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Mapping Rural Mobility in the Global South: Case Studies of Participatory GIS Approach for Assessments of Daily Movement Needs and Practice in Nepal and Kenya

Pablo De Roulet [1,*], Jérôme Chenal [1,2], Jean-Claude Baraka Munyaka [1] and Uttam Pudasaini [3]

[1] EPFL, ENAC, IIE, Urban and Regional Planning Community—CEAT, Bâtiment BP—Station 16, 1015 Lausanne, Switzerland; baraka.munyaka@epfl.ch (J.-C.B.M.)
[2] UM6P Center of Urban Systems (CUS), Ben Guerir 43150, Morocco
[3] Nepal Flying Labs/NAXA, Kathmandu 44616, Nepal
* Correspondence: pablo.deroulet@epfl.ch; Tel.: +41-78-795-76-21

Abstract: This paper investigates rural mobility in the Global South using a participatory GIS approach to address the lack of mobility data that hampers sustainable planning to support rural development and resilience. Limited rural mobility due to poor infrastructure and financial constraints hinders social and economic activities, impeding development. The study aims to explore the socio-economic impacts of limited mobility, identify software needs for data-scarce environments, and map daily mobility patterns. Fieldwork was conducted in Kenya (2022) and Nepal (2023), collecting geographic data related to mobility. The methodology included community engagement and digital mapping using the QField app for precise data collection. The study highlights the use of participatory GIS to fill data gaps, enabling more accurate mobility assessments. Community engagement revealed gender-specific mobility patterns, with women facing particular challenges in daily activities. The study emphasizes the need for adaptable data models to reflect community-specific mobility needs and the integration of qualitative insights to propose effective and sustainable mobility solutions. This research contributes to understanding rural mobility in the Global South and demonstrates the effectiveness of participatory GIS in overcoming data scarcity and enhancing mobility analysis.

Keywords: participatory geographic information system (PGIS); network analysis; rural mobility; Nepal; Kenya; sustainable planning; rural development; resilience; local resources

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1. Introduction

This paper aims to contribute to the understanding of mobility in rural areas of the Global South using a participatory GIS approach. Limited mobility stems from a combination of a poor state of infrastructure with limited private of public solutions for movement in daily life. This limited mobility in turn hinders the ability of individual to conduct their economic and social activities that prevents further social and economic development.

Mobility appears as a key aspect of sustainable rural development in the Global South. This paper aims to support mobility solutions for rural communities through a flexible data-driven participatory approach to planning. This paper extends and earlier research paper on the methodological framework connecting participatory GIS and mobility in Kenya [1]. This paper attempts to open roads of analysis of interpretation on mobility issues in the Global South by addressing the lack of geographic information systems (GIS) data. It will provide examples of GIS analysis as diagnostics of daily mobility challenges, using service area maps and analysis of real-world daily mobility.

The paper highlights three main objectives of this research. The first objective is (1) exploring the social impacts of limited rural mobility, emphasizing the correlation with subsistence agriculture and financial constraints. The second objective is (2) identifying the

software needs for studying rural mobility in a data-scarce environment. And the third objective is (3) the mapping and analysis of the daily mobility patterns of rural dwellers in the Global South.

The linkage between mobility and its impact on socio-economic conditions is complex as the one influences the other [2,3]. This paper proposes a combination of quantitative and qualitative approach to the issue that allows connecting the lived experience of rural dwellers, as told by members of village communities with GIS mobility modeling. Sustainable development must include mobility solutions based on accurate modeling of rural conditions [4]. With scarce baseline data, the PGIS approach proposed in this paper allows for a combined collection of infrastructure data and informations on living conditions and experience.

This participatory method presents an important potential for sustainable planning by accounting for the local knowledge of communities and their feedback over the collection and analysis [5]. This level of control by communities presents an occasion for the construction of planning solutions, as communities themselves are closely involved the the construction of the datasets. This public participation increases the quantity of data in a transparent manner for territorial assessments [6]. Within current progresses and impacts of sustainable mobility infrastructure solutions, a major current challenge of mobility development programmes is the adequate accounting of user needs [7]. This challenge itself is exacerbated with the digital divide and pleads for inclusive decision-making for resilient food systems [8].

This research was conducted over two months in different regions of the Global South: Kenya in 2022 and Nepal in 2023. The fieldwork involved extensive geographic data collection related to mobility, including roads, pathways, and origin-destination points for rural communities. This paper outlines the methodology used and demonstrates how iterative improvements refined the process, allowing adaptation to the distinct rural contexts in terms of spatial connectedness and socio-economic development.

2. Research Objectives

This study develops three primary objectives. First, it explores the socio-economic impacts of limited mobility on rural communities in the Global South, where subsistence agriculture and financial constraints hinder access to education, markets, and autonomous movement. Second, the study seeks to overcome data scarcity in rural contexts by utilizing Participatory GIS (PGIS) and Volunteered Geographic Information (VGI) to fill data gaps and enable comprehensive GIS analysis. Existing data from projects like OpenStreetMap, although limited, provide a foundation for further data collection using GIS tools. Third, the research focuses on mapping daily mobility patterns through digital community mapping experiments

2.1. Addressing Socio-Economic Impacts of Lack of Mobility

Subsistence agriculture, on which most farmers and food systems in the Global South depend are typically correlated with dispersed habitat and low access to mobility. The limited access to mobility solutions in rural South primarily stems from financial limitations of rural dwellers, most of them being engaged in small family farming activities generating limited revenues. As a result of this limitations in mobility, many dwellers lack access to education, markets and a level of autonomy of movement.

Rural mobility is influenced by levels of connectedness and infrastructure as well as personal income, which multiplies the possible solutions in daily mobility [9].

The planning of mobility solutions, be they private or public-led, are themselves largely constrained by lack of baseline data on rural mobility. Data on important points of destinations, such as major public or private services, are often missing. In this regard, the use of participatory GIS or Volunteered Geographic Information (VGI) solutions can constitute a relatively cheap and actionable solution to fill the data gaps needed as assessment of mobility patterns and needs in specific areas.

2.2. Overcoming Data-Scarcity in Rural Context

A lack of data in the Global South limits the possibility of conducting GIS analysis based on social and economic patterns without extensive data collection. This is especially the case when studying rural mobility, where basic geographic information is missing to conduct GIS analysis at the correct scale. The most common mode of transport of rural dwellers is walking. They use shortcuts and paths that are rarely included in transportation surveys.

The development of crowd mapping, and the OpenStreetMap (OSM) project in particular, allows for a certain level of data analysis. In the context of the Global South, this is, however, generally limited as only main roads and urban areas are extensively mapped [10,11]. Although incomplete, the OSM data layers provide a basis for the data collection of basic infrastructure that can be completed using GIS data collection tools.

2.3. Daily Mobility Mapping

Participatory mapping regarding mobility is a relatively new field and often relies on paper maps for single projects. The use of paper maps poses a significant limitation for further analysis, as it restricts the ability to perform GIS analysis, and transferring paper map information into GIS is extremely time consuming [12]. When discussing with communities, the use of paper maps constitutes an efficient medium to explore the many aspects of their lives and surroundings. It is, however, complex to transcribe back this knowledge to a geographic information system (GIS) and pleads for a direct digital data collection.

This article will present two separate experiments in digital community mapping conducted in the region of Kakamega, Kenya, and in the Birendranagar Municipality, Nepal. The results from the data collection will illustrate possible results of mobility data collection exercise and further analysis.

These two exercises took place over the course of several months and in conjunction with the development of methodological tools, as well as with the incremental implementation of an online software developed on purpose to allow enumerators and community participants to visualise data and produce maps (https://usafiri.io/, accessed on 27 October 2024).

The GIS data themselves were collected using the QField app (Android OS), following a review of existing data collection tools. The app was selected for its capacity to cover the essential needs of the data collection exercise. QField is an extension of open-source mapping software QGIS (Version 3.10 and newer) that allows geographic data collection in the field using mobile phones or tablets (https://qfield.org/, accessed on 27 October 2024). The criteria for the selection of the app included the capacity of (1) using aerial imagery as basemap, (2) collecting line segments as well as points, and (3) the possibility to use snapping—allowing points and lines to be connected to other features for later network analysis.

3. Materials and Methods

With great variations depending on the goals and origin of the community mapping, Participatory GIS (PGIS) can mean different things depending on the context. In some cases, the purpose is to contest state narratives, such as in the case of the mapping of indigenous lands [13,14]. It can also take a role of replacing the state, as is the case of mapping informal areas [15,16]. Typically, participatory mapping may combine these two aspects. With the development of the OSM platform, community GIS is becoming generalised and more widely used by a multiplicity of development actors. This includes HOTOSM, the humanitarian tasking system to support emergency mapping as well as multiple projects from the World Bank, and a particular emphasis is placed on hazard mapping, which is now widely used both in paper maps to sensitize communities as well as in digital mapping [17].

