



BACKGROUND PAPER

Digital Technology-Based Climate-Driven Human Mobility Monitoring: A Case Study in Mueang Lop Buri, Thailand

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Digital Technology-Based Climate-Driven Human Mobility Monitoring: A Case Study in Mueang Lop Buri, Thailand

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Abstract

The growing impacts of climate change on human mobility, especially in developing countries like Thailand, underscore the urgent need for innovative monitoring methods that can operate effectively at granular levels. This study leverages digital technologies, particularly Global Positioning System (GPS) location data from mobile devices, to analyze climate-related movements in Mueang Lop Buri, Thailand, during a flood event in 2019. By integrating the Relative Wealth Index and elevation maps, we demonstrate how GPS data can be used to analyze temporary relocation. Our approach utilizes the spatial and temporal granularity of GPS data to identify residents, monitor their evacuation locations, and track the duration of displacement. Importantly, our work incorporates Relative Wealth Index as a proxy for socioeconomic status, showcasing how other nontraditional data sources, when integrated with GPS data, can effectively monitor the responses of different population segments to climate-related challenges. This study highlights the importance of digital technologies, particularly mobile GPS location data, in fostering inclusive climate resilience by providing a data-driven framework that captures vulnerable segments of the population, enhances real-time monitoring, and supports targeted policy interventions.

I. INTRODUCTION

The Intergovernmental Panel on Climate Change Sixth Assessment Report (2023) acknowledges that climate change is already occurring globally and is expected to increase significantly in frequency and severity. By the end of 2023, disaster-related mobility was observed across 148 countries and territories, affecting at least 26.4 million people (Internal Displacement Monitoring Center, 2024), with most displacements occurring in high climate risk regions. These high-risk regions are predominantly developing countries in Asia, where a significant portion of the population's livelihoods are particularly vulnerable to economic and climate shocks.

In Thailand, 11 major flood events have impacted watersheds since 1959, triggered by heavy rainfall, monsoons, and tropical weather systems—two of these occurred in the last 15 years. The country's largest recorded natural disaster was the 2011 mega flood (Hydro Data Science Section HII, 2011), which devastated 66 provinces, especially in the northern and central regions within the Chao Phraya River Basin. The flood lasted about 158 days, from 5 August 2011 to 9 January 2012, submerging 18,000 square kilometers of farmland and inflicting \$46.5 billion in damages nationwide. Lop Buri was one of the hardest-hit areas.

