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Perceived Environmental Barriers and Disability Among Older Adults in the Eastern Himalayan Region of India: A Mixed-Methods Community-Based Study

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Abstract

Background

Older adults living in mountainous regions may experience disability not only because of ageing and chronic illness but also because of environmental and social barriers. However, evidence on how these factors shape perceived disability in mountainous areas of India remains limited. This study examined the prevalence of perceived disability and explored context-specific environmental barriers among community-dwelling older adults in East Sikkim, India.

Methods

An exploratory sequential mixed-methods study was conducted among community-dwelling adults aged ≥ 60 years in East Sikkim between October 2016 and November 2017. In the qualitative phase, 15 older adults from rural (n = 9) and urban (n = 6) areas participated in in-depth interviews. Data were analyzed thematically, and identified environmental barriers informed the quantitative phase. A cross-sectional survey of 450 older adults assessed perceived disability using the 12-item WHO Disability Assessment Schedule 2.0 (WHODAS 2.0). Multivariable logistic regression examined associations between environmental barriers and perceived disability, adjusted for age group, gender, chronic illness, and financial independence.

Results

The prevalence of perceived disability was 60.7% (95% CI: 56.0-65.2). Qualitative analysis identified five environmental barriers perceived by the participants: terrain-related, pedestrian infrastructure, public transportation, social isolation, and digital exclusion. After adjustment, major problems with public transportation (AOR 5.35, 95% CI 2.93–9.78), pedestrian infrastructure (AOR 3.29, 95% CI 1.78–6.08), and social isolation (AOR 4.78, 95% CI 2.70–8.47) were independently associated with perceived disability.

Conclusion

Perceived disability among older adults in East Sikkim was associated with chronic illness as well as perceived environmental barriers. Improving age-friendly transportation, pedestrian infrastructure, and opportunities for social participation may support healthy ageing in mountainous settings.

Introduction

Population ageing is accelerating globally, posing complex health, social and economic challenges for independence, functional ability, and well-being [1]. Regardless of ageing, disability is not inevitable

consequences, but the likelihood of perceiving a disability or living with a disability does increase with age [2]. Perceived disability are self-reported difficulties in activities and participation in accordance with International Classification of Functioning (ICF), that provide a valuable measure of lived experience and may not be fully captured by biomedical assessments alone [3–6]. One of the most consistent predictors of disability is socioeconomic disadvantage, poor nutrition, and inability to access healthcare [2]. This perception of disability and challenges faced by older adults may be further intensified in mountainous regions such as the Eastern Himalayas, where rugged terrain, limited infrastructure, economic constrains can shape daily life access to services [7–9].

India is undergoing epidemiological transition with proportion of the population aged over 60 years doubling from 10% to 20% in just over 20 years [10]. Recognizing the global significance of demographic ageing, the World Health Organization (WHO) has emphasized functional ability and well-being through the United Nations decade of Healthy Ageing (2021–2030), which calls for contextually relevant strategies to support older population [11]. Despite these commitments, evidence on how healthy ageing frameworks is operationalized in developing country remains limited [12, 13].

Recently over 23% of older adults aged 60 years and above have been reported to share the total global burden of diseases. Disability-adjusted life years (DALYs) per head are now 40% higher in low and middle-income regions owing to the increased incidence of cardiovascular diseases along with sensory, respiratory and infectious disorders [14]. Additionally, non-communicable diseases now constitute as the leading causes of morbidity in older age groups [15]. More than half of adults aged 60 years and above live with at least one chronic condition, most commonly hypertension, diabetes, and musculoskeletal disorders [16, 17]. Multimorbidity, defined as the presence of two or more chronic conditions, is highly prevalent and is consistently associated with functional limitations, loss of independence, and an increased risk of disability [18–20]. Evidence from the Longitudinal Ageing Study in India (LASI) further indicates that 65.89% of older adults in Sikkim report at least one chronic condition, the highest prevalence in the north-eastern region of India [21].

Sikkim is located in the Eastern Himalayan region of India and is characterized by dispersed settlements across steep mountainous terrain, with heavy monsoon rainfall. These environmental conditions may place additional physical demands on older adults living with chronic conditions and may further contribute to difficulties in maintaining daily activities and mobility. At the same time, the state is undergoing demographic and social transitions, including declining fertility and changes in family structure, which may influence traditional support systems for older adults [22–24].

Environmental and social conditions that shape the daily lives of older adults are particularly relevant in mountainous settings. Research from the Himalayan region has largely focused on vulnerabilities related to climate change, poverty, and access to healthcare [8, 9, 13, 25]. Studies from eastern Nepal have shown that neighbourhood conditions and physical environmental features are closely associated with quality of life (QOL) and functional health among older adults [26]. Similarly, qualitative evidence from central Nepal highlights challenges in accessing healthcare services that extend beyond geographical

barriers [25]. However, this body of work provides limited insight into how broader environmental factors influence perceived disability and everyday functioning among older adults in mountainous regions of India.

