinja, is often politically motivated,

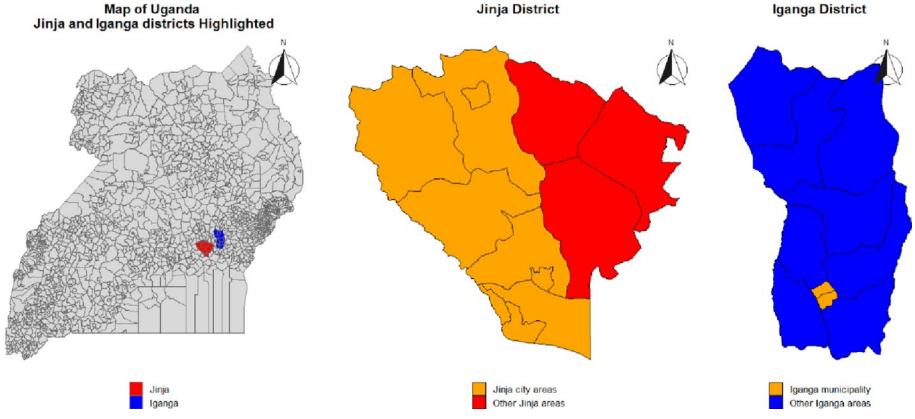

Fig. 1 National and district showing study areas

with politicians, including the president, promising city status in exchange for political support [12, 13]. To qualify for city status in Uganda, an area must have a population of at least 350,000 people and the ability to cover over 50% of the costs for social services and development projects. However, newly created cities frequently fall short of generating revenue [12, 13]. For instance, the population of Jinja Municipality stood at 72,931 (400,000 during the day), but local politicians voted to merge the municipality with nearby town councils, bringing the combined urban population to at least 150,000 (night residents). Both Jinja and Iganga Districts lie along the Uganda–Mombasa transit corridor and serve as commercial hubs on Lake Victoria's shores—a region projected to experience high urban growth intensity 53].

3.2 Study design

The study utilizes cross-sectional survey data collected in November 2021 through household listing of 5987 households within two divisions of Iganga Municipality (2118 households) and three divisions of Jinja City (2121 households). Within each division, five parishes were randomly selected. In each selected parish, 50% of villages were randomly chosen using a table of random numbers, and a complete household listing was conducted in all selected villages. The household listing data collection tool included questions on the number of individuals living in the dwelling, residence status, and basic household characteristics such as structure and assets. The household questionnaire was administered to the household head or an adult household member (aged 18 years or older) who was knowledgeable about household living conditions, assets, and service access. Some variables, such as the material quality of floors, walls, and roofs; the number of rooms in the dwelling; and asset ownership, were collected through direct observation by enumerators. Additionally, information on the number of household members, the number of households sharing a toilet facility, bank account ownership, phone ownership, and mobile money access was obtained through respondents' self-reporting. Details on the data collection methods are reported elsewhere [20].

3.3 Study variables selected for multidimensional deprivation

The selection of 21 variables (Supplementary Table 1) for the Multidimensional Deprivation Index (MDI) was informed by Sen's capability approach [47] and validated against global frameworks, including the UN-Habitat slum household definitions and relevant Sustainable Development Goals (SDG) indicators. Within the capability framework, these indicators were chosen to capture both intrinsic deprivations—direct shortfalls in essential functionings such as adequate shelter, safe sanitation, and clean water—and instrumental deprivations, which constrain capabilities indirectly by limiting the means through which valued functionings can be achieved. Indicators' selection was aligned with SDG Target 11.1.1, which monitors the proportion of the urban population living in slums, informal settlements, or inadequate housing, and with the operational framework developed by Lucci et al., [28] for identifying slum-like living conditions [28]. Table 1 situates the six empirically identified deprivation domains within the capability approach, distinguishing between intrinsic deprivations that directly undermine basic functionings and instrumental deprivations that constrain the means through which valued capabilities are achieved.

Table 1 Mapping urban deprivation domains to intrinsic and instrumental capabilities

	Deprivation domain	Type of deprivation	Capability linkage (Sen's capability approach)
1	Access to electricity	Intrinsic and instrumental	Electricity is a means that enables multiple functionings, including studying after dark, safe food preparation, access to information, and income-generating activities. Intrinsically, reliance on unsafe energy sources poses substantial risks to health and fire accidents
2	Mobile phone–enabled financial services and communication	Instrumental	Access to mobile phones and digital financial services enhances capabilities related to economic participation, risk management, social connectivity, and access to services. Deprivation limits households' ability to save, transfer resources, respond to shocks, and engage with markets and institutions
3	Adequate dwelling occupancy (overcrowding)	Intrinsic and instrumental	Intrinsically, overcrowding undermines dignity, privacy, rest, and physical and mental well-being. Instrumentally, it constrains children's learning, increases disease transmission, and limits adults' ability to work or engage in productive activities from home. A house is considered to provide a sufficient living area for the household members if three or fewer people share the same room
4	Sanitation facilities	Primarily intrinsic	Lack of adequate sanitation directly compromises health, bodily integrity, dignity, and personal safety. In dense urban settings, sanitation deprivation also generates collective health risks, reinforcing community-level capability losses
5	Clean water access	Intrinsic and instrumental	Clean water is intrinsically essential for survival and health. Instrumentally, inadequate access increases time burdens, exposure to disease, and limits opportunities for education, employment, and care work
6	Structural housing quality	Intrinsic and instrumental	Intrinsically, poor housing materials expose residents to physical insecurity and environmental hazards. Instrumentally, substandard structures reduce resilience to climate shocks and constrain the use of housing for learning, work, and social participation. A housing structure is considered durable when certain strong building materials are used for roofs, walls, and floors

To capture housing quality, we incorporated indicators on floor, wall, and roof materials, as well as overcrowding. Overcrowding was operationalized through two measures: the number of persons per sleeping room, and the number of households sharing a single toilet or latrine—both consistent with international definitions of inadequate shelter (SDG 11.1). Water access was assessed based on source classification (e.g., improved vs. unimproved sources such as unprotected wells, springs, or tanker deliveries), on-premises availability, and time taken to collect water, with collection times exceeding 30 min classified as inadequate. These indicators align with SDG Targets 6.1 and 6.2 on universal access to safe water and sanitation. Sanitation adequacy was evaluated using both infrastructural and usage criteria. Sanitation facilities shared by more than two households were classified as inadequate, even if they met the technical definition of "improved" (e.g., ventilated improved pit latrines), in accordance with global guidelines recognizing shared sanitation as a health and dignity risk in high-density settings.

Given the widespread energy uncertainty in many urban informal settlements, the index also includes energy-related indicators aligned with SDG Target 7.1 on access to affordable, reliable energy. These include household connection to the national grid, use of electricity for lighting and cooking, and the presence of a separate kitchen to reduce indoor air pollution and fire risk. To reflect material wealth and financial inclusion—particularly as outlined in SDG Targets 1.4 and 8.10—the index incorporates household ownership of selected durable assets, including radios, televisions, bicycles, motor vehicles, mobile phones, and land. These items serve as proxies for socioeconomic status and the ability to withstand economic shocks.