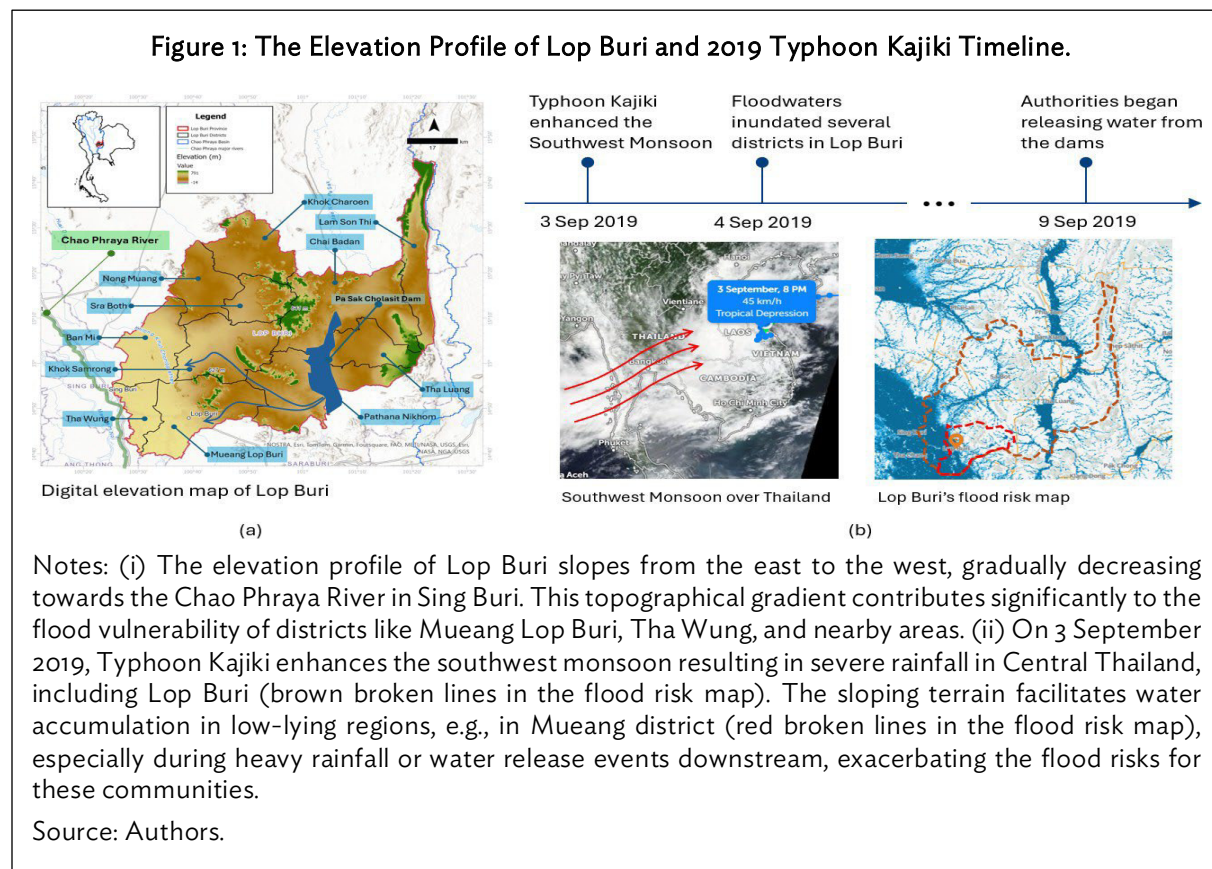
Flooding and droughts are key drivers of weather-related displacements, generally referred to in the literature as climate-related human mobility. Climate-driven human mobility, or climate mobility, includes various movements because of climate change impacts like rising sea levels, extreme weather events, and prolonged droughts. Climate mobility can be temporary, such as short-term relocation because of immediate threats, or permanent, like relocation because of ongoing environmental changes. The escalating impacts of climate change on human mobility, coupled with increasing societal tensions, security concerns, and resource conflicts during droughts or floods (Tanyag, 2018; Villar, 2021), highlight the urgent need for detailed analysis of climate risks and mobility.

However, climate mobility is not equally accessible to all. Socioeconomic status significantly influences one's ability to relocate. Those with higher incomes and resources can more easily move to safer areas, while those with lower socioeconomic status often lack the financial means and social support to do so. Recent studies (Almulhim et al., 2024; Berlemann & Tran, 2020; Beyer & Milan, 2023; Brottrager et al., 2023; Tanyag, 2018) provide substantial evidence that groups like farmers, fisherfolk, women, older adults, and the urban poor are particularly vulnerable to climate emergencies, often facing severe impacts. These impacts can force them to leave their homes, either voluntarily or involuntarily. Despite the increasing frequency and intensity of such disasters, comprehensive policies and data-driven measures to ensure timely and inclusive services for displaced individuals, such as emergency aid, social protection, and psychological support, remain lacking (UNESCO & UNU-IAS, 2023). This exacerbates existing inequalities, leaving vulnerable populations at greater risk of the effects of climate change.

Quantitative models use statistical relationships between various factors to understand mobility patterns over large areas and time periods, extending insights from localized

studies (Niva et al., 2021). While econometric methods have expanded our knowledge of climate mobility, they often produce inconsistent results because of data differences (Abel et al., 2019; Beine & Parsons, 2017). Government household censuses and surveys remain key for quantifying climate mobility, but are often retrospective and slow to inform timely solutions on their own (Lu et al., 2016). Combining government data with new technologies and private data, such as mobile phone usage, social media activity, and online platforms, open new opportunities in addressing inequalities in climate response at high levels of granularity.

One nontraditional data source is mobile Global Positioning System (GPS) location data, or GPS data, which track movement of mobile devices and hence could be used to monitor how people move during climate-related disasters. A key advantage of GPS data is its granularity and frequency. We track the devices daily, taking advantage of knowing their current and next locations at a spatially granular level, which yield patterns in human movements.