In this exercise of participatory mapping, enumerators with basic knowledge of GIS are working in pairs, with representatives of the local population for data collection. Participants are selected by local representatives ("village chief" in Kenya and "ward representative" in Nepal). Sampling for community mapping follows a practical and territorial logic and trust with local stakeholders rather than statistical representativity [5,18]. The main criteria for the selection of participants are a gender balance and good knowledge

of their village and its surroundings. This selection method is replicable in other areas, provided there is good contact with local communities and representatives. Ten members of the community participated in Kenya, and sixteen in Nepal.

The method used for this research can be located between the traditions of Participatory GIS (PGIS) and Voluntary GIS (VGI), combining the community mobilisation dynamics of the former and the predefined approaches more linked to the former [19,20]. The research objectives have been predefined from the outset as focused on mobility. This choice places some constraints on the type of data that are used and processed in the analysis as elements of mobility mapping. In particular, it requires the use or creation of a road network and sets of points defined as origins and destinations in the daily mobility of communities.

The road network offers limited flexibility for defining it in collaboration with community members. Mobility research in any context depends on existing datasets and established standards to map mobility networks. The amount and quality of data necessary for network analysis require the use and updating of pre-existing datasets, often provided by large institutions or crowdmapping initiatives. To simplify the process, the decision was made to adopt the classification system used in Kenya and Nepal's OpenStreetMap standards, which distinguishes between different types of network segments, such as paths, roads, and whether they are asphalted or not.

In contrast, defining origins and destinations (O-D) allows for more dialogue and community input. While the concept of O-D as a basis for transport analysis remains unchanged, the identification of points of interest important to the community is open for discussion and is integrated as much as possible, while balancing these definitions with existing standards, whether from OpenStreetMap (OSM) or local official data sources.

QField was opted as the most adequate tool to collect mobility data in this context. QField is integrated with the QGIS open-source software (Version 3.10 and newer). Its integration with QGIS allows to perform all the main data collection process needed to collect accurate and precise geometries, including snapping, and the use of offline basemap imagery. The main limitation of this tool is that it is more complex to use than other data collection options, such as KoBo or ODK. The setup of data collection templates in particular requires a good understanding of GIS concepts and the QGIS software. The function of snapping was also used to connect the points categories of mobility barriers and street profiles to roads to ensure that any identified obstacle would be correctly associated to a given road segment.

The data collection tool QField was selected for this exercise for its ability among open-source GIS to integrate certain specific GIS capabilities, in particular the function of snapping, which is essential to digitize a road network. The ability to include a basemap in the project is also essential in allowing the enumerators to point exactly at the locations of the different routes and points of interest (Figure 1).

The use of QField also allows the reference of the basemap to be used in a variety of purpose, including navigate, ensure no overlap with other enumerators, and locate points of interest directly over a building, a stream, or a well.

The broad categories of geographic features needed for mobility analysis include the transportation network, potential origins and destinations, as well as barriers that can hinder movement (Table 1).

Table 1. Data layer contents and data types.

Category	Data Layer	Data Type
Transportation Network	Road Network	Line data
Mobility Barriers	Infrastructure Barriers	Point data
	Road incidents	Point data
	Crime or Wrongdoing	Point data
Points of Interest/Amenities	Markets, Shops, Banks, Money Transfers Water Points, Religious sites, Industry	Point data
Health	Pharmacy, Clinic, Health Posts, Hospitals	Point data
Education	Kindergarten, Primary School, University, Training Centre	Point data
Government	Local, State, District, Country, other Government offices	Point data

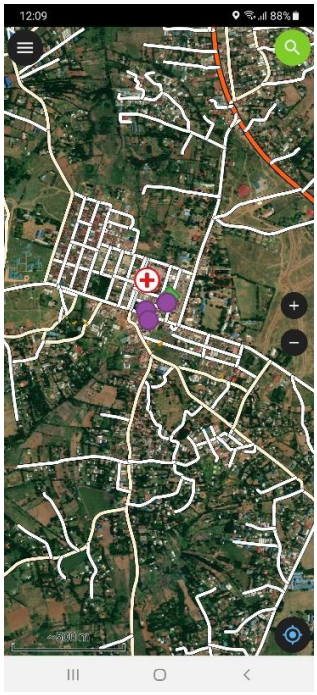

Figure 1. QField Screen capture. A health facility is identified and inserted in data collection in Mumias East, Kenya, using QField and Bing basemap imagery. Symbols in this example include a medical facility, and official buildings.

The data collection exercise also included the functionality of tracking. The collected line geometries reflect broadly the path used by the enumerators during transect walks. Street profiles were collected, although not used, in the final mapping product. Pictures taken by enumerators at regular intervals in their transect along different types of roads allow for a comparison between the aerial view and the road seen from the ground (Figure 2). This collection of street profiles allowed for the identification of numerous paths located in dense vegetation to later digitize a more complete mobility network.



Figure 2. A street picture next to its aerial imagery (~1 m resolution) facilitates the identification of paths where they are not directly visible from aerial imagery. The yellow point on the aerial imagery above shows the location where the picture below was taken.

4. Results

4.1. Socio-Economic Impacts (Objective 1)

Limited mobility solutions for the rural population of the global south impacts on socio-economic conditions at collective and individual levels. The exisiting scientific literature on the subject highlights a number of consequences of lack of mobility at multiple levels. At an immediate level, access to basic services, such as healthcare and education, is limited and made difficult for many rural residents [21]. This aspect was discussed during the Focus Group Discussion (FGD) conducted on the field and highlighted how women are particularly affected by these aspects as they are generally in charge of health and bringing children to schools, as was consistently described in both Kenya and Nepal.

Limited mobility also produces broader constraints on socio-economic activities for rural population. Among other aspects, access to markets are limited by the distances needed to cover to sell agriculture products [22,23]. Focus groups in Kenya highlighted, for instance, that the selling of milk in East Mumias, Kakamega, was exclusively done in the village selling the milk walking along the way until all was sold. In this regard, the mobility of subsistence agriculture presents a specific set of spatial relationships where short distance activities are adapted to the options of movements of residents.

Even when access to a motorcycle allows faster travel, the road conditions are identified as a major obstacle. For instance, a non-exhaustive collection of locations of different types of mobility barrier in East Mumias highlighted 119 seasonal and permanent mobility barriers spread across the area that included damaged infrastructure, open sewage, water logging, and unmaintained paving (Table 2).

Table 2. Permanent and seasonal mobility obstacles in East Mumias.

Obstacle Type	Seasonal	Permanent	Grand Total
Damaged infrastructure	23	33	56
Unmaintained paving	3	1	4
Waterlogged area	52	7	59
Grand Total	78	41	119

The qualitative information collected from participants during focus groups illustrated the difficulties of farmers to access markets due to a number of obstacle of different categories. A distance of several kilometers mostly on foot limits the possibility of carrying weight to sell products, as illustrated in the activities listed in Table 3, presented below. Occasionally varying mobility modes, such as the use of motorcycles, bicycle, or public transport can help with walking longer distances, but these are limited by road conditions. Overall, the limitations of mobility hinders the possibility of accessing further-away markets, and consequently the possibility of income from agriculture.

Walking and short-range mobility largely shapes the geography of subsistence agriculture in the Global South. These interlinked modes of subsistence and mobility structure the living spaces of residents in multiple ways. Limited by short accessible distances, local farmers rely on an economy of agriculture that mostly sells and consumes in close surroundings, most often in the village itself. Although differences in levels of reliance on motorized transport modify the opportunities to rural residents and the organisation of livelihoods and family economies, the observation from Birendranagar and Kakamega illustrates that the walking mode still overwhelmingly dominates modal journeys, as in most of the Global South [24–26].

Table 3. Women of the community present their main activities, their estimates of distances and time spent walking, and other means of transport.