3.4 Analytical strategy

Data analysis was conducted using STATA 2018 in several stages. First, we conducted an exploratory factor analysis (EFA) that included all the items hypothesized as measures of deprivation. The Kaiser–Meyer–Olkin (KMO) test was conducted to assess sample adequacy, and Bartlett's test of sphericity was used to evaluate the suitability of the data for factor analysis. A KMO value of at least 0.60 was considered indicative of an adequate sample. Factors with eigenvalues greater than 1 were retained, and varimax rotation was applied to facilitate clearer factor-loading patterns. Finally, only items with factor loadings of 0.50 or higher were retained in the final specification of the deprivation domains, as a loading of 0.50 is commonly regarded as the minimum threshold for practical significance in factor analysis [38].

Second, CFA was conducted on the selected items to evaluate the strength of their associations with the hypothesized latent constructs. The model was estimated using maximum likelihood estimation with robust standard errors derived from bootstrap resampling (500 replications) to ensure stability and mitigate potential estimation bias. Model fit was assessed using the Comparative Fit Index (CFI), Root Mean Square Error of Approximation (RMSEA), and the Tucker–Lewis Index (TLI). In accordance with Hu and Bentler's (1999) recommendations, a CFI and TLI of ≥ 0.95 and an RMSEA of ≤ 0.05 were considered indicative of good model fit.

To further improve the model's fit and more accurately represent the complex interrelationships among indicators, covariance paths were specified between select latent constructs and key observed variables. This specification was informed by both empirical modification indices and theoretically plausible justifications, recognizing the possibility of residual correlations among certain items that may not be fully captured by the latent structure alone. Finally, only items with factor loadings of 0.50 or higher were retained in the final specification of the deprivation domains.

We generated the MDI in two steps. First, we generated weights for each item based on the item's relative contribution to the overall factor structure. Each item's weight was computed by multiplying the proportion of variance explained by its respective factor (i.e., the factor's share of the total explained variance) with the inverse of the number of items that loaded strongly on that factor.

$$w_i = \frac{1}{n_{di}} * v_{di} \tag{1}$$

$$v_{di} = \frac{p_{fi}}{p_f} \tag{2}$$

where w_{di} is the weight for item i dimension di, v_{di} is the percentage contribution to the overall cumulative factors' variance, p_{fi} is the percentage of total variance for factor i, and p_f is the cumulative variance percentage of the identified factors.

Unlike expert-based weights, which may introduce normative bias, or equal weights, which assume homogeneity across all indicators, our approach empirically captures the salience of each deprivation domain while retaining comparability across dimensions. This method is especially appropriate in the context of urban deprivation, where dimensions such as housing quality or service access may have uneven empirical influence across localities.

Aligned with the MPI approach, the resulting weights were then used in the second step to compute individual deprivation scores and aggregate them into an MDI that reflects both the breadth and intensity of deprivation at the household level [2]. We also borrowed the same approach to estimate the percentage of deprived people in each domain and item measure.

4 Results

4.1 Exploratory and confirmatory factor analysis

EFA yielded a Kaiser–Meyer–Olkin (KMO) measure of 0.751, indicating that the items were suitable for factor analysis. In addition, Bartlett's test of sphericity was highly significant ($p < 0.001$), rejecting the null hypothesis of no correlation among the variables. These two preliminary diagnostics confirmed that the dataset was appropriate for factor analysis. Furthermore, the internal consistency of the items was strong, with a Cronbach's alpha coefficient of 0.81, and the average inter-item covariance was 0.02—both suggesting reliable measurement properties. Based on the eigenvectors, the EFA identified six latent dimensions, collectively explaining approximately 70% of the total variance observed in the dataset (Fig. 2). Based on the factor loading cutoff of 0.5, the identified six dimensions were electricity access, mobile phone financial access and communication, optimal dwelling occupancy, improved sanitation facilities, clean water access, and optimal dwelling structure (Supplementary Table 2).

To validate the latent structure of the urban deprivation constructs, CFA was performed on the EFA selected items (Supplementary Table 2). The model demonstrated an excellent fit to the data across multiple indices. CFI was 0.969, indicating a close alignment between the hypothesized model and the observed covariance structure, with values above 0.95 generally considered indicative of good fit. TLI was 0.959, further supporting the model's adequacy by penalizing for complexity and reinforcing the parsimony of the latent constructs. RMSEA was 0.037, with a 90% confidence interval ranging from 0.035 to 0.040, suggesting a high probability of close fit to the population data. Collectively, these indices provide strong empirical support for the factorial validity of the specified measurement model.

The final CFA model retained 12 of the 19 original indicators identified in the EFA, based on a loading threshold of 0.50 (Table 2). While the core structure remained stable, some dimensions were slightly refined. For instance, the electricity access deprivation dimension was constructed using three indicators: household use of electricity for lighting, connection to the national grid, and television ownership. Financial and communication deprivation was captured by mobile phone ownership and engagement in mobile money transactions within the previous 12 months. The adequate dwelling occupancy deprivation dimension included households with only one sleeping room and shared sanitation facilities used by four or more households. The sanitation deprivation dimension was captured solely by households with unimproved toilet facilities, while clean water access deprivation was defined by reliance on unimproved water sources for cooking and drinking. Lastly, the structural deprivation dimension was defined by substandard floor and wall materials in the household.