Despite growing recognition that local conditions play a central role in shaping disability in later life [27–29], empirical evidence from mountainous regions of India remains scarce. Addressing this gap is essential for designing age-friendly and contextually appropriate interventions aligned with the goals of the Decade of Healthy Ageing and sustainable development (SDG 3: good health and well-being). This study therefore aims to access the prevalence of perceived disability, identify context-specific environmental barriers, and examine their associations among community-dwelling older adults.

Methods

Study Design and Settings

This study used an exploratory sequential mixed methods design among community-dwelling older adults in East Sikkim, India [30]. The design consisted of an initial qualitative phase followed by a quantitative survey conducted from October 2016 to November 2017. Integration between the qualitative and quantitative phases occurred during instrument development, whereby findings from the qualitative phase informed the selection and construction of variables used in the quantitative survey (Fig. 1).

Phase I: Qualitative component

Participant recruitment and data collection

The qualitative phase adopted an exploratory descriptive design to identify environmental barriers experienced by community-dwelling older adults in their everyday lives.

Participants for the qualitative phase were purposively selected to capture variation in place of residence and socioeconomic background, including individuals from a rural setting (Ranka village) and an urban setting (Ranipool town). Eligibility criteria included adults aged 60 years or older who were residing in the study area and able to communicate their experiences. Recruitment was facilitated through community contacts and local health workers familiar with the study area.

Data were collected through in-depth semi-structured interviews conducted in Nepali language. An interview guide was developed based on a review of relevant literature and preliminary observations from the pilot field visit. Interviews were conducted by the first author, a female doctoral researcher trained in qualitative research methods and with a professional background in physiotherapy. The interviewer was familiar with the sociocultural context of the study area, which facilitated rapport with participants. Interviews were conducted in participants' homes in a private setting and lasted approximately 30–40 minutes. With participants' consent, interviews were audio-recorded to ensure

accurate documentation of responses. Detailed field notes were also maintained during and immediately after each interview to capture contextual information and non-verbal observations relevant to the study.

Data Management and Analysis

All audio recordings were transcribed verbatim in Nepali by the interviewer and subsequently translated into English for analysis. Minor grammatical adjustments were made during translation to improve readability while preserving the original meaning of participants' narratives. Field notes were expanded immediately after data collection to ensure key statements and contextual details were accurately documented. All identifying information was removed from transcripts and field notes and replaced with unique participant identification numbers.

Data was analyzed using thematic analysis as described by Braun and Clarke [31]. The analysis involved familiarization with the data through repeated reading of transcripts and field notes, followed by inductive coding. Initial codes were developed directly from the dataset manually using Microsoft Word to ensure close engagement with the data. Codes representing similar ideas were grouped into broader categories, and potential themes were generated. Emerging interpretations and coding decisions were discussed within the research team to enhance reflexivity and analytic rigor. Themes were reviewed and refined to ensure that they accurately reflected the dataset and addressed the research objectives. The coding decisions, theme development, analytic reflections throughout the analysis, as well as regular peer discussions within the research team were documented.

Themes identified during thematic analysis were interpreted as context-specific environmental barriers to older adults' daily functioning. These themes informed the development of survey items for the subsequent quantitative phase, enabling further examination of their association with perceived disability.

Phase II: Quantitative component

Participant recruitment and data collection

The quantitative survey included community-dwelling older adults 60 years and above who had resided in the selected study areas for at least one year and were able to provide informed consent. Sample size was calculated using the standard formula for estimating a single population proportion. In the absence of prior local estimates of perceived disability, a conservative prevalence of 50% was assumed to maximize variability. Using a 95% confidence level and an absolute precision of 5%, the minimum sample size was estimated at 384 participants. After adjusting for an anticipated non-response rate of 15%, the final required sample size was calculated as 452 participants.

Fieldwork for this survey was conducted concurrently with the ICMR project (Northeast seed grant 2014:3283) among the same participants in East Sikkim, but the research objectives, outcome

measures, and analytical framework differed. The objective of ICMR project was to assess functional impairments among older adults using Instrumental Activities of Daily Living (IADL) scale. The principal investigator of the ICMR project served as a supervisor for the present doctoral research. Sociodemographic characteristics and QOL outcomes from this dataset have been reported previously in a separate publication [32].

A multistage sampling strategy was employed for participant recruitment, with the sampling process presented in Fig. 2. In the first stage, rural and urban administrative units were selected as sampling clusters. From the total of 52 Gram Panchayat Units (GPUs) and 29 urban wards in East Sikkim, 18 GPUs and 8 municipal wards were selected using computer-generated random numbers. According to the rural-urban population distribution reported in the 2011 Census of India, approximately 72% of the population resides in the rural areas and 28% in urban areas. To reflect the rural-urban population distribution, approximately 18 participants were recruited from each selected rural GPU and 15–16 participants from each selected urban ward. In the absence of a formal household sampling frame, the systemic field-based approach was adopted to improve geographic representation. Within each selected cluster, field investigators followed predefined access routes, including main roads and footpaths, and progressively extended recruitment to dwellings across different elevations. This approach was intended to minimize selection bias in a dispersed settlements characteristic of hilly terrain. All eligible older adults encountered during household visits were invited to participate, and recruitment continued until the required sample size was achieved. If more than one eligible older adult resided in household, one participant was selected using simple random selection.