II. STUDY AREA AND THE FLOODING EVENT

Lop Buri is regarded as a wealthy agricultural province in Thailand. Most of the land of Lop Buri is utilized as cropland, particularly producing upland crops (57%) and rice (17%), while 18% are classified as forestland (Patarasuk & Binford, 2012). It has 11 districts with Mueang Lop Buri and Chai Badan as the most populated districts in this province. Being adjacent to the Chao Phraya River, Lop Buri's elevation varies significantly—from about -2 meters above sea level near the river to higher elevations further east, about 840 meters above sea level (Figure 1[a]). In addition to the Chao Phraya Dam, the Pa Sak Cholasit Dam, located within the province, contributes to flood risk because it releases water during extreme rainfall events, further exacerbating flooding, especially in low-lying areas like Mueang Lop Buri.

The province has a significant proportion of low-income households, with many residents relying on subsistence farming and seasonal labor (Duangbootsee, 2023; Office of the National Economic and Social Development Council - Thailand, 2022), which are highly susceptible to disruptions caused by natural disasters (Karamba, 2022). Women and children are particularly vulnerable. Women often have limited access to economic resources and are more likely to be engaged in informal and low-paying jobs (UN Women, 2022). Children, especially those from low-income families, face heightened risks during floods, including displacement, interruption of education, and health issues (Boudet et al., 2018). The combined impact of these factors exacerbates the vulnerability of these groups, making them more susceptible to the adverse effects of extreme weather events like typhoons and floods.

In August 2019, Typhoon Podul made landfall and quickly moved through Viet Nam and the Lao People's Democratic Republic before entering Thailand at Nakhon Phanom Province on 29 August. This was shortly followed by Typhoon Kajiki (Figure 1[b]). These typhoons caused heavy rains and severe flooding¹ in Thailand, with significant impacts reaching the flood-prone Chao Phraya River Basin. Authorities had to release water from the Chao Phraya Dam² to manage the increased water levels, which led to further flooding downstream³. In Lop Buri, the water release caused significant flooding, affecting numerous households and agricultural lands. This study focuses on Mueang Lop Buri, one of the affected districts in Lop Buri province, by the 2011 flood event.

¹ <https://reliefweb.int/report/thailand/aha-centre-flash-update-no-01-tropical-storm-podul-and-tropical-depression-kajiki>.

² <https://reliefweb.int/report/thailand/rising-chao-phraya-brings-renewed-flood-alert-7-provinces>.

³ <https://crisis24.garda.com/alerts/2019/09/thailand-flood-alert-in-seven-provinces-as-of-september-9-update-3>.

III. RELATED WORKS

Scholarly interest in climate-related human mobilities, increasingly referred to as “climate mobilities,” has expanded significantly in the last two decades. Boas et al. (2019) and Cundill et al. (2021) have contributed to this body of research, which originates from earlier studies on environmental migration, as noted by Morrissey (2012). Piguet (2018) highlights that climate migration or climate mobility involves the displacement of individuals or communities because of significant shifts in environmental conditions attributed to climate change. This movement can be temporary or permanent, voluntary or forced. This may occur within a single country or across international boundaries (International Organization for Migration, 2019; Villar, 2021), and its impact will accelerate exponentially, with estimates of 50 million–250 million people affected by 2050, rising to 630 million by 2100 (Almulhim et al., 2024). Recent comprehensive reviews (Borderon et al., 2019; de Sherbinin et al., 2022; Ghosh & Orchiston, 2022; Hoffmann et al., 2020; Schewel et al., 2024; Šedová et al., 2021; Selby & Daoust, 2021) have assessed the impact of climate on migration patterns. These reviews also address the legal and conceptual complexities surrounding the terms “climate migrants” and “refugees,” as explored by McAdam (2012) and Wiegel et al. (2019). Avis (2017) and Piguet (2018) discuss the challenges of defining different types of mobility, ranging from temporary to permanent.

Quantitative data on internal displacement and cross-border movements induced by natural hazards remain scarce because of the highly variable spatial and temporal nature of such data, as noted by Bohra-Mishra et al. (2014) and Lu et al. (2016). Comprehensive, high-resolution spatial and temporal data—essential for climate migration studies—are limited. Existing research encounters several methodological challenges, including inconsistencies in data collection, difficulties in attributing individual migration events to climate change, and numerous contextual factors influencing migration decisions, as discussed by Feng et al. (2010); Henry et al. (2004); Lu et al. (2016); Mueller et al. (2014). In an era of escalating environmental stressors and risks, understanding the intricate interactions between the drivers of climate mobility is crucial. In this work, we present a data-driven analysis utilizing innovative data sources to respond more promptly and effectively to climate challenges. This approach could serve as a framework for monitoring climate mobility.