Activities	Distance from/to Home (at Home, 100 m, 1 km, 5 km)	Frequency (Daily, Weekly, Irregular, Several Times a Day)	Transport Mode (Foot, Bicycle, Public Transport)	Obstacles on the Way (Infrastructure, Disturbances)	Approximate Time Spent on Travel for This Activity
Domestic activities	At/near home				
Farming activities	At/near home				
Bringing/collecting children to/from school	3 km	every week day	walking, bicycles (few), boda (motorbike) boda (motorbike) (few)school bus for private schools (negligeable)	road condition, people disturbance, flooded rivers (rain season)	From 5.45 am to 6.30 am (45 min)
Fetching firewood	2–3 km in rural paths and forest areas	twice a week	walkingsometimes husband carries on bicycle	road condition, people disturbance, flooded rivers (rain season) snakes/wild attacksharassment and risk of rape	From 7 am to 12 am (distance walking and fetching)
Selling milk	400 m, 1 km	daily	walking, boda (motorbike) cancels profit. Selling while walking	road condition, people disturbance, flooded rivers (rain season)	20–30 min
Church	100 m–2 km (long range exceptions)	weekly	walking, bicycle, boda (motorbike), vehicles	road condition, people disturbance, flooded rivers (rain season)	20–30 min
Office work	Most stay at workplace. 5 maj–30 km for those who have houses and commute	every week day	boda (motorbike), matatu (minibus)	price, road conditions, police	15 min
Social meetings	vicinity	multiple each day	walking	road condition, people disturbance, flooded rivers (rain season)	20–30 min
Political rallies	up to 8 km	political season. Couple times	walking, bicycle, boda (motorbike), vehicles	road condition, people disturbance, flooded rivers (rain season)	long walk
Bringing children to health centre	1–5 km	occasionally	boda (motorbike)	road condition, people disturbance, flooded rivers (rain season)	long walk
Going to the market	vicinity/main market on Saturdays 5 km	multiple times in the week	walking, bicycle, boda (motorbike), vehicles	road condition, people disturbance, flooded rivers (rain season)	short or long walks depending if local or main market

4.2. Data-Scarcity in a Rural Context (Objective 2)

Despite the presence of a few collective and individual mobility solutions in the Global South, like motorcycles and bicycles, daily mobility is generally conducted by foot. This research allowed the collection of networks of paths and a realistic GIS mobility analysis of rural mobility with a finer granularity of data than existing official or private routing data providers, such as ESRI's ArcGIS Online Network Analysis Services, or the OSM current state of the map.

At the time of this study, ESRI's existing mobility network, provided as a network service, is broadly similar to the existing OSM data. The data scarcity of the existing GIS rural data is best illustrated in comparison to the additions made by the research team, whose methodology will be explained below. A comparative observation of what areas can be reached using ESRI ArcGIS Pro services and with the mobility network data that were collected by the research team can be observed in Figure 3. The Service Area comparison illustrates the areas covered at certain network distances of facilities (in this case schools). Conducted on two maps with lower and higher network density, the comparison illustrates how the non-inclusion of paths presents many uncovered areas because they are located at certain distances from main roads. Rural mobility is, however, mainly pedestrian, and a realistic picture of local mobility must reflect the uses of rural paths and shortcuts.

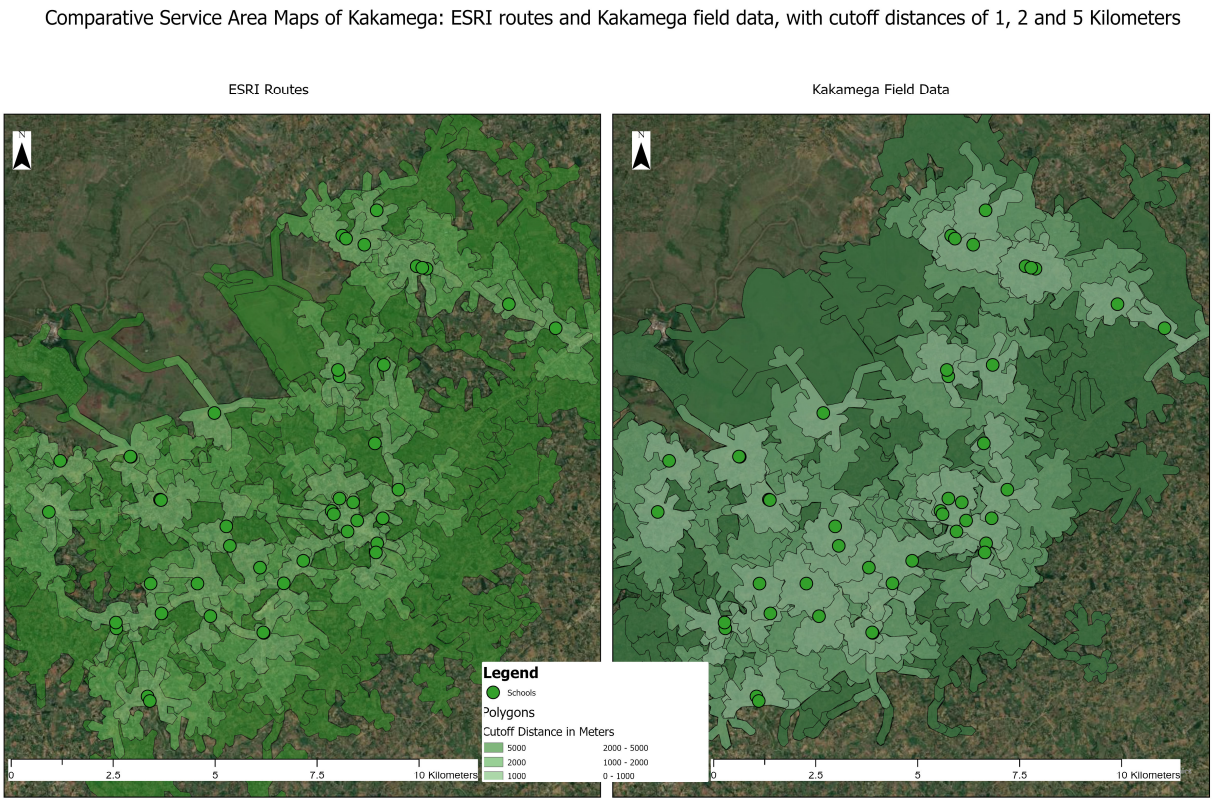

Figure 3. Comparison of ESRI routing services and field data to study rural mobility.

The data collection process led to the inclusion of numerous roads and points of interest, either based on existing OSM mappings or specific to the community. Streets, roads, and paths represented the largest portion of mapped items. Before the visit to Kakamega, the existing OSM database primarily featured main roads and junctions, lacking coverage of the rural roads and small paths used daily by the community. In Kakamega, for instance, the number of roads mapped significantly increased the total in the Mumias East region. As the focus of data collection shifted toward the daily activities of rural residents, the number of mapped segments grew while their lengths shortened, reflecting a more localized, pedestrian-oriented network.

Including walking as a mode of transport in rural mobility analysis necessitates the creation of thousands of line segments representing roads and paths, covering areas of interest spanning approximately ten by five kilometers, as was the case in Kakamega and Birendranagar. The collection of these data allows for the calculation of daily mobility mapping based on a dense network of paths. Figure 4 below illustrates the number of new segments created in the map of Kakamega. The number of new segments in the new GIS data represents over 300 km, which is roughly equivalent to the pre-existing data retrieved from OSM data. It is notable that the number of new segments is three times higher than the original 2528 in OSM. In turn, the average length of OSM segments is much larger at an average of 126 m, and the new segments at an average of 41 m. This reflects how the crowdmapping of OSM focussed on the main roads, while the new data collection focussed on collecting a dense net of data within a small territory.