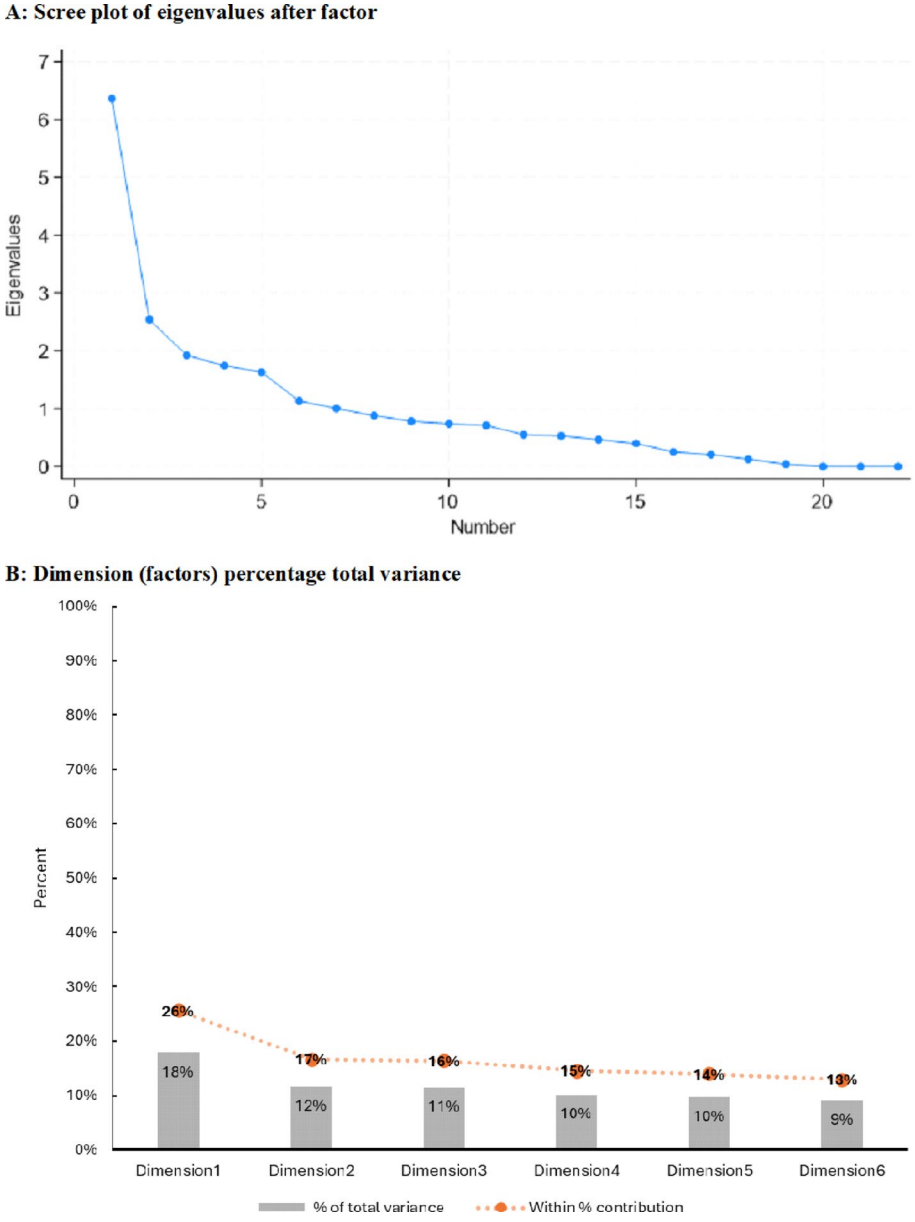

Fig. 2 Selected dimensions based on eigen-values

4.2 Overall deprivation

Overall, deprivation was widespread and overlapping across households. Nearly all households (97%) experienced deprivation in at least two items, while 93% and 60% were deprived in at least three and four items, respectively (Fig. 3). When examined at the dimensional level, approximately 95% of households were deprived in at least one-third (2 out of 6) of the deprivation dimensions, and about 45% were deprived in at least half (3 out of 6) of the dimensions (Fig. 3), underscoring the cumulative nature of urban deprivation in the study areas.

At the population level, sanitation emerged as the most pervasive deprivation domain. As shown in Figs. 4A and 67.2% of individuals lacked access to improved sanitation facilities. High levels of deprivation were also observed for electricity access (59.6%) and optimal dwelling occupancy (54.9%), reflecting widespread deficits in basic urban

Table 2 Confirmatory factor analysis

	Standardized Coefficient	*P*-value	95% CI		Bootstrap 95% CI (1000 replications)	
Lack of electricity access						
Household doesn't use electricity for lighting	**0.99**	< 0.001	0.96	1.00	0.97	1.00
Household not connected to the electricity national grid	**0.95**	< 0.001	0.91	0.98	0.93	0.97
No Television ownership	**0.67**	< 0.001	0.58	0.77	0.58	0.77
No wall clock	0.35	< 0.001	0.26	0.45	0.25	0.46
No refrigerator ownership	0.32	< 0.001	0.23	0.40	0.24	0.40
Lack of mobile communication and financial access						
Household has no one with mobile phone	**0.51**	< 0.001	0.50	0.52	0.44	0.57
Household has no one with bank account	0.45	< 0.001	0.34	0.56	0.37	0.53
No household member that has had mobile phone financial transactions in the last 12 months	**0.63**	< 0.001	0.42	0.85	0.55	0.72
Overcrowding						
No land ownership	0.46	< 0.001	0.43	0.49	0.38	0.53
One roomed house	**0.61**	< 0.001	0.58	0.63	0.55	0.67
At least 3 people per room	0.25	0.00	0.09	0.40	0.10	0.39
Latrine shared with at least 4 other households	**0.51**	0.00	0.22	0.79	0.33	0.68
Poor sanitation facilities						
Unimproved latrine	**0.65**	< 0.001	0.63	0.67	0.58	0.73
Poor latrine with openings	0.14	0.01	0.03	0.25	0.04	0.24
Lack of access to clean water						
Unimproved water source for cooking	**0.87**	< 0.001	0.85	0.89	0.75	1.00
Poor water source for drinking water	**0.90**	< 0.001	0.58	1.00	0.76	1.04
Substandard dwelling structure						
Substandard house floor	**0.87**	< 0.001	0.86	0.87	0.83	0.90
Substandard house walls	**0.70**	< 0.001	0.63	0.76	0.65	0.75
Cooking not done in separate room	0.34	< 0.001	0.26	0.41	0.27	0.41

Boldface standardized coefficients represent the highest factor loading within each latent domain

CI Confidence interval

services and housing adequacy. Deprivation in access to clean water affected 32.2% of the population, while 17.8% experienced deprivation related to poor housing structures (Fig. 4A).

Disaggregating these dimensions into specific indicators further highlights the severity of living condition deficits (Fig. 4B). Approximately two-thirds of individuals lacked access to improved latrines, and over half shared sanitation facilities with four or more households. Nearly half of households did not use electricity for lighting, and one in five were not connected to the national electricity grid. Water insecurity remained substantial, with around 30% of households relying on inadequate sources for drinking and cooking. Overcrowding was also common, with 38% of households living in single-room dwellings, while poor housing quality persisted for a notable share of households, as reflected in substandard floor (16%) and wall (10%) materials.

4.3 Multidimensional deprivation

Table 3 summarizes patterns of overlapping multidimensional household deprivation (see Supplementary Table 3 for additional details). Overall, 29% of households experienced concurrent deprivation in access to electricity and clean water. A further 19% were deprived in both optimal dwelling occupancy and improved sanitation facilities.

