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Geographic information system-based prioritization mapping for urban search and rescue in Poblacion, Davao City

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ABSTRACT

Reading Natural catastrophes frequently have substantial consequences, such as infrastructure damage and loss of life. These unanticipated circumstances often result in trapped individuals under rubble debris that needs rapid response and attention. Natural catastrophes can cause a large number of victims, and so a crisis might destabilize the entire area if the authorities' Urban Search and Rescue (USAR) operations are ineffective. Prioritization maps are a highly valuable tool in this approach since they may improve and automate the "decision-making" process by showing the most critical regions. This study creates prioritization maps based on population density per barangay and the population of the declared employees in the barangay to identify and prioritize the most critical areas before and after a catastrophe. These maps reflect heavily populated locations using population density metrics, showing areas with potentially more significant concentrations of people needing help after catastrophic occurrences. When a disaster happens, the USAR personnel, using these prioritization maps, can make informed decisions to allocate resources and manpower effectively. Utilizing these maps will contribute to and ensure an effective and immediate response, resulting in fewer casualties and damage. Population data is processed using Geographic Information Systems to produce these maps. The methodology was applied to the Poblacion District of Davao City, Philippines, and prioritization maps were developed. The maps reflected critical areas of the district and will serve as valuable tools for planning and effectively dispatching USAR personnel in times of a natural catastrophe.

Keywords: Geographic Information System, Natural Disaster, Population Density, Prioritization Maps, Urban Search and Rescue

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INTRODUCTION

Natural disasters frequently have significant effects, such as infrastructure damage and loss of human life. Structure collapse and massive rescue incidents are becoming more common domestically and globally. The reasons for the collapses range from natural disasters like earthquakes to spontaneous collapse, terrorism, and technology. As our infrastructure ages, as we continue to build enormous structures in seismic, hurricane, and other natural hazard locations, and as deadly weapons like explosives become more accessible to terrorists, the frequency of collapsed structural tragedies is projected to rise.

Natural phenomena are unpredictable events that necessitate immediate response and attention. The number of casualties is determined by the magnitude of the disaster and the proficiency of Urban Search and Rescue (USAR) operations (Nefros et al., 2018). Emergency Medical Services (EMS) are a critical component of the city's emergency response system, providing medical transport and care for the sick and injured. As part of EMS, USAR personnel are trained to assist in the rescue and medical treatment of individuals in complex situations. USAR operations focus on locating, rescuing, and providing initial medical care to victims trapped in confined spaces, particularly in urban or industrial environments. Urban areas are especially vulnerable to disasters due to their dense populations, tall structures, intricate street systems, and socially diverse communities with ethnic, religious, and linguistic considerations (Statheropoulos et al., 2015).

The USAR system has four stages: mitigation, readiness, response, and recovery (Nasar et al., 2023). Each disaster management cycle phase has various duties for dealing with the crisis. Numerous definitions of Search and Rescue have existed over the years (Cooper, 2005). This phrase was initially described as "the act of locating and transporting victims of a serious catastrophe to safety." Another definition was with the distinction between search and rescue operations, with search operations involving the use of available personnel and facilities to locate people in difficulty, and rescue operations involving the retrieval of people in distress, meeting their immediate medical or other needs, and transporting them to a safe location. In the aftermath of disasters, time is a critical factor in ensuring the effectiveness of Urban Search and Rescue (USAR) operations (Chenji et al., 2012). The swift and accurate prioritization of affected areas for resource allocation is essential to mitigate further damage and protect lives. However, the large number volume of information, coupled with limited USAR personnel, can lead to delays and errors in prioritization, potentially increasing casualties and eroding public trust in governmental authorities. Therefore, implementing an automated system for prioritizing USAR tasks is essential to enable informed and timely decision-making.