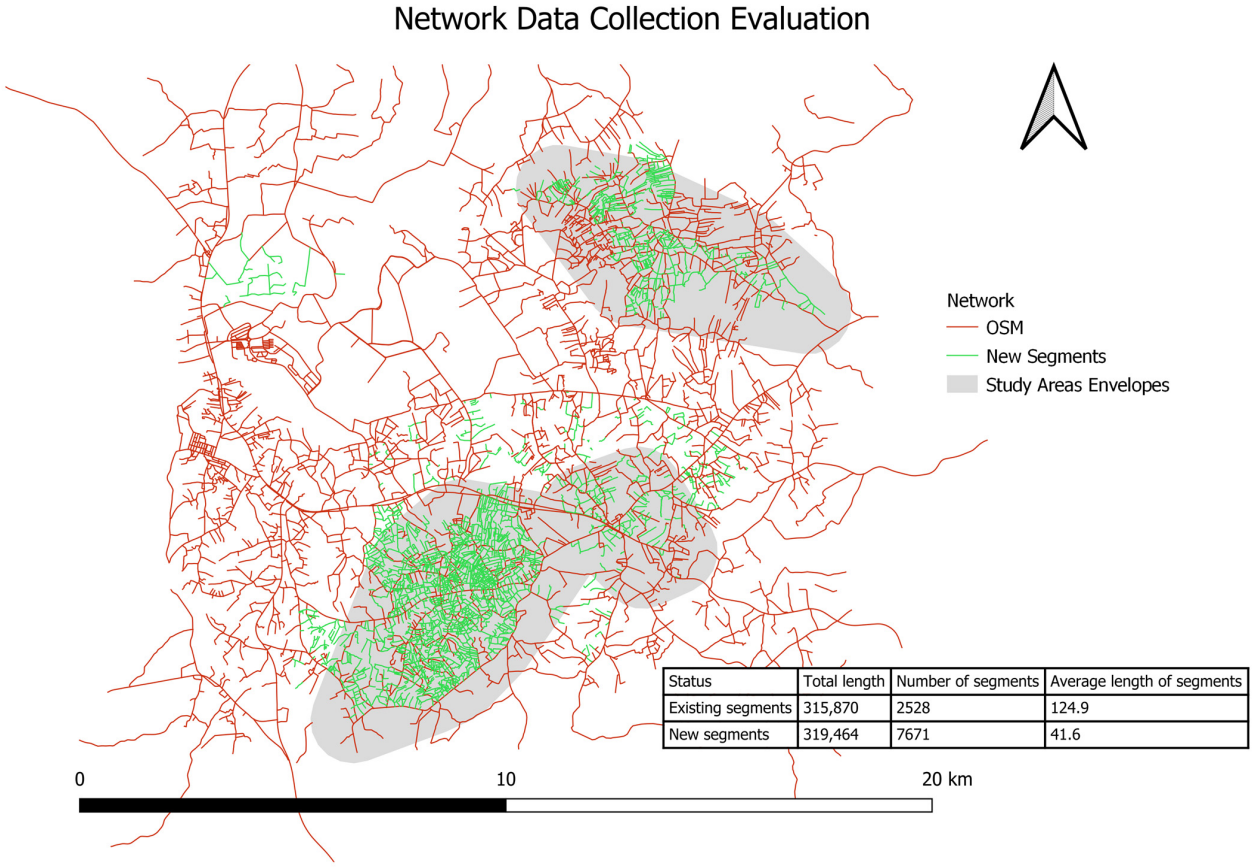

Figure 4. Road segments collected in Mumias East over the existing map of the area.

4.3. Daily Mobility Mapping (Objective 3)

Combining community engagement and GIS, the research allows a close integration of rural dwellers' description of their daily life before its mapping.

1. Identify rural hubs and points of interest

Community-relevant data are collected in dialogue with the local community. This requires the facilitators to be ready to adapt their data models to community specificities and maintain structured data collection models. The readiness to adapt and include new items in the data models is needed to follow community activities and mobility needs. It is, however, necessary to maintain a sound structure in the data model and avoid multiplying the numbers of data layers for each new item.

This structure requires the facilitators to prepare broad categories of geographic and material features, such as water or economic resources. These broad categories must be adapted to include categorical descriptions.

The inclusion of new items and dataset can be done most conveniently by projecting a table of the locations the community indicates are central to their daily life and mobility. The inclusion of some activities might prove difficult to collect. This is the case for mobile activities in particular. Some farmers, for example, indicated that they sell milk in the villages walking to multiple locations in their daily routine. Although it is possible to map such movements, their mapping was deemed too complex to include in the collection exercises, and the research team preferred limiting the mapping to fixed objects.

Members of the communities of Lusheya and Khaunga were gathered to discuss their daily movements in and around their houses and communities. Participants were divided into two groups by gender, following the gendered division of daily tasks and place in the rural economy. In this exercise, community members are invited to list their activities in a typical 24-h timeline and highlight their activities. Most community members are farmers, although a small number of clerical employees also included their daily activities.

Most activities and related mobility needs are common to men and women, although some key housework mobility tasks are specifically attributed to women. This is the case in particular with collecting water—in the absence of running water in the households—and firewood. The latter activity was identified with specific risks of harassment.

The activities were listed in a table to identify the main destinations of community members during their daily activities. In the absence of access to means of transport other than walking, most activities happen within a limited distance to the households. The following table shows the main activities described by community members and their approximate associated distances and frequencies.

Community members also identified the different modes of transport used for the different activities. In most cases, travel was made by foot, although for less frequent and more distant activities. In both Kenya and Nepal, motorcycle taxis ("boda-bodas") or public minibuses ("matatus") may be used to access a central place, such as a health centre, a political rally, or a government office.

Men and women from the community presented their estimated distances and travel times for their daily activities. Table 3 below shows how women described their movements and frequencies, and these were discussed on a large screen to present broad estimates of movements. Women's mobility differs depending on their work and status, but encompasses house work and the care of children on top of their professions. The period when the study was conducted, shortly before the 2022 presidential elections in Kenya, was also reflected in most participants describing participation to political rallies.

Once the main categories of destinations were identified, community members were invited to highlight the frequency with which they went to said places. The list of destinations served as the basis to collect the data during the mapping exercise. As such, the categories of items were integrated as layers into a QField questionnaire that enumerators would use during walks with community members.

A similar exercise was conducted with community members of Birendranagar. Modifications in setting the exercise and systematization of information collection allowed precise technical elements to be collected, as well as for a more holistic approach to data collection and mobility to be included. As research on mobility limitation, the exercise tends to forget the positive elements that may emanate from issues in transport.

Research participants were thus asked to express if they also envisioned positive aspects in the situation of the village. As a result, from the answers of participants, a number of elements came up that bring an understanding of positive aspects of current mobility practices. Participants identified important bonds of solidarity between villagers. One important aspect of the solidarity mentioned is that owners of two-wheeled vehicles are often keen to give a lift to other villagers, and make themselves available easily in case of emergencies.

The slower pace of movements seems to support stronger social bonds. Long walks to bring children to schools, for example, constitute an important means of connecting between villagers, where women in particular discuss their affairs. Villagers also mentioned in a broader sense that their relative isolation brings other positive outcomes. This included,

in particular, what they considered the consumption of healthier organic food mostly produced in the village itself. Although not directly collectable information, the perception of villagers of their mobility issues also bringing positive outcomes is important in the sense that the mobility assessment and proposed solutions will take into account these aspects and propose solutions that maintain these positive aspects as much as possible. The use of this information at that stage does not imply the collection of specific features, rather it implies that the conclusion of any quantitative study would have to take into account the proposal of solutions that maintain the positive aspects of the current state of rural mobility. This inclusion of qualitative remarks in the methodological framework is a necessity to provide sound results to the study. This inclusion of qualitative and quantitative approaches follows the tradition of mixed methods central to understanding rural mobility in the global south [27].

The exercise also included the systematic collection of travel time to and from places to various facilities.

2. The size of the study area depends on the required data density for the mobility mapping

One key aspect of this process is the definition of the boundary of the study area. The size of the area of interest influences how data can be collected and what will constitute a complete dataset. To calibrate the expected data/information density to the size of the area of study, the data collection must be prepared accordingly. A small area demands great precision in both geometric and tabular data (quantitative and qualitative). A larger area requires the simplification of features and a preselection of the main categories of geographic features (e.g., collecting information relating to health centres, but not informal shops).

The size of the area of interest influences the means needed to complete the data collection. In a small area, all data collection can be done on foot, while if focusing on a larger area, it might be necessary to accommodate the data collection with faster means of transport (e.g., bicycles or motorcycles). Although participants indicated some irregular travel to further distances, the mainstay of their movements was located within a 5-to-10-km radius in both Nepal and Kenya (Table 4).

Table 4. Summary of community participants, commuting needs, and estimated distances.

Small Area/Walking Distance (5 km Radius)	Medium Area (10/25 km Radius)	Wider Area (25/50 km Radius)
Day-to-day activities	Regular displacements	Access to central and specialized facilities
School, work, market	Religious service, health care	Specialized healthcare, renewal of official documents

3. Intermediary results: paper maps and transects

In the absence of the precise mapping of rural areas, community members are invited to describe the main landmarks of their community with the help of data enumerators. The mapping exercise of the area using paper serves as the basis to identify the main landmarks, such as government offices—most often location chief offices, health centres, schools, and rivers and streams. This paper map was not drawn to scale but allowed the relation of central features in relation to others to be identified.

The surveys start in a central place, at the chief's or assistant chief's office of the surveyed locations. Community members and enumerators are accompanied by a village elder, a community member chosen within the villages. As no current mapping of the villages is accessible (or apparently even exists), village elders were key not only to guiding enumerators to key points of interest, but also to set the limits to other villages, so enumerators would not overlap with the collection of others.

Walks in the villages lasted generally from around 5 h, and enumerators were guided to visit schools, religious sites (in Kenya these are mainly Churches of various observances),

health centers, and shops, but also water access points and mills where farmers grind their maize to later consume or sell ugali, a common staple food in Kenya and the region.

Enumerators also conducted an important exercise of identifying the aspects of many types of rural roads and paths with geolocalised profile pictures, which allowed the road aspect to be compared from the ground through the high-resolution imagery base map used on the QField collection tool. This aspect of the data collection was especially important in the context of rural Kakamega, where the tree cover is dense and often hides parts of roads and paths, which limits the extent and possibility of remote mapping.