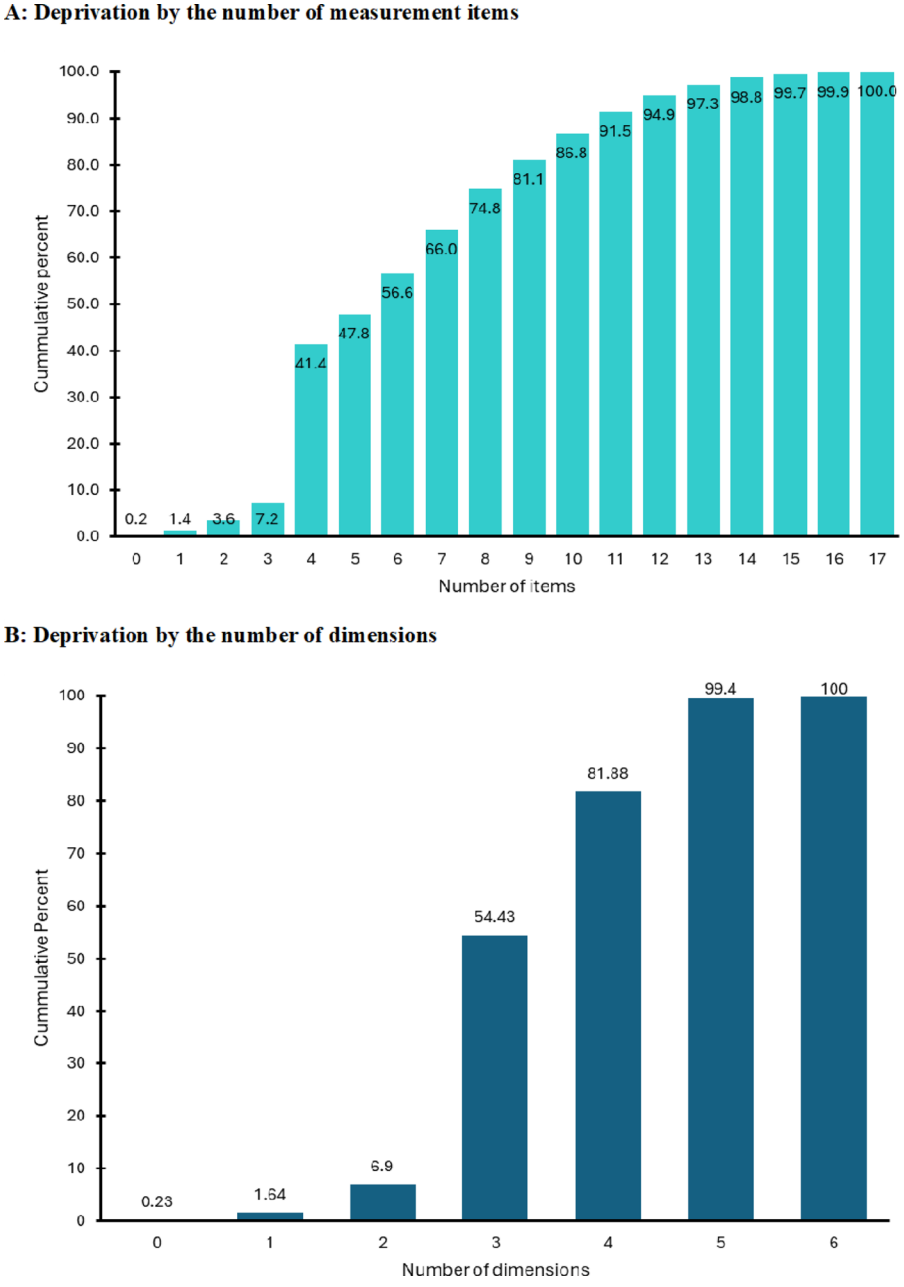

Fig. 3 Deprivation distributed by the number of measurement items and dimensions

More severe forms of overlapping deprivation were also evident: 13% of households were deprived across three dimensions—electricity access, optimal dwelling occupancy, and improved sanitation facilities—while 9% experienced deprivation across four dimensions, namely electricity access, optimal dwelling occupancy, improved sanitation facilities, and dwelling structural quality (Table 3).

4.4 Multidimensionally deprived population

Figure 5A presents the distribution of the population across three levels of multidimensional deprivation: vulnerability to multidimensional deprivation (k = 1/6), multidimensionally deprived (k = 2/6), and severely multidimensionally deprived (k = 3/6).

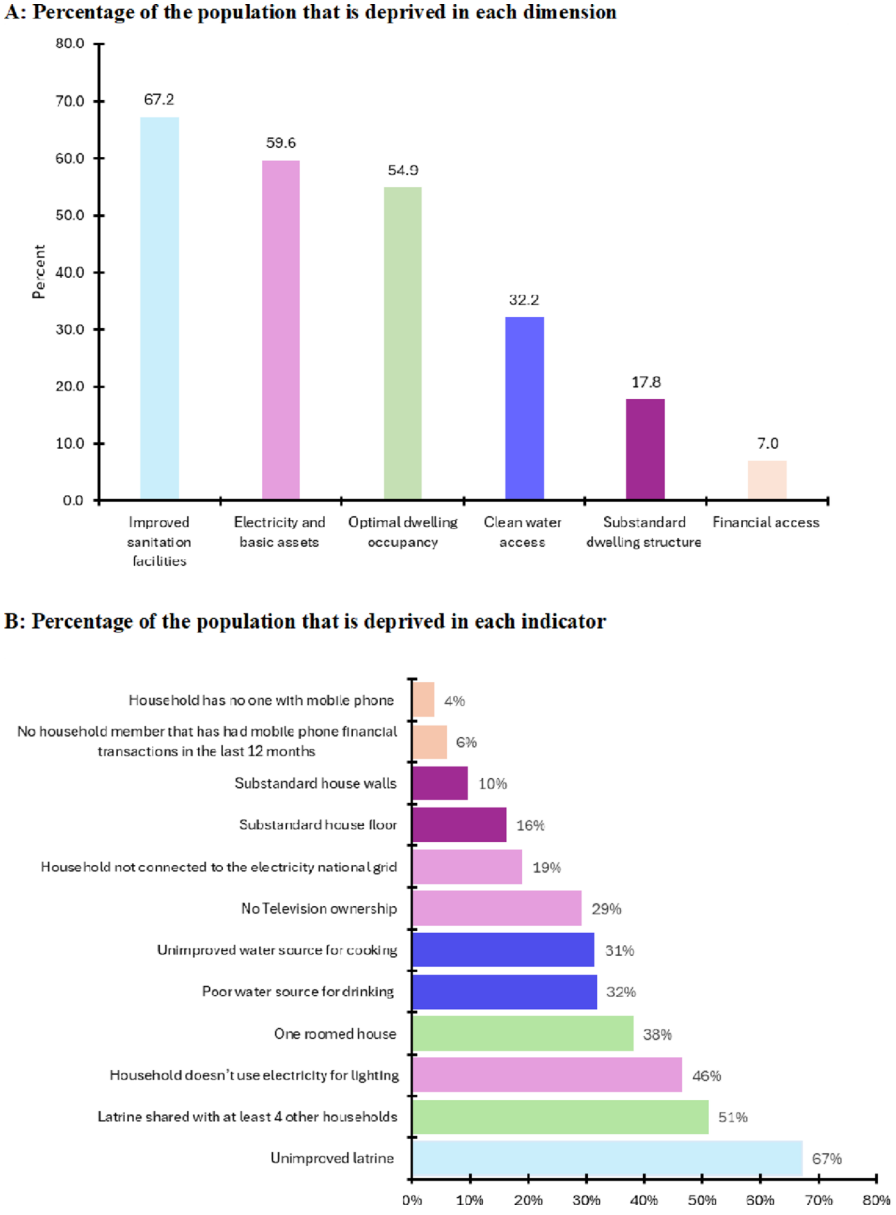

Fig. 4 Percentage of the population who were multidimensionally deprived

Overall, 32% of the population was classified as multidimensionally deprived (incidence, H). Among those deprived, the average intensity of deprivation (A) was 52%, indicating that a multidimensionally deprived individual lacked just over half of the deprivation items. The resulting Multidimensional Deprivation Index (MDI), defined as the product of incidence and intensity, was 17% (Fig. 5A), capturing the overall level of deprivation in the study population. Notable spatial variation was observed between the two study sites: Jinja City exhibited a substantially higher MDI than Iganga Municipality (29% versus 18%), representing a difference of 10% points (Supplementary Table 4).