The creation of a spatial model meant to distribute USAR activities strategically. This allocation was established by considering the priority index allocated to the disaster-affected regions. The criteria used for the prioritization were identified through a thorough search of literature studies and discussions with USAR professionals. Using the analytic hierarchy process (AHP) method, the relevance of the identified criteria was computed as weights. In addition, a method that utilizes multi-criteria decision-making (MCDM) and AHP alongside GIS were be established to calculate the priority index of affected regions for allocating USAR professionals (Hassanzadeh and Nedovic-Budic, 2016).

The proper preparation of USAR activities is essential during the crisis response phase when there is a short period of time with a decreasing possibility of saving trapped persons. They demonstrated an enhanced decision-support system for deploying USAR resources in disaster-affected areas. A two-phase decomposition technique structures the issue as iterative interconnected phases of mixed-integer programming (MIP) models. During the planning period, Phase One adopts a comprehensive multi-phase allocation approach to guarantee equal and effective demand satisfaction across all affected regions. Phase two adjusts the distribution of resources provided in the previous phase to each district in the following term. This attempts to reduce the total weight of Search and Rescue (SAR) response times by considering secondary damage risk, resource coordination, and recovery time requirements. The decision framework offered here provides professionals with essential focal areas and priorities for improved mitigation, readiness, and response results (Ahmadi et al., 2022).

Spatial analysis and planning aimed at constructing urban emergency assistance systems—including medical, search and rescue, law enforcement, and other essential services—must consider the area's design, layout, and suitability. Effective planning for these facilities requires collaboration among professionals, decision-makers, emergency response personnel, administrative bodies, and active participation from local communities and other stakeholders affected by the decision. The most significant criteria for thorough planning in establishing such facilities are selected based on recommendations from existing literature and expert insights. Among these criteria, population density is one of the most crucial factors to consider.

Population density is a crucial indicator of potential risk in urban areas, particularly in high-density zones. These zones often include trading centers, social and commercial facilities, and densely populated urban settlements, where the need for emergency services is paramount to mitigate potential losses during emergencies (Erden and Coskun, 2010). As cities grow and urbanize, the correlation between population density and the demand for emergency services becomes even more pronounced. Studies have shown that densely populated areas are more susceptible to emergencies, necessitating well-distributed emergency service facilities to ensure rapid response and minimize casualties (Perry and Lindell, 2003; Cutter, 2012).

In addition, research by Alexander (2000) emphasizes that urban areas with high population density tend to face more significant challenges during disaster events, including congestion, limited access to emergency vehicles, and higher casualty rates. Therefore, strategically locating emergency facilities within or near these high-density zones is crucial for effective disaster management. Similarly, the work of Mileti (1999) highlights the importance of integrating population density into the broader context of urban resilience, where emergency systems are part of a comprehensive strategy to reduce vulnerabilities and enhance community preparedness. Moreover, Lindel (2021) underscores the need for a holistic approach to urban emergency planning that considers population density and other factors such as infrastructure vulnerability, economic activity, and social dynamics. By doing so, urban planners can develop more robust and adaptable emergency assistance systems that are better equipped to serve the needs of high-density areas.

GIS is an excellent contribution to disaster management as it provides needed situational awareness through conceptualizing spatial data on maps. A more practical application is GPS's real-time tracking of search and rescue teams, remarkable points of interest, and even the vehicles utilized. Also, having updated maps would add to the convenience of easily connecting designed plans and documented efforts, integrating those areas that are already searched or still need to be searched from the data collected from multiple sources (Hanssen, 2018).

The placement and dispatch of an emergency unit are critical and tough decisions for any emergency medical service (EMS). Some time-sensitive services, such as ambulances, require a time-based prediction to send the proper unit in response to an emergency scenario, as an incorrect assignment could result in a life-or-death crisis (Alamari, 2020). The shortest path is determined by identifying the lowest cost path between the two specified termini. The cost may be estimated in terms of money, travel time, or maximum benefit depending on the requirements of the situation. A GIS tool can help you find the fastest or shortest path between two points. GIS has a wide range of applications, including fire station and gas station site study, calculating the optimal route for service stations, and identifying the most practical placement for medical centers (Sushma, 2013).