Measurement of perceived disability

Perceived disability was assessed using the 12-item World Health Organization Disability Assessment Schedule version 2.0 (WHODAS 2.0), a standardized instrument developed by WHO to measure activity limitations and participation restrictions [33]. With prior permission, the questionnaire was translated into Nepali language using a cross-cultural adaptation process involving forward translation, back translation, review by bilingual experts, and pilot testing. Minor linguistic adjustments were made following pilot testing to improve clarity for participants.

The instrument evaluates functioning across six domains: cognition, mobility, self-care, getting along with others, life activities, and participation in society. Each item is scored on a five-point Likert scale ranging from 1 (no difficulty) to 5 (extreme difficulty or inability to perform the activity). Item scores were summed to obtain a total disability score, with higher scores indicating greater functional limitation.

As WHODAS 2.0 does not provide a standardized cutoff for disability classification, a cutoff score of 24 or higher was used to classify participants as having perceived disability, based on its use in prior study [34, 35]. Participants were therefore categorized into two groups for analysis: no perceived disability (score < 24) and perceived disability (score ≥ 24).

Measurement of environmental barriers

Environmental barriers identified during the qualitative phase were incorporated into the quantitative survey through a structured module. For each domain, representative statements were developed based on participants' narratives to ensure contextual relevance and clarity. Participants in the quantitative phase were asked to indicate the extent to which each environmental factors affected their daily life. Responses were recorded using a binary code (0 = minor problem; 1 = major problem), based on how the barrier was perceived to substantially limit mobility, participation, or independence. This approach enabled the incorporation of context-specific environmental factors, derived from qualitative findings, into quantitative analysis examining their association with perceived disability.

Data analysis

All quantitative data were entered into Microsoft Excel and subsequently analyzed using IBM SPSS Statistics version 27. Statistical significance was defined as a p value < 0.05. Descriptive statistics were used to summarize participant characteristics.

The distribution of WHODAS 2.0 scores was assessed using the Shapiro–Wilk test and visual inspection, which indicated deviation from normality. For the primary analysis, perceived disability was operationalized as a binary variable using a predefined cut-off score on the WHODAS 2.0 scale. The prevalence of perceived disability was estimated with 95% confidence intervals. Associations between sociodemographic characteristics and perceived disability were assessed using the chi-square test.

Multivariable logistic regression analysis was conducted to examine the association between environmental barriers and perceived disability. AOR with 95% confidence intervals were reported. The model was adjusted for potential confounders, including age group, gender, presence of chronic illness, and financial independence. These variables were selected based on relevance within the ICF framework, which recognizes demographic and health characteristics as key determinants of independence and disability in older adults.

Model performance was evaluated using Nagelkerke R^2 and the Hosmer–Lemeshow goodness-of-fit test. Multicollinearity was assessed using variance inflation factors (VIF), with values < 5 indicating no significant multicollinearity.

As a sensitivity analysis, multiple linear regression was performed using WHODAS 2.0 score as a continuous outcome variable. The same independent variables included in the logistic regression model were entered simultaneously. Unstandardized regression coefficients (B) with 95% confidence intervals were reported and p-value of < 0.05 was considered statistically significant.

Results

Qualitative findings

A total of 15 older adults participated in the qualitative interviews, including nine participants from rural areas and six participants from urban areas. The characteristics of the study population are summarized in Table 1.

Table 1
Demographic characteristics of participants in the in-depth interviews

Characteristic	frequency	percentage
Gender		
Male	7	46.7%
Female	8	53.3%
Locality		
Rural	9	60%
Urban	6	40%
Age group (years)		
≤ 69	9	60%
≥ 70	6	40%
Marital Status		
Married	11	73.3%
Unmarried/Widowed/divorced	4	26.7%
Living arrangement		
With Spouse /Alone	3	20%
With family	12	80%

Thematic analysis of in-depth interviews identified five themes related to environmental barriers experienced by older adults: (1) Terrain-related barriers (2) Pedestrian infrastructure barriers (3) Public transportation barriers (4) Social isolation, and (5) Digital exclusion.

Terrain-related barriers

Most participants had spent their lives engaged in agricultural work and other nature-based livelihoods. As they grew older, they still expressed a strong desire to remain physically active by tending their fields, visiting relatives, and making spiritual visits to local monasteries. They expressed a strong emotional attachment to the hills, describing them as an important part of their cultural identity. At the same time, they explained that with advancement in age, living in hills made everyday activities physically demanding.

“If I leave home for some work, there is a high chance I’m late. Even a short distance takes a long time here. In the hills, being out after dark is only for young people. Old people like us could be swept away by the river or fall off a cliff with one wrong step.” (Male, 69, rural resident)

Pedestrian infrastructure barriers

Participants reported that simply leaving their home involved navigating long flights of steps, uneven footpaths, and slippery surfaces. Although they remained motivated to seek medical care, reaching their destination or transport pick-up points was often physically demanding and challenging.