Figure 5B illustrates how deprivation across the six identified dimensions is distributed by severity category. Lack of access to electricity emerged as the most critical and pervasive domain: 27% of the population was vulnerable to multidimensional deprivation, 32% was multidimensionally deprived, and 35% was severely multidimensionally deprived in

Table 3 Distribution of the households multidimensions

	Multidimension	Count	Percentage	Cumulative percentage
1	Electricity and basic assets, clean water access	1748	29.5	29.5
2	Optimal Dwelling occupancy, Improved sanitation facilities	1174	19.8	49.4
3	Electricity and basic assets, Optimal Dwelling occupancy, Improved sanitation facilities	793	13.4	62.8
4	Electricity and basic assets, Optimal Dwelling occupancy, Improved sanitation facilities, Substandard dwelling structure	533	9.0	71.8
5	Improved sanitation facilities	316	5.3	77.1
6	Optimal Dwelling occupancy, Improved sanitation facilities, Substandard dwelling structure	208	3.5	80.6
7	Electricity and basic assets, Financial access, Optimal Dwelling occupancy, Improved sanitation facilities, Substandard dwelling structure	201	3.4	84.0
8	Electricity and basic assets, Financial access, Optimal Dwelling occupancy, Improved sanitation facilities	127	2.1	86.1
9	Electricity and basic assets, Improved sanitation facilities	124	2.1	88.2
10	Optimal Dwelling occupancy	113	1.9	90.2
11	Electricity and basic assets, Optimal Dwelling occupancy	89	1.5	91.7
12	Optimal Dwelling occupancy, Improved sanitation facilities, Clean water access	64	1.1	92.7

this dimension. Deprivation in improved sanitation facilities also followed a similar gradient, affecting 29% of those vulnerable, 28% of the multidimensionally deprived, and 24% of the severely deprived population. Inadequate dwelling occupancy was concentrated primarily among the vulnerable (22%) and multidimensionally deprived (24%), with a smaller share among the severely deprived (11%). In contrast, deprivation related to substandard dwelling structures was less prevalent among the vulnerable (5%) but increased sharply with severity, affecting 9% of the multidimensionally deprived and 22% of the severely multidimensionally deprived population.

4.5 Proportion of multidimensionally deprived people deprived in each indicator

At a multidimensional deprivation cutoff of 33% (k = 2/6), a substantial share of the multidimensionally deprived population experienced acute housing and sanitation deficits (Table 4). Approximately one-quarter of multidimensionally deprived individuals lived in overcrowded conditions, characterized by residing in one-room dwellings and sharing a single latrine with at least four other households. In addition, 31% of the multidimensionally deprived population lacked access to improved sanitation facilities, while 18% were deprived specifically of improved toilet facilities. Structural housing deprivation was also evident, with 15% and 9% of the multidimensionally deprived population residing in dwellings with substandard floors and walls, respectively (Table 4).

Among the severely multidimensionally deprived population (k = 3/6), deprivation was both more concentrated and more intense across core living-condition indicators. Close to 15% resided in households characterized simultaneously by unimproved sanitation facilities, shared latrines with at least four households, one-roomed dwellings, and lack of electricity access (Table 4). Structural housing deprivation was similarly pronounced in this group, with approximately 10% and 7% living in dwellings with substandard floors and walls, respectively (Table 4).

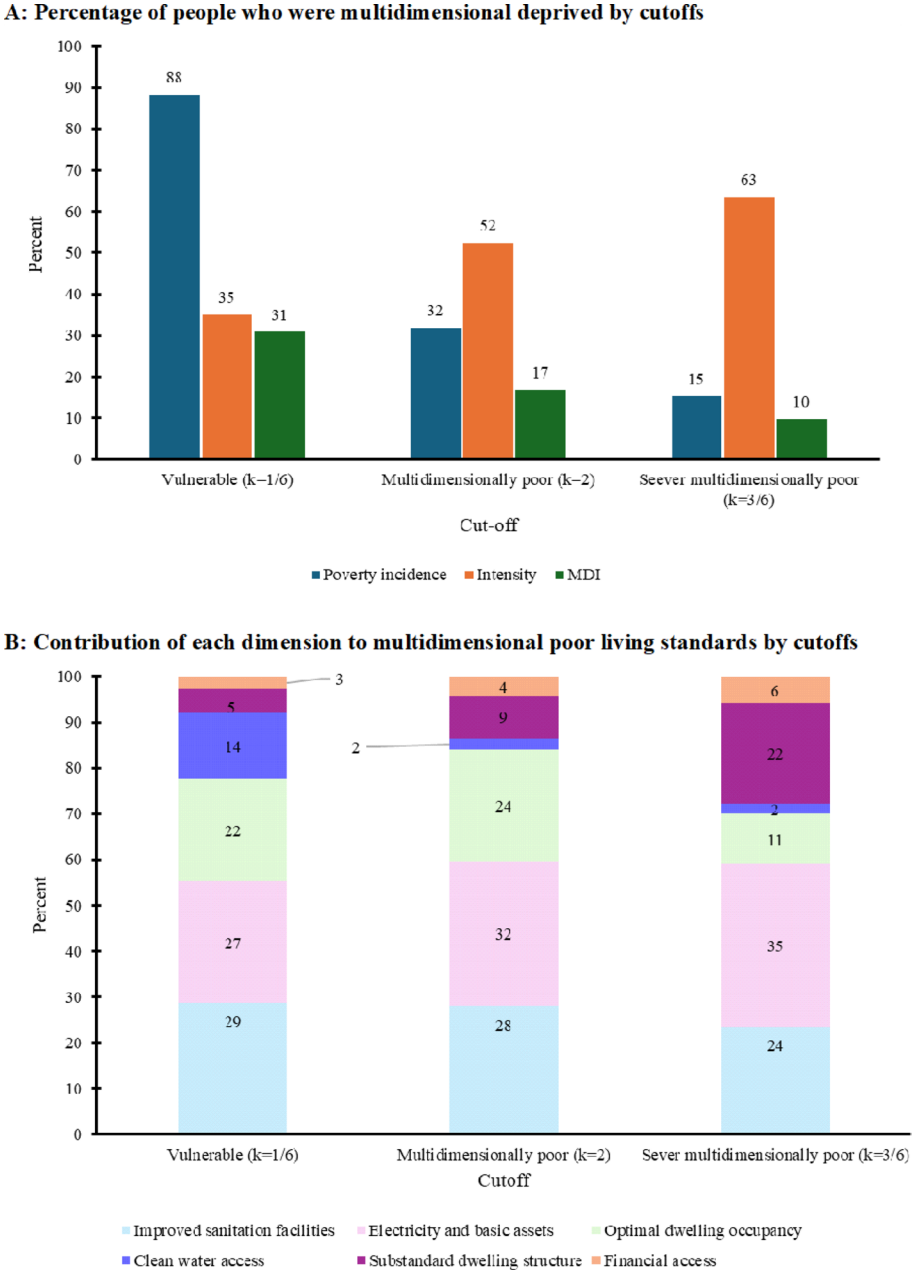

Fig. 5 Percentage of people who were multidimensional deprived

4.6 Deprivation in each indicator among the multidimensionally deprived

Deprivation among multidimensionally deprived households was highly concentrated across a core set of living-condition indicators (Table 5). Nearly all multidimensionally deprived individuals (98%), and the entirety of the severely multidimensionally deprived population (100%), resided in households using unimproved sanitation facilities. Among those classified as severely multidimensionally deprived, deprivation was particularly acute in indicators related to overcrowding and infrastructure: 89% lived in households sharing a single latrine with at least four other households, and 85% resided in one-room dwellings. Energy deprivation was also pronounced, with close to 80% of the severely multidimensionally deprived population living in households without electricity