This research focuses on developing prioritizing maps (heatmaps) for disaster-stricken USAR operations. This map will be critical in determining the strategic distribution of USAR personnel and resources.

This project seeks to construct a precise and dynamic tool by including population density in the GIS framework. This technique maximizes response efforts by directing resources to locations with high population density. This study aims to significantly contribute to disaster response and management, eventually improving the efficiency and efficacy of USAR activities throughout key post-disaster stages. With GIS, real-time data monitoring and analysis, there is great potential to improve the quality of USAR operations in providing life-saving care.

Conceptual framework

The desirable way to understand and describe the flow and transformation of data or resources within this study is through an input-process-output model employed to structure and evaluate different aspects of the research process, as shown in the figure below. In this framework, the input variables are the population density per barangay, the declared population of employees where the maps will be based, and the barangay boundaries. The Process consists of the integration of the GIS Technology. The Output is the prioritization map of the Poblacion district, showing the critical areas and the shortest path to the locations.

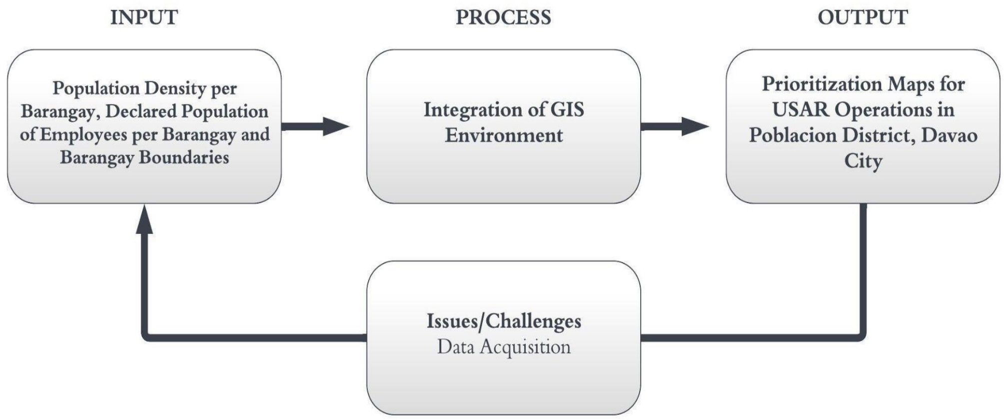

Figure 1. Conceptual framework.

MATERIAL AND METHODS

This study used a quantitative research approach, wherein a systematic empirical method of data gathering and statistical analysis is observed to answer the research questions. Additionally, this follows a quasi-experimental design as it involves manipulating one or more variables to observe their relationship with other variables and draw reasoning about causal relationships. A simulation study is also followed to model complex systems or situations to evaluate the impact of various factors.

Description of the study area

The barangays in the Poblacion District of Davao City, Davao del Sur, Philippines, will be the scope of where this study will focus. The district is located in the city's downtown areas, comprising 40 barangays. Poblacion District is situated in the central part of Davao City, with coordinates approximately 7.0685° N latitude and 125.5984° E longitude. The city's Poblacion area covers 1,144 hectares and is surrounded by the Davao River to the west. It has a business area of 511 hectares and a residential area of 433 hectares. The district's institutional sectors cover 98 hectares. Currently, the district houses important institutions in business and trade, education, medical, administrative, and public transportation. The city's principal commercial and trade hub is the district, where products and services come together. It is surrounded by the districts of Agdao to the north, Talomo to the south, Buhangin to the northwest, and Matina to the southeast.