“I don't dare go out. The steps are too long and many. I start to breathe heavily, and my knees are bad. When it rains, the path becomes so slippery. Just thinking about using those stairs to gompa (monastery) I give up.” (Female, 82, rural resident)

“If I have to move out of my house, first I need to descend from the 4th floor of my building to the ground floor using the stairs. Second, I must walk uphill...ahh, such a difficult stair to reach the road. then I need to ask each passing taxi if they are going to the location I intend to visit; if not, I must change multiple taxis. I don't know how many more stairs I will have to encounter when I reach my destination. Now imagine doing the same thing to return home.” (Female, 67, urban resident)

Public transportation barriers

Participants described public transportation as a challenge to accessing services and participating in community activities, particularly in rural settings where only a few shared taxis (sumo, savari) operate on fixed schedules. Several participants reported avoiding the cramped, bumpy rides or missing the available transport because hospital procedures were delayed.

“Even if I catch the sumo, it’s so packed I feel like my bones are crushed. The bumps on the road make my old spine ache. I’d rather stay home, do my gardening work, and look after my cattle. I avoid travelling by sumo, I come home worse than I left.” (Male, 76, rural resident)

“I sit in the hospital feeling anxious, not because I’m sick, but because I’m afraid that if I miss the scheduled taxi, there’s no other way for me to get back home.” (Female, 68, rural resident)

Social isolation

Older adults experienced reduced interaction with family members, which many attributed to the migration of younger relatives and changing patterns of communication. Limited mobility and health concerns further reduced their opportunities for social interaction outside the home. Despite these experiences of loneliness, many participants described actively engaging in meaningful activities to cope with prolonged periods of solitude.

“Most of the time during the day, I am alone, but I try to keep myself busy. I look for something to do, like pulling out weeds around the house, listening to the radio, repairing old wooden furniture, or making

bamboo baskets. It helps pass the time. Even festivals feel like food without salt. They used to bring the whole family together, but now everyone seems to be too busy." (Male, 65, rural resident)

"Earlier, grandparents used to tell stories to their grandchildren. Now, television and phone (YouTube) tell them stories. I'm not needed anymore. Even when they're at home, they're not really here, their minds are on their phones. I feel like a ghost in my own house." (Female, 69, urban resident)

Digital exclusion

Participants expressed difficulty in using digital applications, particularly communication platforms because they required users to read and navigate text-based interfaces. Participants explained that most platforms were available in English and that even native-language interfaces could be difficult to use because they could speak the language but not read or write it. As a result, limited access to social media and other digital platforms left participants feeling disconnected and without a voice in an increasingly digital society.

"My children tell me to use Google Maps, but I do not know where to start. I don't feel like these things are made for people my age. I can't read the screen properly, and I'm afraid of pressing the wrong thing. The only thing I can manage with confidence is answering incoming calls." (Male, 71, urban resident)

Quantitative findings

Participant characteristics and prevalence of perceived disability

A total of 450 older adults participated in the study, including 324 from rural areas and 126 from urban areas. The mean age of participants was 70.8 ± 8.1 years in rural areas and 69.3 ± 7.3 years in urban areas. Chronic illness was highly prevalent, with arthritis being the most reported condition, followed by vision impairment and hypertension. Sociodemographic characteristics of the study population have been reported previously from the same dataset [32].

The mean WHODAS 2.0 score was 29.0 ± 9.5 among rural participants and 28.4 ± 9.0 among urban participants, with no statistically significant difference between the two groups ($p = 0.61$). The overall prevalence of perceived disability was 60.7% (95% CI: 56.0–65.2).

Association between sociodemographic characteristics and perceived disability

Participants aged ≥ 70 years had a significantly higher prevalence of perceived disability compared to those aged ≤ 69 years in both rural and urban areas ($p < 0.001$). The presence of chronic illness was also strongly associated with perceived disability in both settings ($p < 0.001$). In rural areas, perceived disability was significantly associated with financial dependence ($p = 0.031$), illiteracy ($p = 0.006$), and unemployment ($p = 0.007$). In urban areas, perceived disability was significantly associated with marital

status ($p < 0.001$) and living arrangement ($p = 0.049$), with higher prevalence observed among participants who were unmarried, widowed, or divorced, and those living with family members. Detailed results are presented in Table 2.

Table 2
Association between sociodemographic characteristics and perceived disability among older adults in rural and urban areas (n = 450)

n = 450						
Characteristic	Rural (n = 324)	Perceived disability n (%)	p-value	Urban (n = 126)	Perceived disability n (%)	p-value
Gender			0.065			0.257
Male	149	83 (55.7)		59	32 (54.2)	
Female	175	115 (65.7)		67	43 (64.2)	
Age group (years)			< 0.001			< 0.001
≤ 69	160	82 (51.2)		71	25 (35.2)	
≥ 70	164	116 (70.7)		55	50 (90.9)	
Marital Status			0.968			< 0.001
Married	219	134 (61.2)		91	42 (46.2)	
Unmarried/ Widowed/divorced	105	64 (61)		35	33 (94.3)	
Living arrangement			0.428			0.049
With Spouse /Alone	55	31 (56.4)		35	16 (45.7)	
With family	269	167 (62.1)		91	59 (64.8)	
Financial independence			0.031			0.910
Yes	70	35 (50)		29	17 (58.6)	
No	254	163 (64.2)		97	58 (59.8)	
Literacy			0.006			0.402
Literate	72	34 (47.2)		65	41 (63.1)	
Not literate	252	164 (65.1)		61	34 (55.7)	
Employment status			0.007			0.406
Yes	27	10 (37)		16	8 (50)	
Note: p-values < 0.05 from chi-square indicate statistical significance.						

n = 450					
No	297	188 (63.3)		110	67 (60.9)	
Chronic disease			< 0.001			< 0.001
Absent	84	25 (29.8)		35	8 (22.9)	
Present	240	173 (72.1)		91	67 (73.6)	
Note: p-values < 0.05 from chi-square indicate statistical significance.						