Table 4 Proportion of people who are multidimensionally poor and deprived in each indicator

Dimensions	Indicators	Vulnerable (k=1/6)			Multidimensionally poor (k=2/6)			Severe multidimensionally poor (k=3/6)		
		Proportion (A)	Weight (B)	C=A*B	Proportion (A)	Weight (B)	C=A*B	Proportion (A)	Weight (B)	C=A*B
Clean water access	Unimproved water source for cooking	0.31	0.07	0.02	0.028	0.070	0.002	0.015	0.070	0.001
	Poor water source for drinking water	0.32	0.07	0.02	0.029	0.070	0.002	0.016	0.070	0.001
Improved sanitation facilities	Unimproved latrine	0.59	0.15	0.089	0.313	0.150	0.047	0.153	0.150	0.023
Optimal dwelling occupancy	Latrine shared with at least 4 other households	0.50	0.08	0.04	0.266	0.080	0.021	0.136	0.080	0.011
	One roomed house	0.37	0.08	0.029	0.241	0.080	0.019	0.132	0.080	0.011
Electricity and basic assets	Household doesn't use electricity for cooking	0.47	0.087	0.04	0.178	0.087	0.015	0.126	0.087	0.011
	Household not connected to the electricity national grid	0.19	0.087	0.016	0.179	0.087	0.015	0.126	0.087	0.011
	No Television ownership	0.29	0.087	0.025	0.254	0.087	0.022	0.147	0.087	0.013
Financial access	Household as no one with mobile phone	0.04	0.085	0.003	0.034	0.085	0.003	0.027	0.085	0.002
	No household member that has had mobile	0.06	0.085	0.005	0.054	0.085	0.005	0.040	0.085	0.003
	phone financial transactions in the last 12 months									
Substandard dwelling structure	Substandard house floor	0.16	0.065	0.01	0.147	0.065	0.010	0.098	0.065	0.006
	Substandard house walls	0.10	0.065	0.006	0.089	0.065	0.006	0.066	0.065	0.004
	MDI (sum of C)			**0.303**			**0.167**			**0.097**

Table 5 Proportion of poor people who are multidimensionally poor and deprived in each indicator

Dimensions	Indicators	Multidimensionally poor (k=2/6)	Severe multidimensionally poor (k=3/6)
		Proportion	Proportion
Clean water access	Unimproved water source for cooking	0.088	0.095
	Poor water source for drinking water	0.092	0.107
Improved sanitation facilities	Unimproved latrine	0.983	0.997
Optimal dwelling occupancy	Latrine shared with at least 4 other households	0.834	0.885
	One roomed house	0.756	0.858
Electricity and basic assets	Household doesn't use electricity for lighting	0.558	0.822
	Household not connected to the electricity national grid	0.561	0.818
	No Television ownership	0.798	0.955
Financial access	Household as no one with mobile phone	0.108	0.172
	No household member that has had mobile phone financial transactions in the last 12 months	0.168	0.263
Substandard dwelling structure	Substandard house floor	0.460	0.636
	Substandard house walls	0.280	0.429

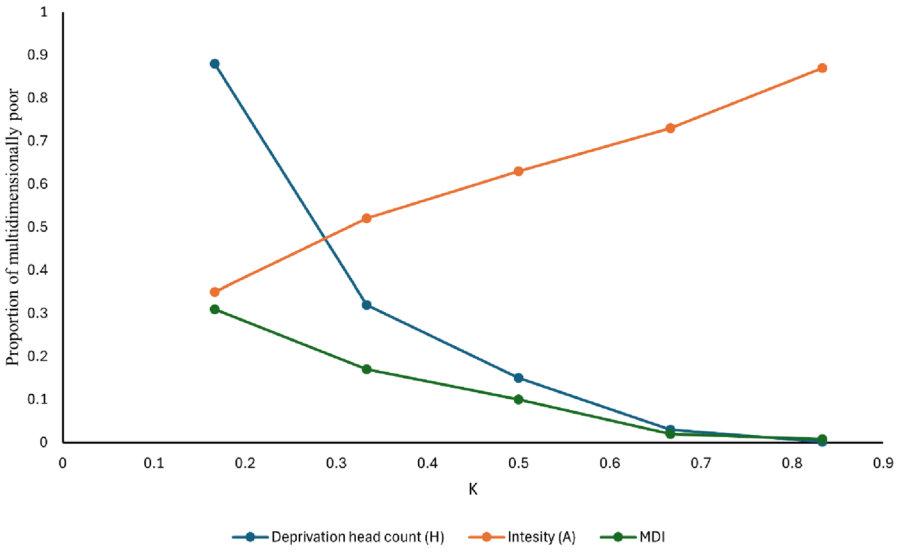

Fig. 6 Sensitivity analysis

access. Structural housing deficits were similarly prevalent, as 65% and 43% of this group resided in dwellings with substandard floors and walls, respectively (Table 5).

Overall, CFA condensed urban deprivation into six empirically validated and interrelated dimensions: electricity access; mobile phone–enabled financial services and communication; adequate dwelling occupancy; sanitation facilities; clean water access; and housing structural quality. The results demonstrate that multidimensional deprivation in these emerging urban settings is characterized by overlapping deficits in basic living conditions, rather than isolated shortfalls. Sanitation, electricity access, and overcrowded housing emerged as the most pervasive and mutually reinforcing domains, underscoring the structural nature of urban deprivation. The typical profile of a multidimensionally deprived household therefore includes residence in a one-room dwelling, reliance on unimproved and highly shared sanitation facilities, substandard housing materials, and lack of electricity—conditions that jointly constrain health, dignity, and the capacity to pursue valued life outcomes.

4.7 Sensitivity analysis

As expected, the deprivation headcount ratio (H) declines monotonically with higher values of k, indicating that fewer households meet the definition of multidimensional deprivation when stricter thresholds are applied (Fig. 6). Conversely, the intensity of deprivation (A) increases with higher k values, as households identified as deprived at stricter thresholds tend to lack multiple basic capabilities simultaneously. The overall MDI declines gradually, following a smooth trajectory across thresholds without sharp discontinuities. At the primary cutoff of $k = 2/6$, the MDI is approximately 0.17, with 32% of households classified as multidimensionally deprived and an average intensity of 52% (Fig. 6). At a cutoff of $k = 3/6$, the headcount reduces to 15%, but the intensity increases to 63%, demonstrating that households captured at higher thresholds suffer from deeper and more overlapping forms of deprivation (Fig. 6). These patterns confirm that our results are robust to reasonable variations in the cutoff and are not artifacts of the selected threshold.