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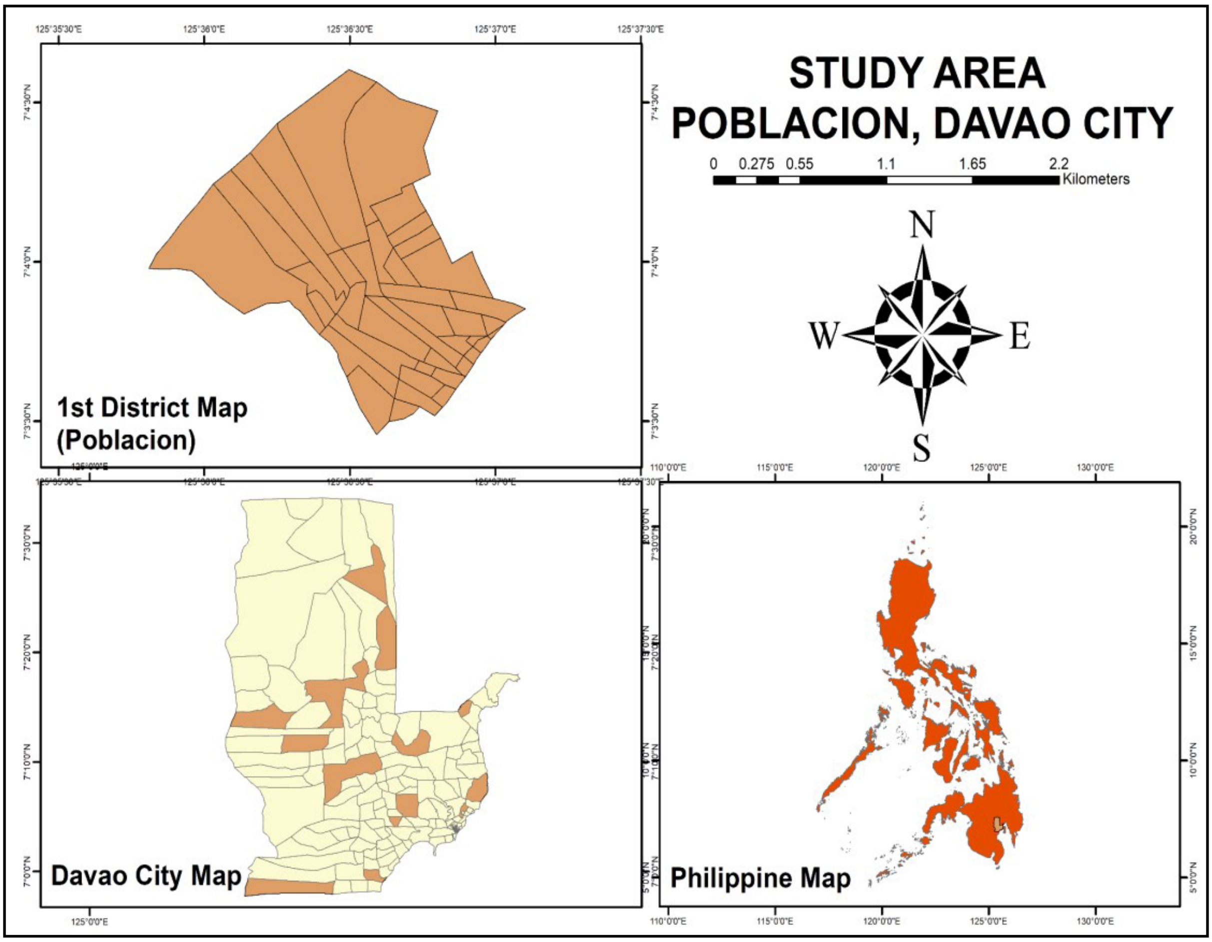

Figure 2. Study Area (Poblacion, Davao City, Philippines).

Data collection

A structured research approach was employed to develop a prioritization map for USAR operations. The study aimed to improve the efficiency and efficacy of the USAR response by identifying and prioritizing locations with the most significant potential for important actions. A thorough analysis of the current literature was done, which included works on disaster management, risk assessment, and GIS-based prioritizing models. Moreover, the methods included spatial analysis regarding the population density and proximity to USAR facilities in each barangay in Poblacion District.