Perceived environmental barriers and perceived disability

In univariable logistic regression models, each perceived environmental barrier was significantly associated with perceived disability. However, after adjustment for covariates (age group, gender, presence of chronic illness, and financial independence), only selected barriers remained significantly associated. Barriers related to public transportation (AOR = 5.35; 95% CI: 2.93–9.78), pedestrian infrastructure (AOR = 3.29; 95% CI: 1.78–6.08), and social isolation (AOR = 4.78; 95% CI: 2.70–8.47) were significantly associated with higher odds of perceived disability. In contrast, terrain-related barrier and digital exclusion did not show an independent association with perceived disability after adjustment. These findings are summarized in Table 3.

Table 3
Association between perceived environmental barriers and perceived disability among older adults (n = 450)

Environmental barriers	**Category**	**n**	**Disabled n (%)**	**AOR (95% CI)**	**p-value**
Terrain-related	Major Problem	269	197(73.2)	1.32 (0.68–2.55)	0.410
	Minor Problem	181	76(42)	1.00 (reference)	
Pedestrian infrastructure	Major Problem	284	230(81)	3.29 (1.78–6.08)	< 0.001
	Minor Problem	166	43(25.9)	1.00 (reference)	
Public transportation	Major Problem	286	231 (80.8)	5.35 (2.93–9.78)	< 0.001
	Minor Problem	164	42 (25.6)	1.00 (reference)	
Social isolation	Major Problem	228	187(82)	4.78 (2.70–8.47)	< 0.001
	Minor Problem	222	86(38.7)	1.00 (reference)	
Digital exclusion	Major Problem	266	180(67.7)	0.87 (0.45–1.69)	0.691
	Minor Problem	184	93(50.5)	1.00 (reference)	
Note: Adjusted for age group, gender, chronic disease, and financial independence.					

Multivariable model performance

The multivariable logistic regression model was statistically significant ($\chi^2 = 261.10$, df = 9, $p < 0.001$) and demonstrated substantial power (Nagelkerke $R^2 = 0.596$). Model fit was adequate, with no evidence of poor calibration based on the Hosmer–Lemeshow goodness-of-fit test ($\chi^2 = 4.52$, $p = 0.807$). Using the selected classification threshold, the model correctly classified 84.2% of participants, with a sensitivity of 89.0% for identifying participants with perceived disability and a specificity of 76.8% for identifying those without perceived disability. No concerning multicollinearity was observed among the independent variables, with VIF values ranging from 1.10 to 1.79.

Sensitivity analysis using continuous WHODAS score (linear regression)

In sensitivity analyses using WHODAS score as a continuous outcome (Supplementary file 1), similar patterns of association were observed. Higher WHODAS scores were significantly associated with older age (B = 3.16; $p < 0.001$), presence of chronic illness (B = 4.76; $p < 0.001$), barriers related to public transportation (B = 5.90; $p < 0.001$), pedestrian infrastructure (B = 2.38; $p = 0.011$), and social isolation (B = 2.96; $p < 0.001$). No significant associations were observed for gender, financial dependence, digital exclusion, or terrain-related barrier. These findings were consistent with the results of the logistic regression analysis.

Discussions

This study provides novel evidence from a mountainous region of India demonstrating that perceived disability in later life is shaped not only by health conditions but also by modifiable environmental and social factors. This study may also provide a preliminary insight as context to LASI Wave 1 data from the same period (2017–2018) where Sikkim was missed and was later added on 2020–2021.

The prevalence of perceived disability among older adults in Sikkim reported in this study was higher than estimates reported in many low and middle-income countries [17, 36–38]. This may be related to the combined effects of population ageing, the high burden of chronic conditions, and the physical demands of living in a mountainous environment. In Sikkim, steep terrain, scattered settlements, and limited infrastructure can make routine activities more physically demanding and may further contribute to functional limitations. These findings support an interactional understanding of disability, in which environmental conditions, together with underlying health status, influence the functional ability of older adults [3, 39].

Relation between perception of environmental barriers and disability

Participants reported transportation to be one of the main barriers and was significantly associated with perceived disability, highlighting the important role of mobility systems in shaping the functional ability of older adults [40, 41]. The limited availability of public transportation services in hilly areas, combined with difficult travel conditions for older adults, may be a major factor restricting access to essential services and discouraging healthcare utilization. Participants also described the psychological stress caused by uncertainty during travel, suggesting that transportation barriers are not only about physical access but can also create anxiety and make older adults feel less confident about travelling. Similar challenges have been reported in other mountainous settings, including rural Nepal [25]. These findings highlight the need for age-friendly transportation systems in mountainous regions to reduce the physical demands of travel. This could include accessible vehicles for older adults, sufficient waiting times, and arrangements to ensure that older adults have transport available for their return journey after scheduled visits, so that they are not left behind.