The practice of transect is an essential element of this participatory approach. It is essential to collect complete information on the locations as the pace of travel allows the inclusion of a variety of places that reflect village life, such as formal and informal shops, wells, and small local industry. It is also essential to reflect the pace of movements of village dwellers and their relation to their territory [28,29]. Transports entail a bodily relation to the territory marked by the means of transport used in mobility, where the effort made to move, the pace, and the possibility or not of discussing with neighbours along the way all entail a particular lived sensation. The corollary to this aspect of mobility is that it is essential for researchers and enumerators to travel across the territories with similar means of transport to those of the local dwellers.

4.4. Measuring Access to Amenities with Collected Data

The data collection allowed the mapping of access to amenities from the different points of the wards/locations. Using diverse sources, the service areas allow all areas within a certain distance of a specific amenity to be located. The example of primary schools illustrates all buildings at every 500-m interval distance and illustrates that a large number of children need to do significant daily walks to access education (Figure 5). Note that here buildings do not equate with population, as many Microsoft buildings included are agricultural facilities. It serves, however, as a proxy to illustrate that the proportion of children needing to do long walks to school is significant.

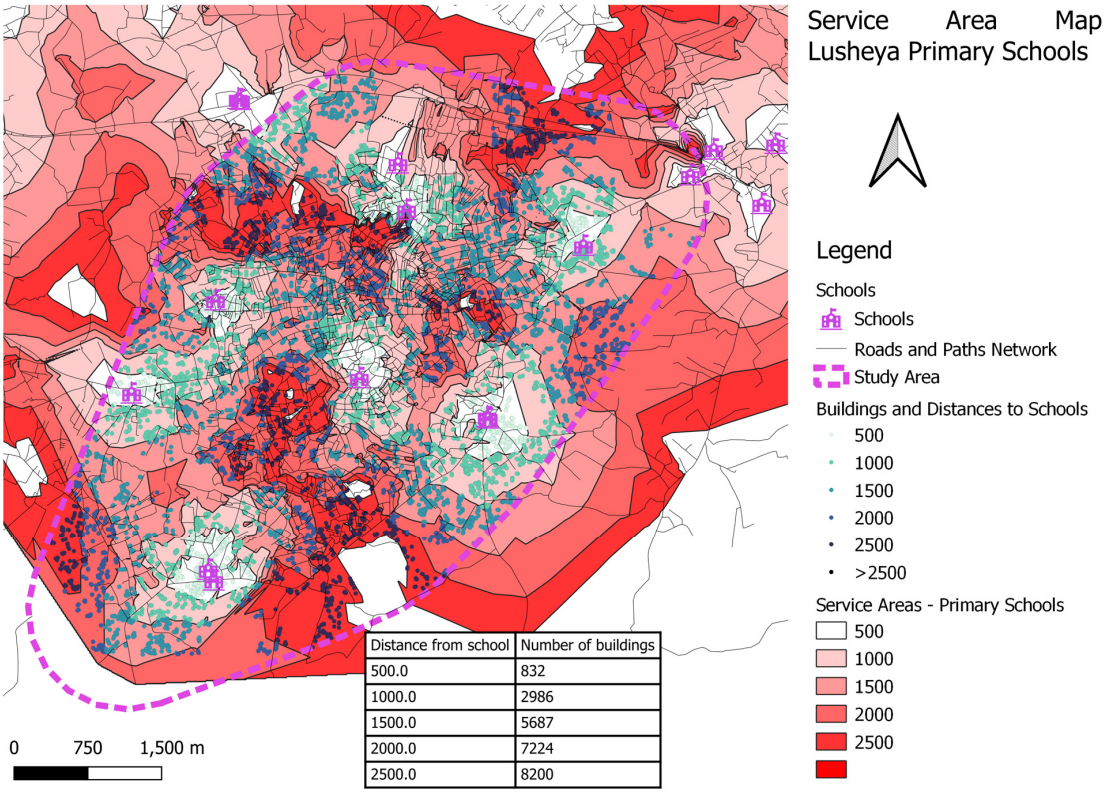

Figure 5. Service area map of Lusheya.

A similar exercise conducted in the Birendranagar rural ward 13 illustrates a similar problem. The lower populations and building density still illustrate the need for significant numbers of children in the area to walk (Figure 6).

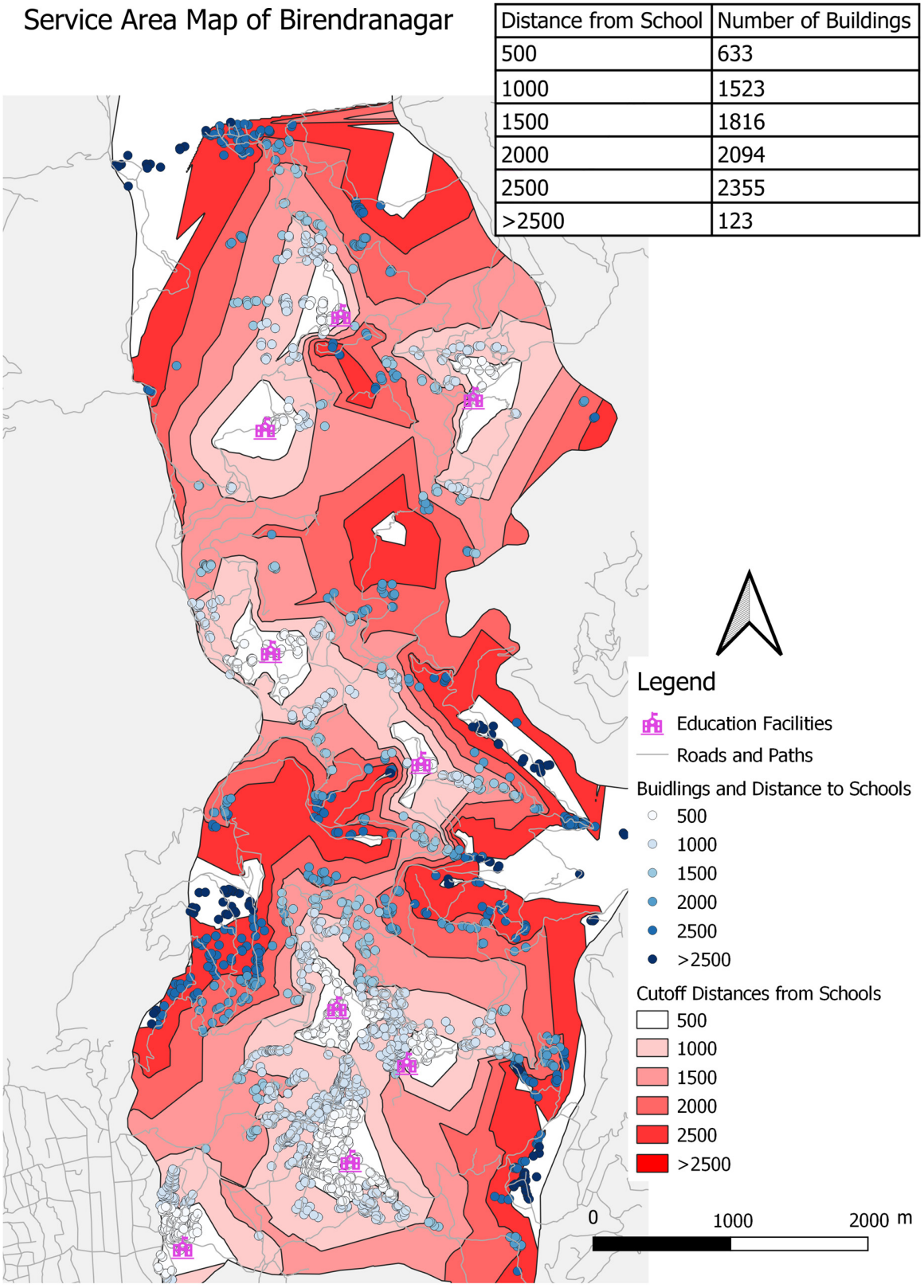

Figure 6. Birendranagar ward 13 service area.

Different types of destination are linked to diverse needs. Access to water requires the proximity of water collection points in a closer vicinity as carrying water and the frequency of the need in a household is high, with several voyages each day, as is the case well beyond Kenya [30]. The collection exercise allowed 182 water points to be collected during the exercise. A map of the water points in relation to dwellings illustrates how most dwellings are located in close vicinity to collective water points (Figure 7).