Two population density layers are created from the data acquired regarding the population of the barangays in Poblacion District. One layer focuses on the population density based on the residents per barangay area, providing insights into the concentration of residents in different barangays in Poblacion District. The other layer considers the number of employees actively working in each barangay. Each population density is considered separately, assuming emergencies may occur during working or non-working hours. Considering these population metrics, USAR personnel and emergency responders can better respond and enhance their strategies and resources.

In preparing the Actual Priority Map (APM), we initiated the process by collecting vital information, specifically the population statistics of each barangay within the first district of Davao City. We sourced this data from the Office of the City Planning and Development Coordinator, which provided us with Davao City's General Profile. After obtaining the population figures, we diligently encoded them into an Excel spreadsheet and saved them as a CSV file for further analysis. To enhance the geographical dimension of our study, we incorporated a shapefile (shp) representing the boundaries of the barangays within Davao City's first district. This allowed us to create a comprehensive geographical dataset. Through data integration, we joined the population data from the CSV file with the geographic boundaries of the barangays. Once the data was united, we calculated the area of each barangay using the 'calculate geometry' function. With the area information in hand, we determined the population density for each barangay by utilizing the field calculator and applying a population divided by area formula. To provide a more precise visual representation of our findings, we classified the population density into distinct break values, allowing us to distinguish population density per square kilometer. This meticulous process enabled us to create the foundational groundwork for our Actual Priority Map, which plays a pivotal role in our thesis research.

Data sources

Developing prioritization maps for USAR operations in Davao City's Poblacion District includes obtaining information that assists in making informed choices about resource allocation and deployment during emergencies. Population density is recognized as a suitable criterion for developing prioritizing maps. To acquire specific spatial data, the researchers approached government agencies. The following data comes from two primary sources: government agencies and a thorough literature assessment. By incorporating these criteria and utilizing information from authoritative sources, the development of prioritization maps for USAR operations in Poblacion District, Davao City, ensures a systematic and well-informed approach to disaster response planning, ultimately improving the effectiveness of emergency interventions in the region.

Table 1. Data and sources.

Data	Sources
Population density	Philippine Statistics Authority (PSA)
Declared employees per barangay	Office of the City Planning and Development (OCPD)
Population per barangay	Office of the City Planning and Development (OCPD)
Barangay boundaries	Office of the City Planning and Development (OCPD)
Road network	Office of the City Planning and Development (OCPD)

RESULTS

Prioritizing affected regions is an essential aspect of making informed decisions for carrying out USAR operations, and it results in greater efficiency and convenience in relief operations during the crisis management phase of a natural disaster. The prioritization map proposed for allocating USAR operation resources after a disaster was applied in the study area of Poblacion District, Davao City, using GIS. This section presents and analyzes the results of the methodology, focusing on the critical areas based on the population density and declared population of employees per barangay.

3.1 Prioritization map based on population density of each barangay in poblacion district

The data presented in Figure 3 represents the population density of the 40 barangays in Poblacion District, Davao City. Based on the barangay general profile released by the City Planning Development Office of Davao City in 2022 and with the integration of GIS tools, barangay 37-D, barangay 31-D, barangay 21-C, barangay 22-C, and barangay 23-C are deemed to be highly dense areas in Poblacion District in terms of the number of residents. Meanwhile, barangay 3-A is the least densely populated, as projected in the figure.

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The map (Figure 3) reveals significant insights for USAR operations. It indicates that the most critical barangays in Poblacion are mainly situated within these five specific barangays: Barangay 37-D, barangay 31-D, barangay 21-C, barangay 22-C and barangay 23-C. This is possible because of the increased business activity along these roadways. Increased commercial activity in these barangays indicates greater concentrations of businesses, industries, and activities. The abundance of business activity generates a lively and energetic environment. As a result, more people and visitors are drawn to the neighborhood. Many choose to reside or stay in these barangays because of the easy access to services, opportunities, and facilities.