Previous studies (Bengtsson et al., 2015; Blumenstock, 2012; Deville et al., 2014; Lu et al., 2012; Lu et al., 2013; Lu et al., 2016; Tatem & Smith, 2010; Wesolowski et al., 2013) have highlighted the utility of mobile network operator call detail records (CDRs) as a complement to conventional survey-based methods. Bengtsson et al. (2015), Tatem and Smith (2010), and Wesolowski et al. (2013) have employed CDRs to track infectious disease spread by analyzing human mobility patterns. Blumenstock (2012), Deville et al. (2014), and Lu et al. (2012); Lu et al. (2013); Lu et al. (2016) have used CDRs to explore internal migration and population movements and to longitudinally assess migration patterns at local and national levels. Our work presents the use of GPS data in monitoring climate mobility.

IV. DATA

The data used in this paper include GPS data and digital elevation maps that were obtained from various digital technology sources (table). The main dataset comprises Thai mobile GPS location data from March 2019 to February 2020. GPS units provide accurate location for almost anywhere on Earth. The dataset was preprocessed by removing all duplicate records, i.e., those with exactly the same device identification, location, and timestamp. The timestamps of the remaining devices were converted from Unix time to Greenwich Mean Time (GMT) and adjusted to the Thailand timezone (GMT+7). GPS data are collected from applications from mobile devices, subject to user permission, which introduces biases based on the types of applications used. For example, if most applications are lifestyle-related, the data will primarily reflect users of those applications. Additionally, people without internet access or mobile phones are not represented in the dataset. To address these biases, we use supplementary data to identify groups that may be underrepresented, such as those with different socioeconomic statuses.

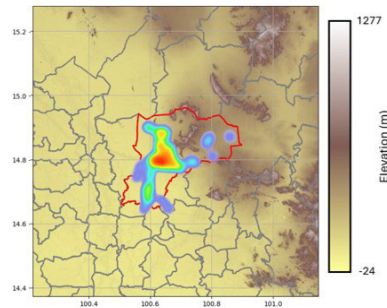
Data Sources for Monitoring Movement During a Flood in Mueang Lop Buri.				
Data Type		Period	Source	Number of Samples
Mobile Global Positioning System Data				
Device ID (UUID format)	operating system	March 2019–February 2020	Acquired from third-party source	26 million unique devices in Thailand
Longitude				
Latitude				
OS version				
Timestamp (ms)				
Supplementary Data				
Relative wealth index	2019	Meta	NA	
Digital elevation map	2020	NASA		
ID = identifier, ms = millisecond, NASA = National Aeronautics and Space Administration, NA = not applicable, UUID = universally unique identifier.				
Note: This table lists data from digital technologies, e.g., mobile devices and satellites, which, when combined, provide meaningful insights into population movements during specific events.				
Source: Authors.				

Supplementary datasets are used to estimate the socioeconomic status of the population and enrich our analysis. Meta’s Data for Good team, in collaboration with University of California, Berkeley, developed the RWI⁴ to provide micro estimates of wealth and poverty for low-income and middle-income countries at a 2.4 kilometers (km) resolution. This index is based on surveys from over 1 million households and linked to nontraditional

⁴ <https://dataforgood.facebook.com/dfg/tools/relative-wealth-index#methodology>.

data sources like satellite imagery, mobile phones, and Facebook connectivity data. Using these inputs, a supervised model predicts the RWI for each populated 2.4 km grid cell. NASA's digital elevation maps (Franks et al., 2020) from the Shuttle Radar Topography Mission provide detailed representations of the Earth's surface topography.

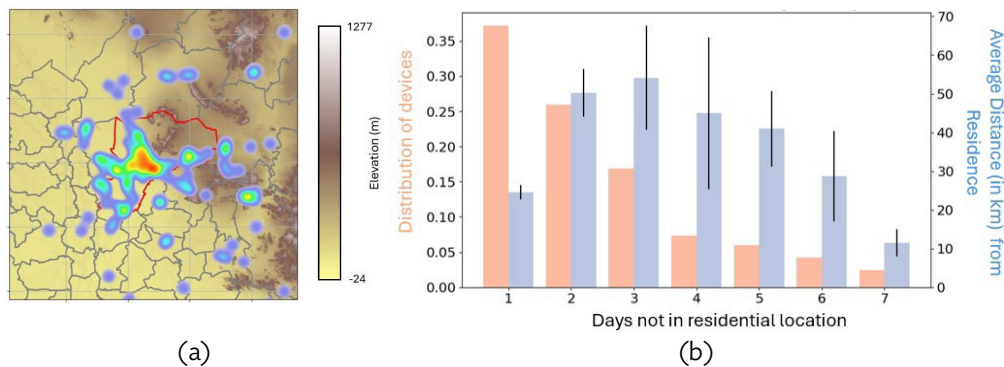
Figure 2: Heatmap Showing the Distribution of Residential Locations in Mueang Lop Buri.