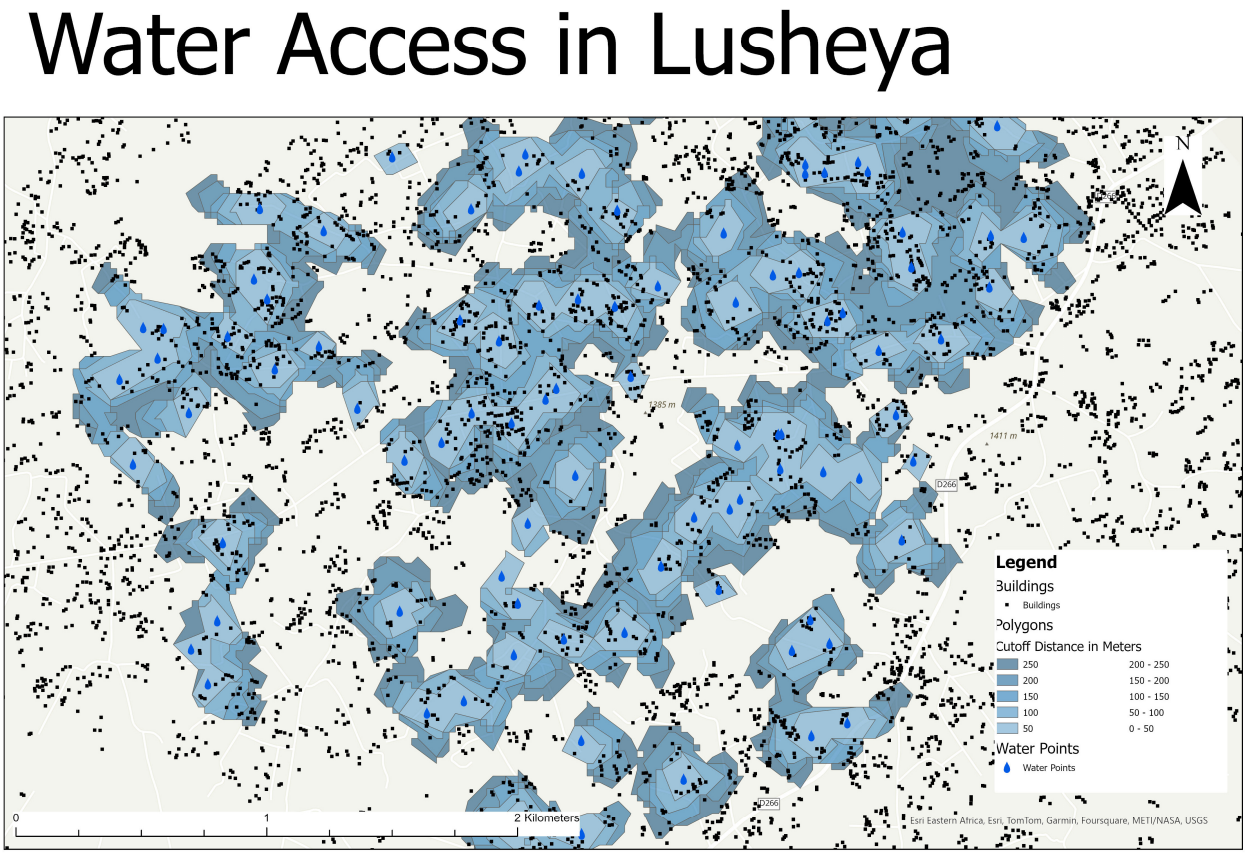

Figure 7. Lusheya water access service area map.

The density of points located outside a 500 m service area from any community well illustrates, however, the large number of dwellers that need to travel more than 500 m (there and back) to access water in all seasons. As community members explained, individual water points present in most houses do not give access to water all year round, when the dry season does not allow individual access. This results in a number of travelers carrying water, which constitutes an important outlay of time and effort, mostly undertaken by women for basic living needs.

4.5. Validation of the Data with Communities

4.5.1. Data Validation by Making Maps

This research project is closely linked to the development of a GIS platform application that includes the creation of maps by enumerators and community members together. This approach of data validation stems from the tradition of F-VGI, or Facilitated VGI, where participants are provided with a simplified access to GIS software and data to provide geographic information [31,32].

This approach, as conducted in Birendranagar, Nepal, allows the participant to access their data in a common exercise and produce maps from the data inputs. This closer look at the data results in maps of sufficient quality with the use of symbology discussed in common with the community members.

Maps produced by community members belong to a GIS-amateur genre (Figures 8 and 9). With a simple and easy-to-use tool developed during the course of the project, the online mapping tool Usafiri (https://usafiri.io/), community members were invited to build themselves the maps with the support of the research team. This method had the compared advantage with the paper map exercise to allow community members to directly verify and correct the data that were corrected in the previous weeks.

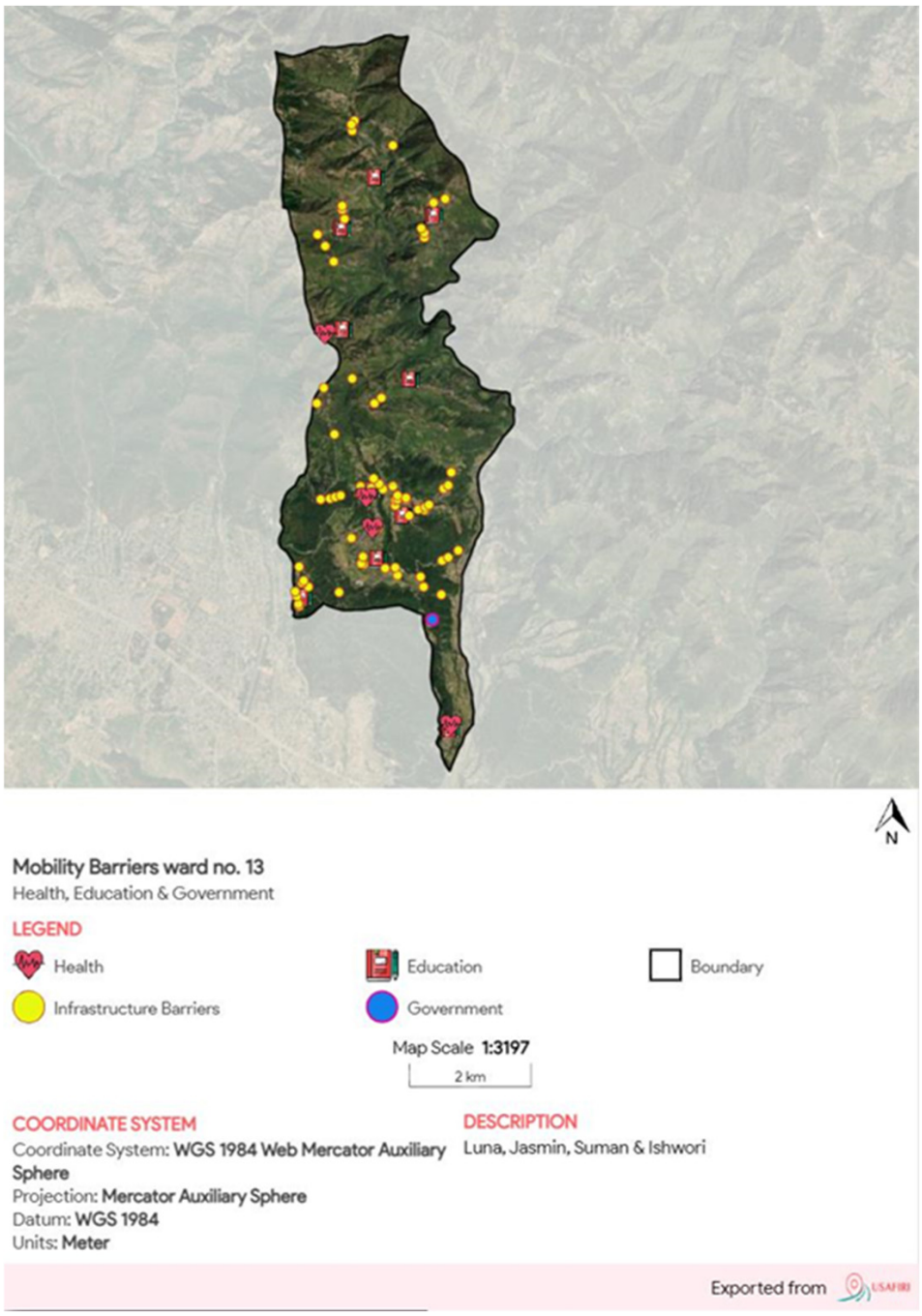

Figure 8. Community map highlighting mobility barriers.