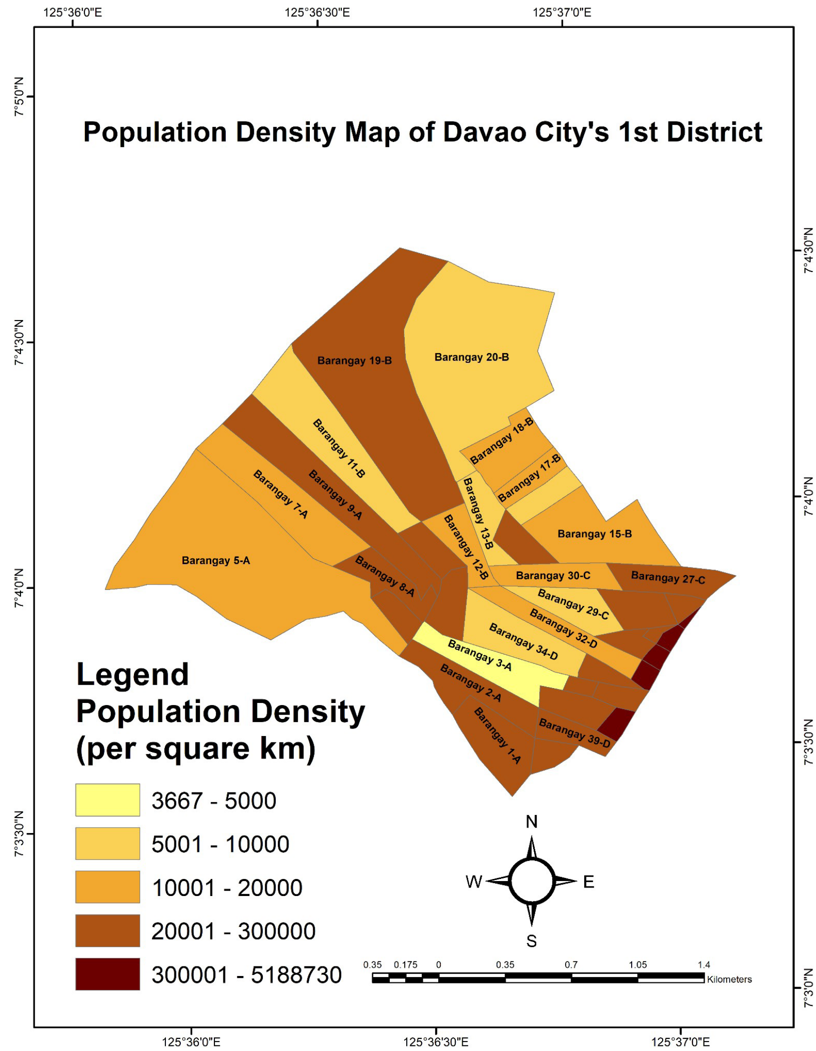

Figure 3. Prioritization map (Population density per barangay).

3.2 Prioritization map based on population density of declared employees in each barangay

The figure 4 presents another population density map of Poblacion District but with the consideration of the number of employees working in each of the 40 barangays. Since an emergency may occur during working hours, highly dense areas are prioritized for urban search and rescue operations. As what appears to be in the darkest shade in the figure, barangays 27-C and 35-D are considered to be highly densely populated in terms of residents and employees. Meanwhile, barangays 5-A and 1-A are less densely populated in Poblacion District.

Examining the map (Figure 4) corresponding to the population density of declared employees in each barangay in Poblacion District indicates places with higher employee concentration. The most crucial regions are identified to be barangay 27-C and barangay 35-D. As a result, most of the population concentrates in these locations during working hours. The number of employees indicates high economic activity and job prospects. These barangays are prospering in terms of commercial and industrial sectors. These locations have a lot of businesses, factories, offices, and workplaces that attract people.