Barriers related to pedestrian infrastructure were also independently associated with perceived disability. The qualitative findings showed that long flights of stairs, slippery surfaces, uneven pathways, and other environmental obstacles created considerable challenges for older adults, increasing the physical demands of routine activities. Similar findings have been reported in mountainous regions such as Nepal and Bhutan, where inadequate infrastructure has been linked to functional limitations among older adults [42, 43]. Evidence from Taiwan has also shown that perceived environmental barriers, particularly physical and structural barriers, are strongly associated with disability among community-dwelling older adults [44]. Previous research has highlighted the influence of the built environment on functional ability and social participation among community-dwelling older adults [45]. In addition, studies among very old adults have shown that environmental barriers and a poor fit between individuals and their surroundings may have wider implications for health outcomes, including mortality [46]. Together, these findings highlight the importance of considering environmental conditions alongside individual health characteristics when understanding disability among older adults.

Social isolation and digital illiteracy as an under-recognized factor in the hills

Social isolation was strongly associated with perceived disability, even after adjusting for health and demographic factors, highlighting the importance of social context in maintaining functional ability among older adults. The qualitative findings suggest that changing family structures, migration, and reduced interaction between generations may limit social participation and contribute to the loss of meaningful social roles. These findings are in line with previous evidence showing that social isolation and reduced social participation are associated with several adverse health outcomes, including cognitive decline and increased mortality risk [47, 48].

Interventions that encourage social engagement, including community-based programs and the integration of social support into primary healthcare, may therefore play an important role in reducing disability among ageing populations. Such approaches are also consistent with the World Health

Organization's Healthy Ageing framework, which emphasizes the importance of supportive environments and maintaining functional ability in later life [49].

Although digital exclusion was not independently associated with perceived disability in the adjusted analysis, the qualitative findings indicate that it may still affect functional outcomes indirectly by limiting access to information, essential services, and social networks. As societies become increasingly dependent on digital technologies, limited digital literacy may further widen existing inequalities, particularly in geographically constrained settings where access to healthcare and other essential services is increasingly mediated through digital platforms [50, 51]. Evidence from India also indicates low levels of digital engagement among older adults, reflecting persistent structural, educational, and access-related barriers [52]. These findings highlight the need for inclusive digital strategies that consider the needs and capabilities of older adults and ensure that digitalization does not further exclude those who are already socially or geographically disadvantaged.

Implications to reduce perception of disability

One of the main challenges in implementing age-friendly policies is translating them from policy into practice. Although many urban age-friendly policies promise substantial improvements at the conceptual level, evidence from studies conducted in several European countries suggests that these commitments often fail to be realized in practice [53]. Our findings indicate that implementing age-friendly policies in mountainous regions may require additional consideration of geographical, infrastructural, and social barriers that influence mobility, accessibility, and participation among older adults.

Strengthening accessible and reliable transportation systems should be a priority for improving mobility and reducing barriers to essential services. Flexible service models and age-friendly vehicle can be designed along with investment in safe and accessible built environments. Interventions such as non-slip pathways, handrails, graded walkways, and designated shaded rest areas may substantially improve mobility and independence among older adults in mountainous regions.

Addressing social isolation requires coordinated efforts across health and community systems. Community-based initiatives that promote social participation, along with the integration of social support screening within primary healthcare, may help identify and support vulnerable individuals. In parallel, inclusive (culturally as well as linguistically appropriate) digital literacy programs, including age-friendly technologies, particularly for older adults living in remote and difficult-to-reach tribal communities is necessary.

These priorities align with the United Nations Decade of Healthy Ageing (2021–2030) and highlights the importance of addressing environmental and social determinants of functional ability in low and middle-income countries undergoing rapid demographic and societal transitions.

Strengths and limitations

The exploratory sequential mixed-methods design provided a comprehensive and context-specific understanding of environmental barriers by integrating qualitative insights with quantitative analysis. A key strength was the use of themes identified through in-depth interviews to inform the development of measurable variables for the quantitative phase. This approach helped ensure that the variables reflected the lived experiences and local context of older adults, while also improving the interpretation of the quantitative findings. Such integrated approaches are still relatively uncommon in gerontological research, particularly in low and middle-income country settings [54, 55]. The use of the standardized and internationally validated WHODAS 2.0 instrument allows comparison of the findings with research from other settings and strengthens the wider applicability of the results. Including both rural and urban populations also improves the relevance of the findings to older adults living in diverse and mountainous environments.

However, several limitations that needs to considered is the cross-sectional design itself which limits the ability to establish causal relationships between environmental barriers and perceived disability. Although self-reported measures used to assess Environmental barriers and disability capture important aspects of lived experience that may not be reflected in objective assessments, it may be subject to reporting bias. Additionally, the approach by which environmental barriers were operationalized as binary variables informed by qualitative findings, may have reduced the ability to detect variation in the association between environmental barriers and perceived disability. Future studies should consider the use of ordinal or multi-item measures to better capture the spectrum of environmental challenges. Finally, the study was conducted in a single district in the Eastern Himalayan region, which may limit the generalizability of the findings to other settings. However, the findings are likely to be relevant to similar mountainous and resource-constrained contexts.