Notes: The residential locations overlay the digital elevation map from the National Aeronautics and Space Administration of Mueang Lop Buri and its surrounding districts. The residential locations are crucial for disaster response and mitigation, determining the potential impact and necessary preparation. The elevation map shows that low elevation is closely related to elevation, with a preference for living in low-lying, high-risk areas.

Source: Authors.

Figure 3: Evacuation Location and Duration of Residents of Mueang Lop Buri



Notes: (a) Refuge locations of Mueang Lop Buri residents overlaid on an elevation map. Flood extent is inferred from the duration residents are away from home. (b) The ratio of evacuated residents is plotted against the days they were away and the average distance to their refuge. (a) and (b) highlight how a Global Positioning System-based monitoring system provides detailed insights into evacuation patterns.

Source: Authors.

V. Results

A. Monitoring Evacuation and Duration of Evacuation

On 28 August, Typhoon Podul struck Viet Nam, followed by Typhoon Kajiki⁵ on 3 September, which intensified the southwest monsoon and led to severe flooding in Lop Buri, particularly in Mueang Lop Buri. The situation worsened when dam administrators released water,⁶ further inundating high-risk areas. Residents of Mueang Lop Buri, located in low-lying areas as shown in Figure 2, are historically prone to flooding due to their geographical locations. During the flood event in September 2019, many residents were forced to evacuate and seek refuge in nearby areas, as depicted in Figure 3(a), from September 1 to September 15. Interestingly, some of these temporary shelters were also in low-lying areas, which may not have been flooded, still posed a risk if conditions had worsened.

To effectively monitor the extent of these floods, we tracked the duration people remained outside their residential areas, providing a clearer picture of the flood's impact on local communities and their displacement patterns. Figure 3(b) illustrates the extent of the flood and the efficiency of the response. The x-axis represents the number of nights a device was away from its home location, while the y-axis shows two key pieces of information: the orange bar reflects the distribution of devices, and the blue bars indicate the average distance traveled from homes to seek refuge.

Notably, about 60%–65% of the temporarily displaced individuals were affected for only 1–2 nights, highlighting the quick resolution of the situation in Mueang Lop Buri. Those who evacuated for just an overnight stay typically relocated within 30 km, often within the same district, suggesting a strong preference for familiar surroundings because of emotional ties, local resources, and nearby support from family and friends. Conversely, individuals who left their homes for longer periods tended to move farther away, indicating a greater level of disruption or uncertainty about the safety of their original locations. Their decision to seek refuge in more distant areas may reflect a need for stability and security as they navigated the aftermath of the flood.