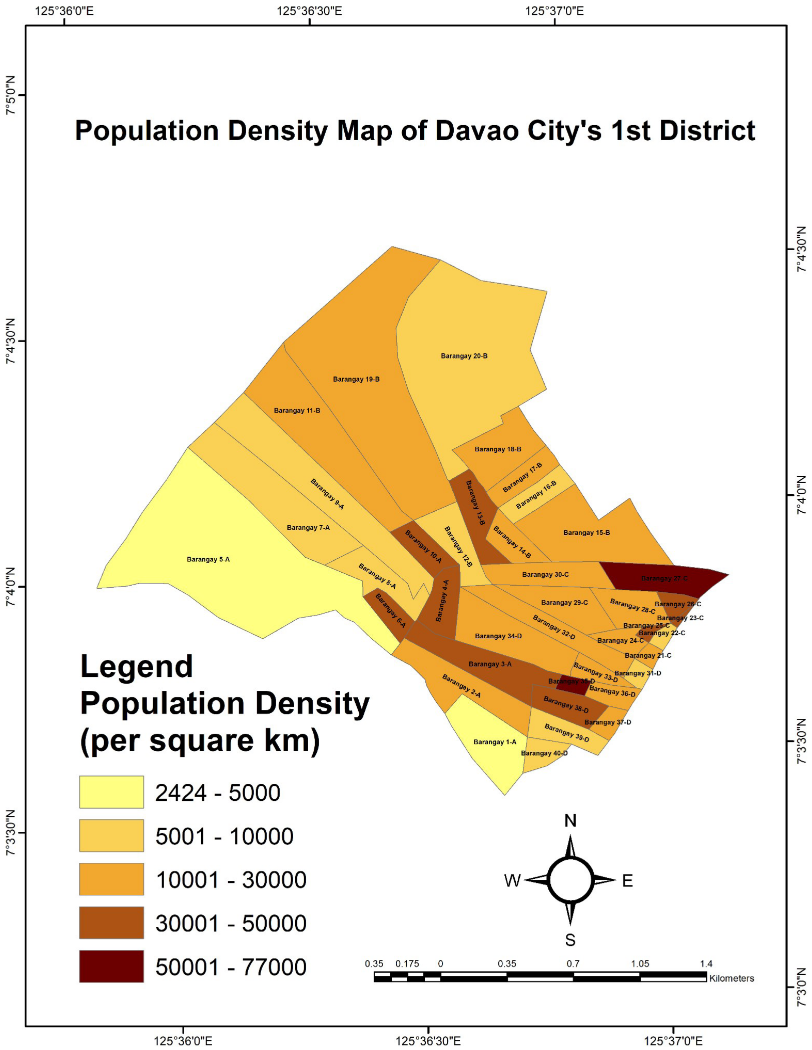

Figure 4. Prioritization map of declared employees per barangay.

DISCUSSION

Implications of population density in disaster response

The concentration of populations in urban centers is a well-documented challenge for disaster management, particularly in densely populated regions (Smith, 2013; Cutter et al., 2012). The results indicate that barangays 37-D, 31-D, 21-C, 22-C, and 23-C are highly vulnerable due to their dense populations influenced by economic activities. Similar findings have been reported in other urban centers, where population density has been linked to increased vulnerability during disasters (Mileti, 1999).

In these barangays, the presence of numerous commercial establishments, industries, and residential areas increases the number of individuals at risk and complicates evacuation and rescue operations. Urban planners and disaster response teams need to prioritize these areas to minimize casualties and enhance the effectiveness of relief operations.

Significance of employment density

The identification of barangay 27-C and barangay 35-D as critical areas due to high employee density underscores the importance of considering employment hubs in disaster response planning. Previous studies have highlighted the need to prioritize areas with high daytime populations, such as business districts, for emergency response (Tierney, 2003; Lindell, 2021). These barangays, being centers of economic activity, are likely to have a large number of people present during working hours, which increases the urgency for USAR operations in the event of a disaster.The high concentration of workplaces, including offices, factories, and commercial buildings, also raises the potential for structural damage, which can exacerbate the risks to the population. This aligns with findings from other urban disaster studies, which show that areas with high employment densities are often more vulnerable to catastrophic events due to the potential for building collapses and mass casualties (Alexander, 2000).