Conclusion

This study suggests that perceived disability is influenced not only by age and chronic health conditions but also by the social and physical environment in which older adults live. Difficulties related to transportation and pedestrian infrastructure, as well as social isolation, were independently associated with perceived disability, while digital exclusion may also contribute indirectly. These findings support the view that disability develops through the interaction between an individual and their surrounding environment. Therefore, efforts to promote healthy ageing should address environmental and social factors alongside medical care. This is particularly important in mountainous areas, where difficult terrain, limited infrastructure, and transportation challenges can further restrict mobility and participation. Improving transportation, pedestrian infrastructure, and opportunities for social participation may help reduce perceived disability and support greater independence among older adults living in these settings.

Abbreviations

AOR

Adjusted Odds Ration
ICF
International Classification of Functioning
WHO
World Health Organization
DALYs
Disability-adjusted life years
LASI
Longitudinal Ageing Study in India
QOL
Quality of Life
SDG
Sustainable Developmental Goals
ICMR
Indian Council of Medical Research
IADL
Instrumental Activities of Daily Living
WHODAS
World Health Organization Disability Assessment Schedule
VIF
Variance Inflation Factors
CI
Confidence Interval

Declarations

Ethics approval and consent to participate

Ethical approval for this study was obtained from the Institutional Ethics Committee of Sikkim Manipal Institute of Medical Sciences (reference number: SMIMS/IEC/C/2016-007, approval number: IEC/399/16 – 007). Administrative permission was obtained from local authorities prior to data collection. All participants received written information about the study in Nepali language, and for participants who were unable to read, the information sheet was explained verbally by the interviewer. Written informed consent was obtained prior to participation using either a signature or thumbprint, according to participant preference. Participants were assured that their responses would remain confidential, and the participation was voluntary.

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Author Contribution

FBPE conceptualized and designed the study, developed the methodology, conducted interviews and data collection, transcribed and translated the interview transcripts, conducted the qualitative data analysis, and drafted the original manuscript. ADR contributed to methodological refinement, quantitative data analysis, contributed to thematic analysis, interpretation of findings, and detail manuscript preparation. VV and AT contributed to data organization, preparation of tables and figures, reference management and revised the manuscript. NJS supervised the study, contributed to thematic analysis and critically revised the manuscript. All authors reviewed the manuscript and approved the final version.