To assess the statistical stability of the confirmatory factor analysis results, we conducted bootstrap resampling with 1,000 replications. The bootstrapped confidence intervals for factor loadings showed minimal variation relative to the original estimates (Table 2).

5 Discussion

The first objective of the study was to develop a multidimensional index of urban living standards deprivation for Uganda's newly gazetted municipalities and cities. The analysis identified six empirically distinct deprivation dimensions: access to electricity; financial and communication access; adequate dwelling occupancy; access to improved sanitation facilities; access to clean water; and structural housing quality. Together, these dimensions capture the multifaceted nature of urban deprivation, revealing deficits in living conditions that extend beyond conventional income- or wealth-based measures [7, 35]. From a capability perspective, these dimensions represent substantive constraints on individuals' agency, autonomy, and freedom to pursue valued ways of living, underscoring how urban deprivation manifests through interconnected shortfalls in essential services and living conditions rather than isolated economic disadvantages.

The second objective of the study was to assess the extent of multidimensional deprivation across households. The findings reveal widespread and overlapping deprivations: nearly all households were deprived in at least two dimensions, over nine in ten were deprived in three dimensions, and more than half experienced deprivation in four or more indicators. In addition, 95% of households were deprived in at least one-third of the identified dimensions, while almost half were deprived in at least half of them. These patterns indicate that deprivation in emerging urban settings is not episodic or isolated but cumulative, with multiple deficits jointly constraining households' capabilities to achieve basic functionings related to health, dignity, safety, and productive living. This cumulative nature of urban deprivation is consistent with earlier evidence from Uganda [21] and aligns with broader regional studies documenting persistent material and public-service deficits in rapidly urbanizing sub-Saharan African cities.

The overall MDI was 17%, with 32% of the population classified as multidimensionally deprived and an average multidimensionally deprived individual was deprived in 56% of the items. Substantial intra-urban variation was observed between the two study sites: Jinja City recorded an MDI approximately 10% points higher than Iganga Municipality, indicating more intense and widespread deprivation in the larger and more densely populated urban centre. This finding underscores the heterogeneity of deprivation within urban areas and challenges assumptions of a uniform urban advantage.

Although these estimates are not directly comparable to Uganda's national Multidimensional Poverty Index (MPI), which in 2020 reported an MPI of 23% with 42% of the population classified as multidimensionally poor and an average deprivation intensity of 54% [50], the contrast is nevertheless informative. It highlights how urban-specific deprivation profiles can diverge from nationally aggregated measures that combine rural and urban contexts and rely on different indicators, thresholds, and normative assumptions. In the Busoga region, where this study was conducted, the MPI was 24%, with 42% of the population identified as multidimensionally poor and an average deprivation intensity of 53% among the poor [50]. However, it is important to emphasize that this

study does not seek to directly compare the MDI with Uganda's MPI, as the two indices are methodologically distinct and conceptually divergent.

Electricity access emerged as a particularly critical dimension of deprivation, affecting nearly 60% of the population. Approximately 46% of households lacked electricity for lighting, a figure broadly consistent with the Uganda Demographic and Health Survey (UDHS), which reports that 58% of urban households nationwide have electricity connections [51]. Deprivation was markedly concentrated among the poorest: an estimated 56% of the multidimensionally deprived and 82% of the severely multidimensionally deprived population lacked access to electricity. These patterns are especially concerning in urban contexts, where education, livelihoods, and access to services increasingly depend on reliable electricity.

Despite recent gains in urban electrification, persistent challenges related to reliability, affordability, and connection costs continue to exclude poor urban households. From a capability perspective, the absence of electricity constrains both instrumental and intrinsic freedoms. Intrinsically, reliance on unsafe energy sources, such as kerosene for lighting or cooking, poses substantial risks to health and safety, including fire hazards and respiratory illnesses [11, 22, 48, 57]. Instrumentally, it limits children's ability to study after dark and restricts opportunities for home-based economic activities, thereby undermining educational attainment and income generation [8].

Water and sanitation deprivation further underscore the infrastructural deficits shaping urban living conditions. Nearly one-third of households (30%) relied on unsafe water sources for drinking and cooking—more than double the national urban estimate of 12% [51]. Although water deprivation was less prevalent among the multidimensionally deprived population, it reflects systemic shortcomings in service provision. Sanitation deprivation was more pronounced, affecting 67% of the total population and nearly one-third of the multidimensionally deprived. In densely populated urban settings, inadequate water, sanitation, and hygiene (WASH) facilities heighten exposure to waterborne and communicable diseases, particularly diarrhoeal illnesses and respiratory infections, which remain major contributors to morbidity among children under five. These WASH-related deprivations illustrate a reinforcing cycle of capability loss: poor sanitation increases disease burden, which in turn reduces productivity, raises healthcare expenditures, and deepens household vulnerability. In capability terms, the absence of safe water and sanitation directly undermines the fundamental functioning of being healthy and avoiding preventable disease—prerequisites for exercising other capabilities, including working, learning, and participating meaningfully in social and economic life.

Overcrowding and substandard housing emerged as prominent and interrelated forms of deprivation. More than half of households (54.9%) experienced suboptimal dwelling occupancy, with 38% residing in single-room structures and many sharing sanitation facilities with four or more other households. Structural housing deprivation affected an additional 17.8% of households, reflected in poor-quality floors (16%) and walls (10%). These deprivations were disproportionately concentrated among the multidimensionally deprived: approximately 76% of the multidimensionally deprived and 86% of the severely multidimensionally deprived population lived in single-room dwellings, while 83% and 86%, respectively, shared sanitation facilities with at least four other households.

The persistence of overcrowded and poorly constructed housing reflects a dual structural challenge: the limited supply of affordable formal housing and the rapid expansion

of unregulated informal settlements driven by demographic pressure and weak urban planning [16, 30, 40]. From a capability perspective, overcrowding and poor housing quality constrain well-being both intrinsically and instrumentally. Intrinsically, they undermine privacy, dignity, and physical health. Substandard housing materials—such as earthen floors and makeshift walls—expose households to flooding, vector-borne diseases, and respiratory illnesses, directly undermining the capabilities of being healthy and living in a secure environment, which are foundational for the realization of other life opportunities. Instrumentally, they limit opportunities for learning, productive work, and social participation. Evidence shows that cramped living conditions impair individuals' ability to study or work effectively from home, with children particularly affected due to limited space for concentration and learning, ultimately compromising educational outcomes and future capabilities [7, 10, 35]. These constraints are especially acute for women and children, whose agency and safety are further restricted by inadequate spatial autonomy.