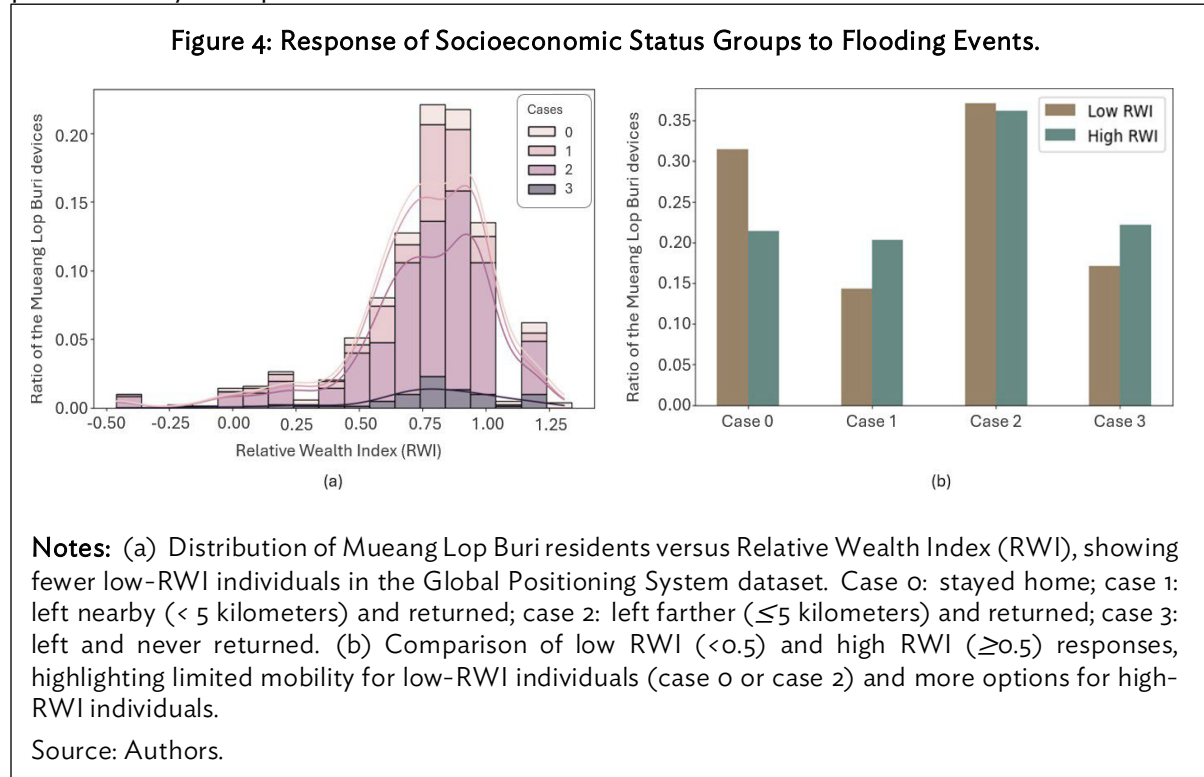
Understanding these patterns is crucial for shaping our response strategies. It underscores the importance of not only immediate recovery efforts, but also the need for tailored support systems that address the specific needs of those temporarily displaced. Developing and upgrading accessible evacuation centers with lower flood risk for short-term evacuees and establishing frameworks for those requiring longer-term assistance can significantly enhance our resilience to future climate-related events.

To gain deeper insights into how residents of different socioeconomic status responded to the 2019 flooding event, we overlaid RWI data. Plotting the distribution of

⁵<https://www.weather.gov.hk/en/informtc/kajiki19/report.htm>.

⁶<https://www.bangkokpost.com/thailand/general/1745549/7-provinces-warned-of-rise-in-chao-phraya-dam-discharge>.

the Mueang Lop Buri population by socioeconomic status, shown in Figure 4(a), we noticed fewer low-RWI individuals in the GPS dataset, possibly because of limited access to technology, financial constraints, or the specific types of mobile applications from which GPS data are collected. We normalized the counts and compared mobility responses between low-socioeconomic status and high-socioeconomic status individuals (Figure 4[b]). Low-RWI individuals often had limited mobility range or did not move, while high-RWI individuals had more choices, from staying home to evacuating or relocating permanently for up to 6 months.



Understanding these mobility patterns is crucial for addressing climate-related displacement. This analysis highlights the need for immediate evacuation measures and targeted support systems that consider socioeconomic disparities. Ensuring low-socioeconomic status individuals are well-represented in the dataset provides a more accurate depiction of their mobility patterns. Nevertheless, normalizing the data allows for a fairer comparison of mobility patterns between different socioeconomic groups. Timely access to data and information can enhance the mobility and resilience of low-socioeconomic status populations. Identifying temporary refuge locations and assessing associated risks for those facing immediate threats can help reinforce needed social services.

VI. DISCUSSION

A. Role of Digital Tools in Monitoring Climate Mobility

The integration of digital tools, such as GPS-based devices, into monitoring climate mobility provides numerous advantages that enhance tracking and response capabilities. Previous works (Boas et al., 2020; Lu et al., 2016; Vazquez-Prokopec et al., 2013) highlight that real-time data collection through GPS and mobile phone CDRs enables precise tracking of human movement before, during, and after climate events, supporting immediate and long-term response efforts. High-resolution spatial data captured through these tools allow researchers to map both large-scale migration patterns and localized disruptions with accuracy that traditional methods lack (Alessandrini et al., 2020; de Sherbinin et al., 2015). Digital technologies also enable scalable data collection across regions and time, supporting interdisciplinary research that merges environmental, demographic, and socioeconomic data for comprehensive policy solutions [8]. Finally, these tools enhance public awareness and policy planning by making data accessible for informed decision-making, aiding governments and communities in climate adaptation projects (Boas et al., 2019; Wojewska et al., 2021).