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Figures

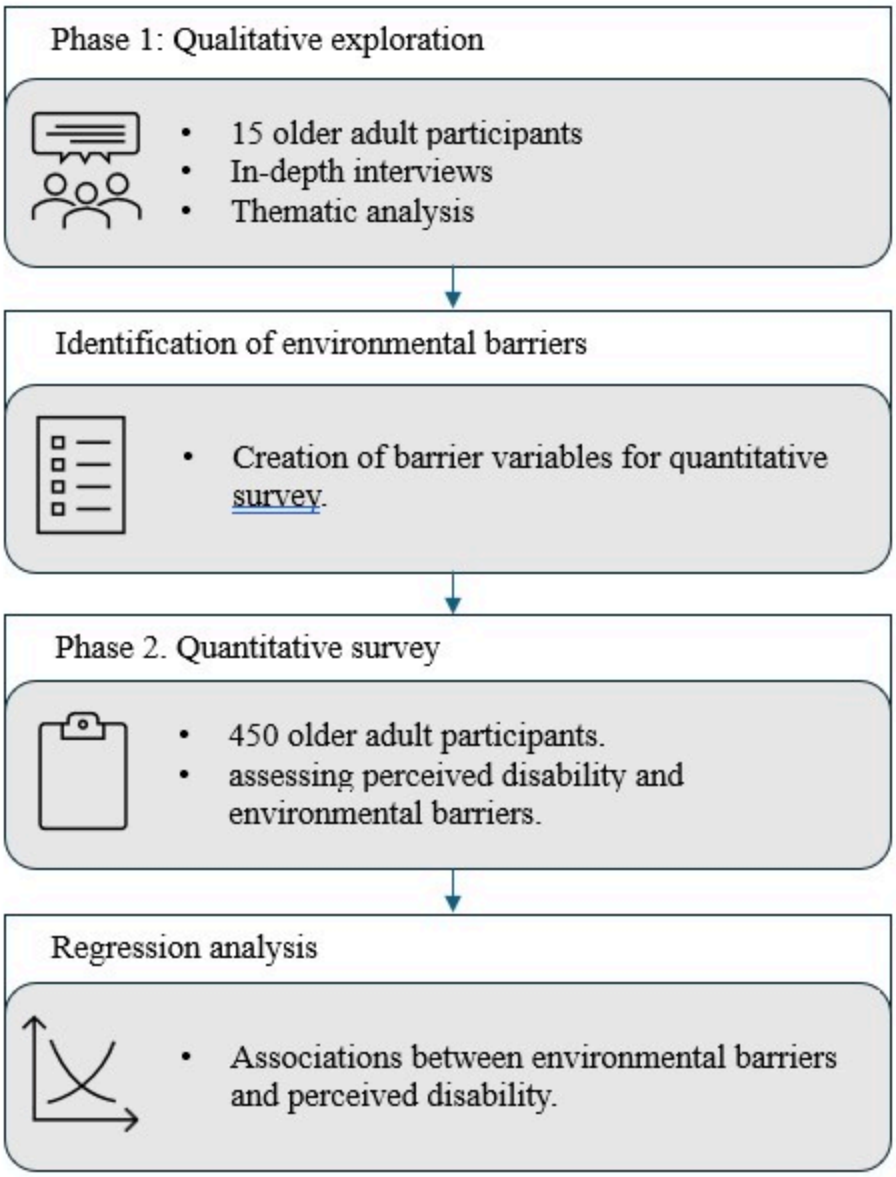


Figure 1

Flowchart illustrating the exploratory sequential mixed-methods design, showing the sequential phases with integration of qualitative findings into quantitative instrument development.

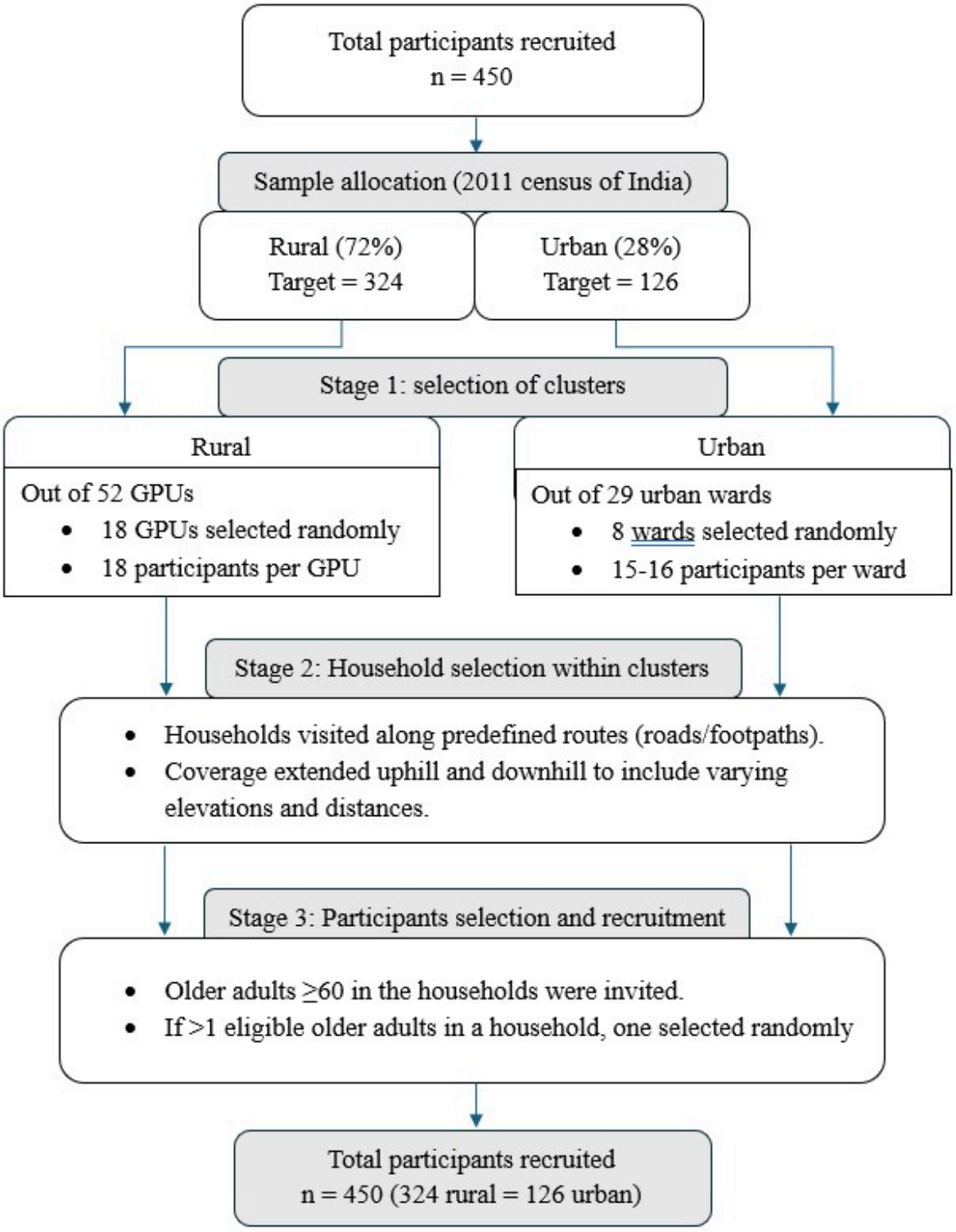


Figure 2

The flow diagram illustrates the multistage sampling process used for participant recruitment in rural and urban areas of East Sikkim.

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- SupplementaryfileS1.docx