Application of prioritization maps

The practical application of these prioritization maps can significantly enhance the decision-making process in USAR operations. Emergency response teams would need to make quick, informed decisions on where to allocate their limited resources in a hypothetical scenario where a natural disaster affects the Poblacion District. For instance, if rescue calls were received from barangay 37-D, barangay 14-B, and barangay 3-A, the prioritization map based on population density would suggest dispatching rescue teams first to barangay 37-D. This decision-making process is supported by the prioritization framework outlined by Lindell (2020), which emphasizes the importance of targeting areas with the highest concentrations of at-risk individuals.

Similarly, if the disaster occurred during working hours, the prioritization map based on employee density would suggest focusing resources on barangay 27-C and barangay 35-D, where a large workforce might be affected. This approach is consistent with recommendations from disaster management literature, which advocate for considering temporal population distributions when planning and executing emergency response operations (Perry and Lindell, 2003).

CONCLUSIONS

In the aftermath of a disaster, situational awareness is essential. This entails precisely and accurately understanding the developing events, impacted areas, available resources, and potential risks and dangers. It assists professionals in successfully organizing and prioritizing response actions. Responders will be able to determine the most critical regions that must be prioritized following a disaster. This research demonstrates that prioritization maps can significantly improve the management and efficiency of USAR operations, benefiting both professionals and personnel involved in disaster response. One of the research's results is that there is a direct relationship between population density and the need for specific services and infrastructure. Areas with a higher population density are likely to have higher service demand. In addition, the prioritizing map serves as a foundation for disaster management. According to the findings, because of the concentration of people and infrastructure, high-density locations are frequently prone or vulnerable to casualties during disasters.

The ease of the exact and timely distribution of USAR teams and medical health responders is an additional possible advantage. Using these prioritization maps, USAR personnel may be designated to the most advantageous locations for quick action, such as the most densely inhabited regions to assist or save. These maps are considered an important instrument in USAR operations since they are useful and result in successful rescue operations. The number of rescued victims is projected to rise due to the application of these maps as guidance by USAR personnel in dispatching their teams. Additionally, it provides a route considered the shortest path a USAR vehicle can take to arrive at the scene in a short time. Emergencies are classified as time-sensitive issues because they need quick care since people's lives are in danger. The initial reaction to an emergency is to transfer victims to the closest medical facility or hospital, to treat a patient on an emergency site, or to treat and transport patients simultaneously to a medical facility. These maps can also be helpful and give government agencies insights into places where it takes more time to reach an affected area that exceeds the standard emergency response time. It can be used as a basis to provide additional facilities to cover that whole area effectively. Overall, prioritization maps play a crucial role in enhancing the effectiveness of disaster response efforts.

Furthermore, this study has limitations. The accuracy of the created prioritizing map is dependent on the available data obtained by the researchers. The population density criteria may not capture all aspects of the priority for USAR activities; thus, other relevant information must be used.

RECOMMENDATIONS

- Residents can benefit from improved disaster response planning, which may save lives and reduce property damage by using the map demonstrated.
- GIS-based prioritization maps can help emergency response personnel determine high-priority areas, making their search and rescue operations faster and more effective.
- All stakeholders, including the local government of Davao, non-government organizations, and emergency response organizations, can acquire input from GIS-based maps.
- GIS-based mapping can help plan and mitigate disaster impacts, which may reduce the residents' vulnerability to hazards and heightened safety and preparedness.
- Other studies that can be explored include procedures integrating ma chine learning algorithms for predictive analyses and analyzing the long-term significance of GIS tools on DRRM.

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