In this study, we present a data-driven methodology for monitoring climate mobility across different socioeconomic status groups. The Mueang Lop Buri 2011 flood event was used as a case study, utilizing government data and other nontraditional data sources, e.g., GPS data, to assess the responses to extreme weather conditions attributed to the ongoing climate crisis. Our approach offers a framework for understanding mobility patterns that provide valuable insights into the adaptive behaviors of the residents in Mueang Lop Buri, Thailand, a particularly vulnerable area to flooding and climate-related disasters.

B. Key Insights from the Case Study

Our study highlights the two main insights into climate mobility. First, the spatial and temporal granularity of GPS data is invaluable for tracking temporary movements during flooding events. Spatial granularity allows us to pinpoint where individuals seek refuge, while temporal granularity helps measure the duration of their stays in evacuation centers. Identifying where individuals seek refuge is important to assess the risk of potential disasters, such as landslides and further flooding, and to ensure efficient relief operations. Measuring the duration of their stays in evacuation centers provides the means to assess community recovery efficiency and historical data to evaluate provisions for future relief operations. These are just a few pieces of information that are crucial for effective response and mitigation efforts because they reveal potential risks in refuge locations and the extent of flooding impacts in home areas.

Second, the use of other GIS data, such as elevation maps or flood risk maps, enriches the monitoring insights. For example, integrating socioeconomic status via proxy data with GPS analysis ensures that the specific responses of vulnerable populations are monitored,

enabling targeted support during temporary relocation. The socioeconomic status proxy also reveals the imbalance between samples from lower socioeconomic status groups and higher socioeconomic status groups. This allows data scientists and analysts to perform additional processing for comparative analysis between groups. Such insights are crucial in planning and disaster response operations. Other data sources that identify demographics, such as the age and gender of displaced individuals, should also be explored.

C. Policy Implications and Recommendations

While significant advancements have been made in our understanding of climate-induced migration over the past two decades, critical gaps persist in key areas that warrant further investigation, e.g., cost-effective data collection, efficient policy formulation, and effective grassroots implementation. Addressing these gaps is essential if we are serious about proactively mitigating the escalating impacts of climate mobility. And one way to address this is through the use of nontraditional data sources from digital technologies. There is a critical need for integrated data systems that combine digital technologies, such as GPS data, with socioeconomic and environmental datasets. Developing centralized data platforms can facilitate the integration and accessibility of diverse data sources, enabling comprehensive analysis for resource allocation and economic planning at both national and local levels. Effective real-time monitoring systems are also essential to track climate-induced human mobility and respond promptly. Implementing low-latency, near real-time data collection and monitoring systems using GPS and other digital technologies can enable timely interventions.

Policies often overlook the specific needs of low socioeconomic status populations in climate resilience planning. By using unified disaster risk reduction applications and platforms for monitoring individuals during disasters, as well as targeted policies, such as information and communication technology subsidies for vulnerable populations, we can ensure equitable access to resources and support during climate-induced relocations. Vulnerable populations are often limited not only by economic constraints but also by a lack of information to make informed decisions. Increasing public awareness campaigns and community engagement initiatives is key to educating and involving local populations in climate resilience efforts. Effective information dissemination, e.g., through mobile applications, is essential for fostering informed responses to climate challenges.

Integrating GPS-based estimate of migration data into disaster preparedness and response plans can improve evacuation planning and resource allocation during climate events because it can detect preferred destinations of affected population. Additionally, developing comprehensive resettlement plans that include housing, employment, and social services for individuals permanently displaced by climate change is crucial.

Innovative strategies, such as the one proposed in this paper, align with insights

from both existing literature (Almulhim et al., 2024; Hoffmann et al., 2021; Oakes et al., 2023; Tanyag, 2018) and the recommendations of international organizations (Intergovernmental Panel on Climate Change, 2023; Internal Displacement Monitoring Center, 2024; International Organization for Migration, 2023; World Bank, 2021) calling for the integration of innovative data sources to complement traditional methods for analyzing migration trends. Emerging data sources, such as GPS data and sensor data, offer timely and comprehensive coverage with a level of geographical precision that can add value to conventional data collection methods, including surveys, interviews, and other forms of data, thus enhancing the accuracy and representativeness of climate migration analysis.

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