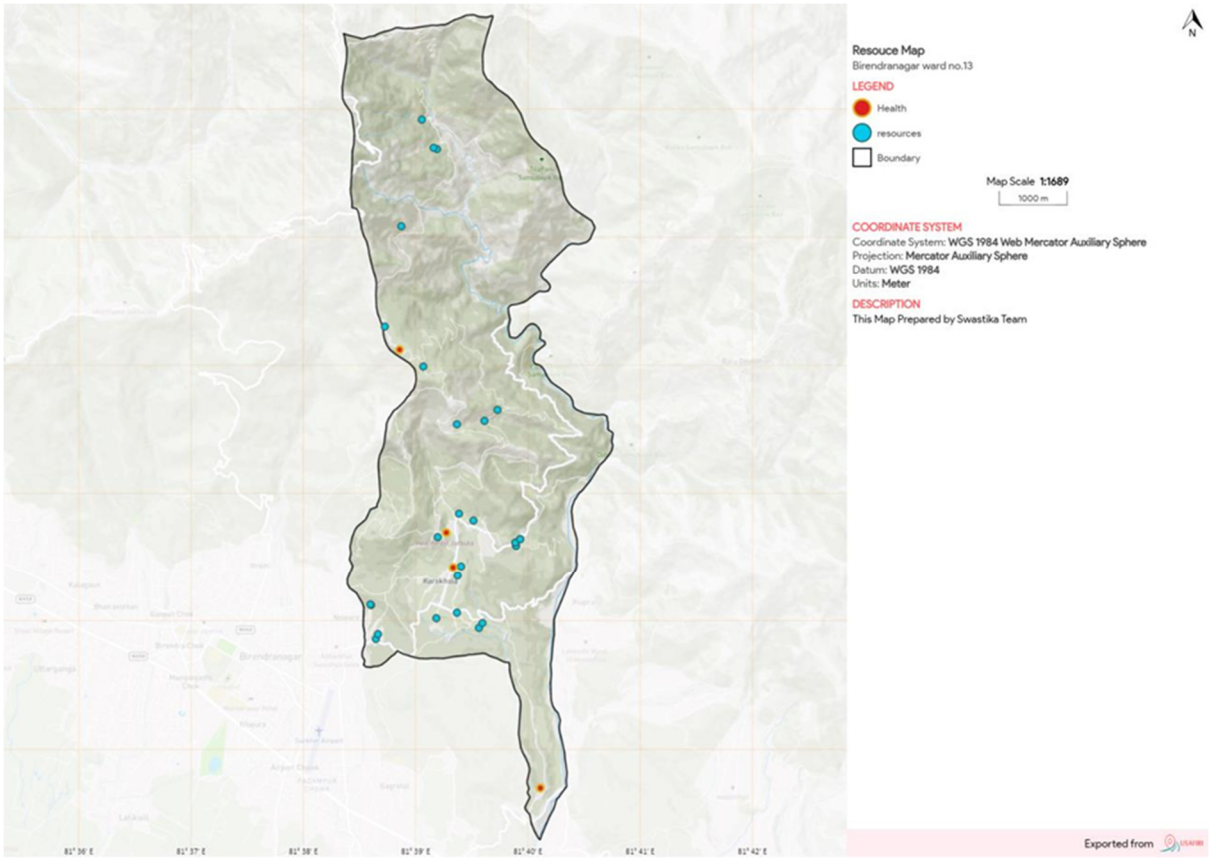

Figure 9. Community map focused on social infrastructure.

A projection of the maps in a public hall that included the community participants and the elected official of the wards and municipality allowed the collected data to be discussed while directly correcting the data.

4.5.2. Dynamic GIS Software Combines with Paper Maps

The nature of the data collection tool used for the exercise allowed the continuous control of the technical quality of the data. As QField permitted the visualisation of the collected data on the device, and later when co-ordinated it allowed several checks of on the computer, the tool itself allowed an important assurance that no collected point or line would be misplaced. The most important quality check of this exercise is not, however, related to the control of point and line position, but to ensure that the main elements defined at the beginning of the collect would correspond to community knowledge.

A form of quality control was continuous, as community members and enumerators constantly exchanged views, and community members were shown the data on the device and actively commented on the situation and positions of elements. The validation, however, needed a specific session where the community members had access both to a wide overview of the areas and sight of all the details on the map. To allow such an exercise to take place, the research team designed and printed two large paper maps in A0 format, representing both the Lusheya and Khauga areas.

The validation session consisted of two main parts. A first session aimed at collecting the impressions of the participants on the overall exercise and whether they considered the focus of the research to correspond to their mobility priorities and issues. A second part focused on the detail of the maps by hearing the movements of participants, and correcting some errors of positions and names of features on the maps.

The discussion around the maps consisted of the participants listing all the main points of interest listed on the maps, as well as adding any element that would not be present,

or correct names that were wrongly spelled on the maps. This validation serves both to correct possible errors and, more broadly, to ensure that community participants recognize the places and validate the overall results.

Another exercise involved having community members map out their own mobility patterns. This activity revisited their daily movement routines, with participants describing their everyday lives, this time using the map for visual support. It helped reveal local movement patterns and allowed for the assessment of the minimum daily distances traveled by community members.

Community members indicated the approximate location of their homes on the map and the main sites of their daily mobility. As explained by these community members, they made all of their daily movements by walking. Public transport solutions, including three-wheelers (boda boda in Kenya or auto in Nepal) and minibuses (matatu) were used to reach areas further away and less frequent destinations, such as health centres or those further from the central administration (Shianda town in Kenya, Birendranagar in Nepal).

This discussion of the daily activities of participants allows the activity spaces of rural dwellers to be observed. Activity spaces are defined as the convex hull of the daily mobility [33,34]. The advantage of this method is its provision of daily activity spaces as simple areas that require the location points of where most activity happens.

In the present case study, they also have the advantage of illustrating the area coverage of the participants' familiar space over the whole study area. The map of the daily mobility hull illustrates that most activities are restricted to a relatively small area. It reflected interestingly in the validation session, as several participants noted that the exercise helped them see their village in a way they had not thought about earlier.

The spatial spread of geographic elements in the villages illustrates the character of subsistence economy of the areas covered during the community cartography. The need to have access to close amenities in daily life by local dwellers results in the villages being covered by a dense net of small shops and industry, such as grain mills, worship places, and water access, among others.

4.5.3. Community Members' Feedback

A final focus group was organised with community participants to understand their opinions on the overall exercise. It aimed to understand their opinions of the exercise in a broader scope than the maps and data collected. It also aimed to let participants voice their critiques of the exercise, positive and negative, to enhance future exercises.

Perhaps the most interesting result of the exercise was that community members pointed to how the data collection exercise pushed them to reflect on their villages and social and spatial dynamics. Some community members pointed out how this exercise was an occasion to discuss in depth with the local authorities and helped them get a better sense of the mobility dynamics of their village. "I learnt to interact with people from different positions", explained one participant.

As parts of the exercises were conducted while walking with village elders, the participants enjoyed the deep knowledge of the elders in explaining village social and economic dynamics. Village Elders are elected as semi-official actors as an interface between the government and citizens; they are generally older people with deep links to their community [35,36]. Participants thus learnt about locations and local points of interest in the villages, as well as walking to and learning about places located deeper into the villages than they usually experience, away from their own immediate vicinity.

One participant noted in particular that he only now realised the importance of the regular location of boreholes and river access points. As many houses have direct access to shallow wells, these are generally useable only during the rainy seasons, while in the dry season the shallow wells do not provide enough water all year round [37,38]. The participant noted that the wide presence of shallow wells contrasted with the more spaced and less frequent permanent water points.

Participants also commented that the visits combined with data collection made them realise the clustering of some of the local amenities. "Most churches are located where most other amenities are. But it also made me realise that a number of villages don't have their own schools and children must walk further", noted a participant. Coupled with the observation of the map, this exercise of validation of the data and the exercise convincingly illustrates that participatory exercise has a useful effect of supporting local community dwellers to orient their observations around their own living space.

Important critiques of the exercise by community members concerned mainly the practical constraints of the exercise. The transect method requiring walking long distances over the day implied that some of the daily exercises lasted from 9 am to 3 pm. The community participants noted that they would have favoured expanding the exercise in each of the locations to four days instead of three to allow for shorter days and distances covered per day. "You should take more time to get good information", as one participant noted at the end of the session.

The impression on the exercise, however, was not unanimous among the participants. Some had suggested widening the area of study and others, on the contrary, suggested surveying smaller parts and focussing on a reduced number of villages and sites. It is not surprising that different opinions emerged from the debriefing of a collection exercise. This provides key insights for researchers to understand that different methods may seem the most appropriate, and that decisions should take into account and weigh a number of factors.

A suggestion of broadening the scope of the survey also came into the discussion. As the Chief of one of the locations pointed out: "These maps can support the administration, by showing the locations of MPESA (mobile money) points, or the posho mills (small maize mills). However, when "the question of road access is a big issue that relates to the land, and to the sensitive issue of land ownership", the feedback from the community members highlighted numerous questions on how to conduct this type of collection exercise. They also remarked eloquently how limited the granularity of official data collection is in rural Kenya.

Results of the first exercise in Kenya provided feedback to enhance and systematise the exercise in Nepal. By this time, the method integrated a GIS Web platform that allowed community participants (supported by enumerators) to discuss the results in smaller groups. They could directly and interactively navigate the data, and produce maps themselves.