The urban living standards deprivations observed in study area mirror those documented across sub-Saharan Africa's secondary cities. UN-Habitat's [54] report on multiple deprivations in secondary cities indicates overlapping deficits in sanitation, water access, overcrowding, and weak infrastructure—domains that our study also identifies as most pervasive [54]. Similarly, continent-wide mapping from 2000 to 2018 reveals chronic household overcrowding in rapidly expanding urban centers and informal settlements, where demographic pressures outstrip affordable housing and formal planning [7]. Underlying these shared patterns are political-economic factors. Decentralization has often created new municipalities for political rather than technical reasons, without commensurate fiscal transfers or institutional capacity, leading to fragmented governance and strained service delivery [13, 42]. Secondary cities typically receive less national investment than primary capitals, reinforcing informality in housing and labor markets and perpetuating energy, water, and sanitation deficits [54]. Unless addressed through targeted, pro-poor urban policies and inclusive planning, these structural dynamics will continue to entrench multidimensional deprivation and inequality across sub-Saharan Africa's secondary cities.

6 Study strengths and limitations

A major strength of this study lies in its methodological departure from conventional indices such as the Multidimensional Poverty Index (MPI), which rely on predefined dimensions and globally standardized thresholds. Instead, the study employs a combination of exploratory and confirmatory factor analysis (EFA/CFA) to inductively identify contextually salient dimensions of deprivation within secondary urban settings in Uganda. This data-driven approach allows the multidimensional deprivation index to be grounded in the empirical structure of local living conditions, thereby capturing the complex interplay of infrastructural, environmental, and socioeconomic constraints that shape urban households' capabilities. By aligning the measurement framework with the lived realities of urban residents in low-resource settings, the study enhances both the construct validity and policy relevance of the resulting index.

However, several limitations should be acknowledged. First, factor-analytic techniques are inherently sensitive to the set of indicators included, the underlying correlation structure, and the specific study context. While EFA and CFA are well suited

for identifying latent dimensions of deprivation, they do not establish causal relationships and may obscure important indicators that are weakly correlated but substantively important from a normative or policy perspective. Moreover, factor solutions may vary across populations or settings, implying that the identified dimensions should be interpreted as context-specific rather than universally applicable. Although the confirmatory factor analysis demonstrated good model fit, alternative factor structures may also be plausible. The resulting structure should therefore be interpreted as an empirically grounded representation of urban deprivation specific to the study settings, rather than as a definitive or universally applicable classification.

Second, the analysis is geographically restricted to secondary cities and newly established municipalities, which are often characterized by transitional governance arrangements, evolving infrastructure, and rapid population growth. While this focus is appropriate for addressing the study's objectives, it limits the generalizability of the findings to other urban contexts, particularly large metropolitan centres with more established infrastructure systems and different development trajectories.

Nonetheless, many of the governance, infrastructural, and service-access characteristics observed in Iganga Municipality and Jinja City are not unique to these settings. They exemplify broader challenges—such as informal settlement expansion, infrastructure deficits, and constrained municipal capacity—that characterize many of Uganda's rapidly growing secondary cities. Similar patterns of decentralization, administrative transition, and uneven service provision are also evident in other urbanizing regions of Uganda, including the Greater Kampala Metropolitan Area, and in comparable settings across sub-Saharan Africa. As such, while statistical generalization should be approached cautiously, the findings offer analytically transferable insights for understanding urban deprivation in similar contexts.

Finally, the study focuses primarily on access to infrastructure and services (e.g., electricity, water, sanitation), without capturing dimensions of service quality, reliability, or continuity, which are critical for understanding the lived experience of deprivation in urban informal settlements. Infrastructure may be nominally available but functionally unreliable, unsafe, or unaffordable dimensions not fully captured by the indicators used. This limitation may lead to under- or over-estimation of deprivation in some domains. Future research should therefore integrate qualitative measures and service-performance indicators, including reliability, safety, affordability, and user experience, to provide a more comprehensive assessment of urban deprivation and its implications for wellbeing.

7 Conclusions

The six dimensions identified in this study provide critical insights into the structural determinants of urban living conditions in Uganda's newly gazetted municipalities and cities. The findings demonstrate that conventional urban–rural comparisons, which often portray urban areas as uniformly better off, obscure substantial intra-urban inequalities. In rapidly expanding urban settings such as Jinja and Iganga, aggregate urban advantages conceal pockets of severe deprivation linked to inadequate housing, unreliable infrastructure, and limited access to essential services.

Uganda's current pace of urbanization—among the fastest in sub-Saharan Africa—has not been matched by commensurate investments in basic infrastructure and urban

planning. The failure to synchronize urban expansion with the provision of electricity, safe water, sanitation, and affordable housing has created systemic vulnerabilities in newly designated cities and municipal suburbs [4, 48]. From a capability perspective, these infrastructural deficits translate directly into constrained freedoms, limiting individuals' ability to achieve fundamental functionings such as good health, safety, dignity, and productive participation in economic and social life.

In this way, multidimensional deprivation in urban living standards manifests as capability deprivation, trapping households in cycles of limited opportunity and reinforcing intergenerational disadvantage. Addressing these challenges therefore requires integrated, multisectoral policy responses. Interventions targeting single domains—such as housing alone—are unlikely to generate meaningful improvements in wellbeing unless accompanied by simultaneous investments in water, sanitation, and electricity access. Policymakers and development partners must adopt data-driven, context-specific strategies that recognize the interdependence of urban deprivations and respond to the complex interplay between spatial, infrastructural, and socioeconomic constraints. Particular attention should be directed toward emerging municipalities and secondary cities, where the pace of urban growth continues to outstrip institutional capacity, regulatory oversight, and public infrastructure investment.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s44282-026-00367-w.

Supplementary Material 1.

Author contributions

RMK, CB, JNS, and PW collected data. RMK analyzed the data and wrote the initial draft of the manuscript. CB, BS, JNS, AN, JA, MMK, CF, and PW contributed to interpreting of the results and reviewed the manuscript. All authors have approved the final version of the manuscript for submission.

Funding

Data collection was part of the implementation of family planning for the project funded by the John Templeton Foundation, Grant number 62045. The funders had no role in the study design, data collection and analysis, decision to publish, or manuscript preparation.

Data availability

The data underlying this study, along with the analysis codes, is publicly accessible via the Open Science Framework (OSF) repository [19].

Ethical Considerations

Ethics approval and consent to participate

Ethical approval for this study was obtained from the Makerere University School of Public Health Research and Ethics Committee (Ref: SPH-2021-146) and Uganda National Council for Science and Technology (Ref: HS1826ES). Administrative clearance was also sought from the leaders of Jinja City and Iganga Municipality prior to data collection.

Consent for publication

All authors provided consent to submit to the journal. The manuscript is an original, unpublished work and has not been simultaneously submitted to, or is not being evaluated in, other media or journals.

Informed consent

Written informed consent was obtained from all participants, and anonymity was ensured for all the collected data. The data files were stored on password-protected computers to safeguard privacy and confidentiality.

Competing interests

The authors declare no competing interests.

Received: 7 June 2025 / Accepted: 4 March 2026
Published online: 13 March 2026

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