The large paper maps and screening materials prepared in advance enabled community representatives and local authorities to provide feedback on the collected data. An appreciation survey was conducted to gauge participants' impressions of the exercise. The validation exercise also served as an opportunity to evaluate and discuss the conditions surrounding the community mapping process.

Among the feedback received, participants commented on the comfort levels during the data collection. This included discussions about the heat during field activities and the quality of the food provided. Some participants felt that the exercise was too lengthy and demanding, particularly due to long walks in high temperatures. However, most participants noted that the exercise offered a valuable opportunity to closely observe and understand their surroundings, as well as to discuss the conditions of various amenities in their villages with local authorities.

A validation session allowed the addition of elements used in the first fieldwork with other methods. Refining the first exercise allowed a broader group of stakeholders in both rural and urban mobility to be included.

The large maps that were shown to communities were commented on and annotated to illustrate origins and destinations in the community's daily life, as illustrated ion Figure 10. In a later confirmation exercise, the homes (origins) and main destinations were located on the network and calculated along the network with an Origin–Destination Matrix to see distances involved in daily mobility.

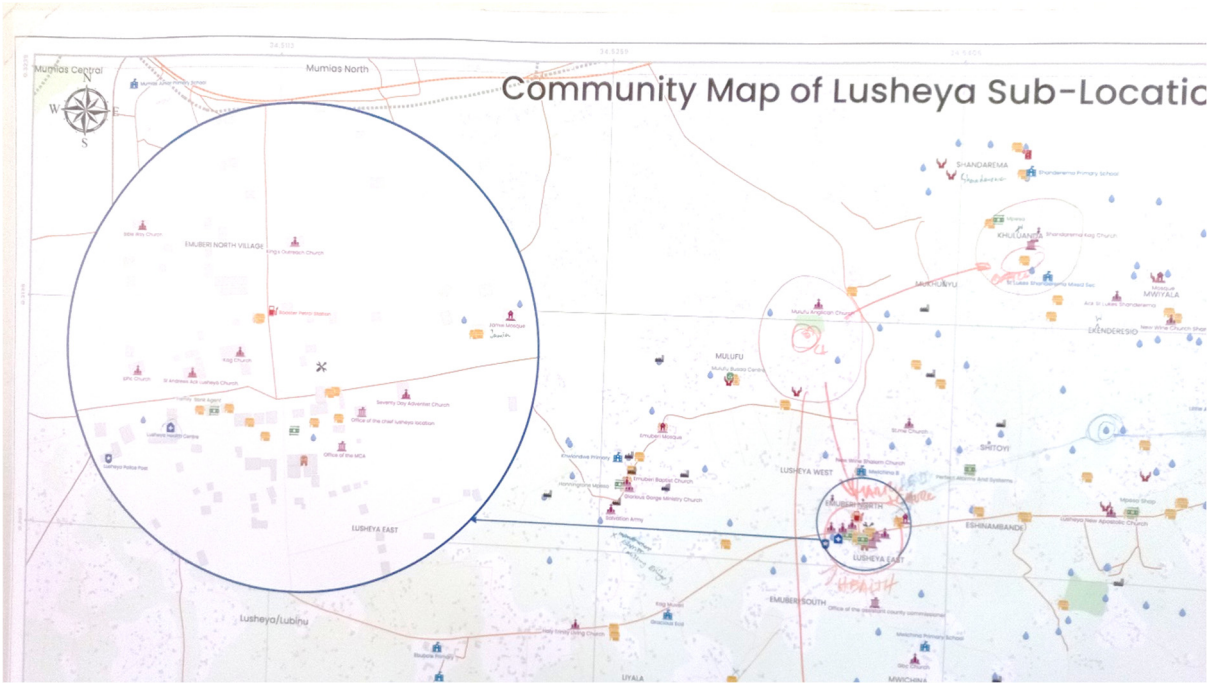

Figure 10. Detail of an annotated community map of Lusheya.

A female participant from Lusheya identified some key destinations such as the market, the water point, and the local church. Although there are numerous churches on the whole territory, the different faiths of the congregants are not necessarily catered for close to their houses. The calculated distances between origin (home) and destinations are shown in Table 5.

Table 5. Example of distances between the home of a Lusheya woman and local amenities.

Origin and Destination	Distance on the Network (Meters)
Home–Water	310.78
Home–Shop	1268.03
Home–Church	2550.25

The distances traveled by this woman effectively highlight the varying ranges of distance based on different activities. The nearest water point is just 310 m away, making it the shortest distance, while shops and, particularly, the church, are located farther away. The gendered roles within the community, which assign water collection almost exclusively to women, clarify why female respondents identify this as a regular activity, while male respondents do not include it in their activities.

A male member of the community, working in a local office, indicated his regular movements. The distance to the church is also the longest of his regular movements, justified by a lower frequency of movement, as shown on Table 6.

Table 6. Example of distances between the home of a Lusheya man and local amenities.

Origin and Destination	Distance on the Network (Meters)
Home–Office	1179.26
Home–Health	1405.39
Home–Church	4335.79

The table of movement samples shows a close correlation of distances as estimated by the communities in the first exercise described above, where community members indicated their daily, weekly, and less regular mobility. Both examples of mobility shown above illustrate relatively long walks for religious service, despite a strong density of places of worship in the area. This is due to a great variety of churches, including Catholic, Anglican, various protestant faiths, and a small number of mosques. As a result, on a weekly basis, church-going can involve relatively long distances.

Overall, the examples calculated with network analysis are quite congruent with the estimates made by the community at the beginning of the exercise, as shown in Table 3. The use of paper maps is, however, complex and time-consuming to reimport into a GIS. As Seeger notes in his commentary about this process: "The value of the local knowledge to the planning process [is] clear, but so too [are] the limitations of the process in which the information was collected" [12].

5. Discussion and Conclusions

The research demonstrates that limited mobility significantly impacts daily life for subsistence farmers and rural dwellers. Financial constraints limit access to essential services, education, and markets, perpetuating a cycle of poverty and limited development.

By utilizing participatory GIS and engaging with local communities, the study was able to collect detailed and accurate data on rural mobility patterns. This approach not only filled existing data gaps but also provided valuable insights into the daily movement needs of rural dwellers. The fieldwork in Kenya and Nepal showcased the effectiveness of digital mapping tools like the QField app, which allowed for the collection of comprehensive geographic data, including roads, paths, and points of interest.

This research brings a novel method for the assessment of rural conditions by combining PGIS approaches tailored for mobility. Its inclusion of community participants in the process brings the concerned populations to propose the identification of the information and data that are the most relevant to their daily mobility. This offers great possibilities of local inclusion in sustainable development and mobility planning. Its context-specific approach, in turn, slightly limits the replicability of the exercise as all data are bound to be focussed on slightly different perspectives of daily movements. In sum, this method demands adaptations to the context that may discourage mobility planners to use it.

The research experiment on community mapping for mobility indicates possible methods and tools to assess mobility in the rural Global South. The possibility of using GIS tools adapted for high data density can be used in rural environments characterised by a lack of existing data, provided there are an adaptation of methods and the inclusion of community knowledge in the process. Technical data collection tools for small areas and rural mobility present limited options. QField appears the most appropriate in the current development as it permits the updating of existing data and the use of snapping. GIS network analysis corroborates the estimates made by community members in the mapping exercises. Its validation weight is important as it should serve to justify mobility plans based on a combination of community needs assessments supported by spatial analysis.

The research highlights the importance of considering both quantitative and qualitative data when assessing rural mobility. Community engagement revealed specific gender-based mobility challenges, with women often facing greater obstacles in their daily activities. These insights underscore the need for mobility solutions that are tailored to the unique needs of different community members. For example, development organisations successfully implemented women-centered bike-sharing programs in Africa, Asia, and South America. These programs can provide affordable bicycles and e-bikes, offering a practical solution to reduce travel time and physical exertion for women engaged in everyday tasks such as fetching water or going to the market [39,40]. Such sustainable solutions are particularly valuable in all regions, including with difficult terrain.

Additionally, there is a crucial need for financial empowerment initiatives to help women purchase bicycles, motorcycles, or even pool resources for vehicle ownership. By

improving access to personal transportation, these initiatives would empower women, facilitating easier access to markets, education, and healthcare, thereby contributing to their overall economic and social mobility [41,42].

Overall, the study advocates for the continued use of participatory GIS as an actionable method for improving rural mobility. By incorporating community-specific data and perspectives, policymakers and planners can develop more effective strategies to enhance mobility and support socio-economic development in the Global South. This research contributes to a deeper understanding of rural mobility issues and provides a framework for future studies and interventions aimed at improving the lives of rural populations.

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