Enhancing Efficiency in Landslide Damage Assessment with Drone Technology

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Abstract: *Landslides are a major natural hazard in Sri Lanka, particularly during monsoon periods when heavy rainfall triggers numerous events. Approximately 52% of Sri Lanka's administrative districts are susceptible to landslides, affecting 30% of the land area (19,500 km²) and 38% of the total population (7.6 million people) across 13 of 25 districts. The activation of the Second Inter-Monsoon of 2023 led to increased rainfall in Badulla, Galle, Kegalle, Matara, and Ratnapura districts, resulting in five significant landslides that caused substantial damage to homes, agricultural land, and infrastructure, as well as four fatalities. To support effective post-disaster recovery, it is essential to rapidly assess the extent of these damages. This study employs a multi-phase approach to accurately and efficiently assess landslide damage. The initial phase involved identifying landslide locations and gathering preliminary data from local authorities, including details on damaged houses, fatalities, and injuries. A comprehensive field reconnaissance was then conducted to collect site-specific information. Drone surveys at each landslide site captured high-resolution aerial images, which were processed using Agisoft Metashape software to create orthomosaic images, digital surface models, and 3D models. These outputs facilitated the extraction of key information, including landslide boundaries, initiation points, and the extent of damage to property and infrastructure. Complementing the drone surveys, ground-based damage assessments provided a holistic understanding of the impact on property, agricultural land, and infrastructure. Data analysis, using both drone images and survey data, quantified damages, and applied unit costs to estimate economic losses, totaling LKR 160.1 million across all sectors. The study demonstrates that drone technology significantly enhances the efficiency and accuracy of damage assessments, reducing both time and resources compared to traditional methods. The findings underscore the value of drone technology in disaster management, providing timely and reliable data to inform recovery and reconstruction strategies. Recommendations include adopting drone technology for rapid damage assessment, investing in training for disaster management personnel, and integrating advanced technologies into disaster response frameworks.*

Keywords: Landslides, Rapid damage assessment, Drone technology, Second-inter monsoon

Introduction

Sri Lanka, an island nation distinguished by its varied topography and tropical environment, is becoming increasingly vulnerable to landslides, a natural hazard with extensive repercussions. The island's hilly topography, characterized by steep slopes and unstable geological formations in the central highlands, heightens vulnerability to landslides. The geological elements and tropical climate can induce weathering and erosion. Suboptimal land-use practices, including deforestation, mining, and cultivation on sloped terrains, exacerbate soil instability, resulting in an increased frequency of landslides. Furthermore, Sri Lanka's monsoonal climate and elevated precipitation, particularly in the central and southern regions, result in soil saturation and heightened pore water pressure, precipitating landslides that damage infrastructure, property, and life.

The Second Inter Monsoon period of 2023 underscored Sri Lanka's vulnerability to landslides, resulting in numerous occurrences that inflicted extensive damage. Heavy rainfall resulted in five large landslides in the districts of Badulla, Kegalle, Matara, and Ratnapura, causing severe damage to properties, agricultural land, and infrastructure, along with four fatalities.

Damage mapping is crucial for facilitating rapid emergency responses, such as aiding rescue, humanitarian, and rehabilitation efforts in affected regions. The regions impacted by the devastation must be recognized, and it is essential to ascertain which roads, railways, airports, and ports are operational for disaster assistance. It is equally essential for crisis response following a landslide event.

Conventional approaches to post-disaster evaluation frequently require laborious ground surveys, hindering rapid response and recovery efforts. Recent improvements in drone technology provide a viable option, facilitating swift data collecting and analysis. Drones can deliver critical information for evaluating damage severity, pinpointing impacted regions, and facilitating decision-making by acquiring high-resolution photography and topography data.

This study examines the utilization of drone technology to evaluate the effects of significant landslides that transpired in Sri Lanka during the Second Inter Monsoon of 2023. The research seeks to illustrate the effectiveness of drone-based data collecting in facilitating landslide emergency response and recovery operations through the analysis of case studies from impacted districts. Additionally, it aims to estimate the economic losses resulting from these landslides, supplying critical data for disaster risk mitigation and insurance applications.

The incorporation of drone technology into landslide catastrophe management presents numerous potential advantages. Expedited damage evaluation enables effective resource distribution, prioritizing of rescue operations, and prompt commencement of recovery strategies. Drone technology can substantially improve the resilience of communities impacted by landslides by closing the divide between disaster occurrence and response.

This study enhances the existing knowledge regarding the utilization of drones in disaster management. The study seeks to furnish actual evidence of the technology's efficacy in a practical setting, thereby guiding policymakers, disaster response organizations, and researchers in formulating and executing effective landslide risk mitigation plans. Ultimately, the results of this research will aid in establishing a more resilient Sri Lanka, proficient in addressing the issues presented by landslides.

Literature Review

A systematic literature review was conducted in line with PRISMA guidelines, ensuring a thorough and structured approach to identifying, selecting, and synthesizing relevant studies. A comprehensive search was performed across several databases, including Google Scholar, ScienceDirect, and IEEE Xplore, using keywords such as "drone technology", "landslide emergencies", "disaster management" and "damage assessment". The search focused on peer-reviewed articles published between 2010 and 2023, ensuring that the most recent and relevant studies were included. The review was limited to studies that specifically addressed the deployment of drone technology in landslide scenarios.

A landslide is the downward movement of rock, earth, or debris along a slope due to gravity, often triggered by natural events like heavy rainfall, earthquakes, or volcanic activity (Varnes, 1958). Landslides cause significant impacts, including loss of life, destruction of infrastructure, and disruption of communities (Schuster & Highland, 2001). They also lead to long-term environmental damage, altering landscapes and ecosystems, and can trigger secondary disasters such as flooding (Varnes, 1978).

Therefore, damage assessment of landslides is crucial for several reasons. First, it helps in quantifying the immediate impact on infrastructure, property, and human lives, providing essential data for emergency response and resource allocation (Wieczorek, 1996). Second, accurate damage assessments guide the planning of recovery and reconstruction efforts, ensuring that they are effective and targeted (Schuster & Highland, 2001). Third, damage assessments contribute to the long-term mitigation of landslide risks by identifying vulnerable areas and improving land-use planning and hazard zoning (Fell et al., 2005). Without thorough damage assessments, recovery efforts may be inefficient, and future risks may not be adequately addressed.

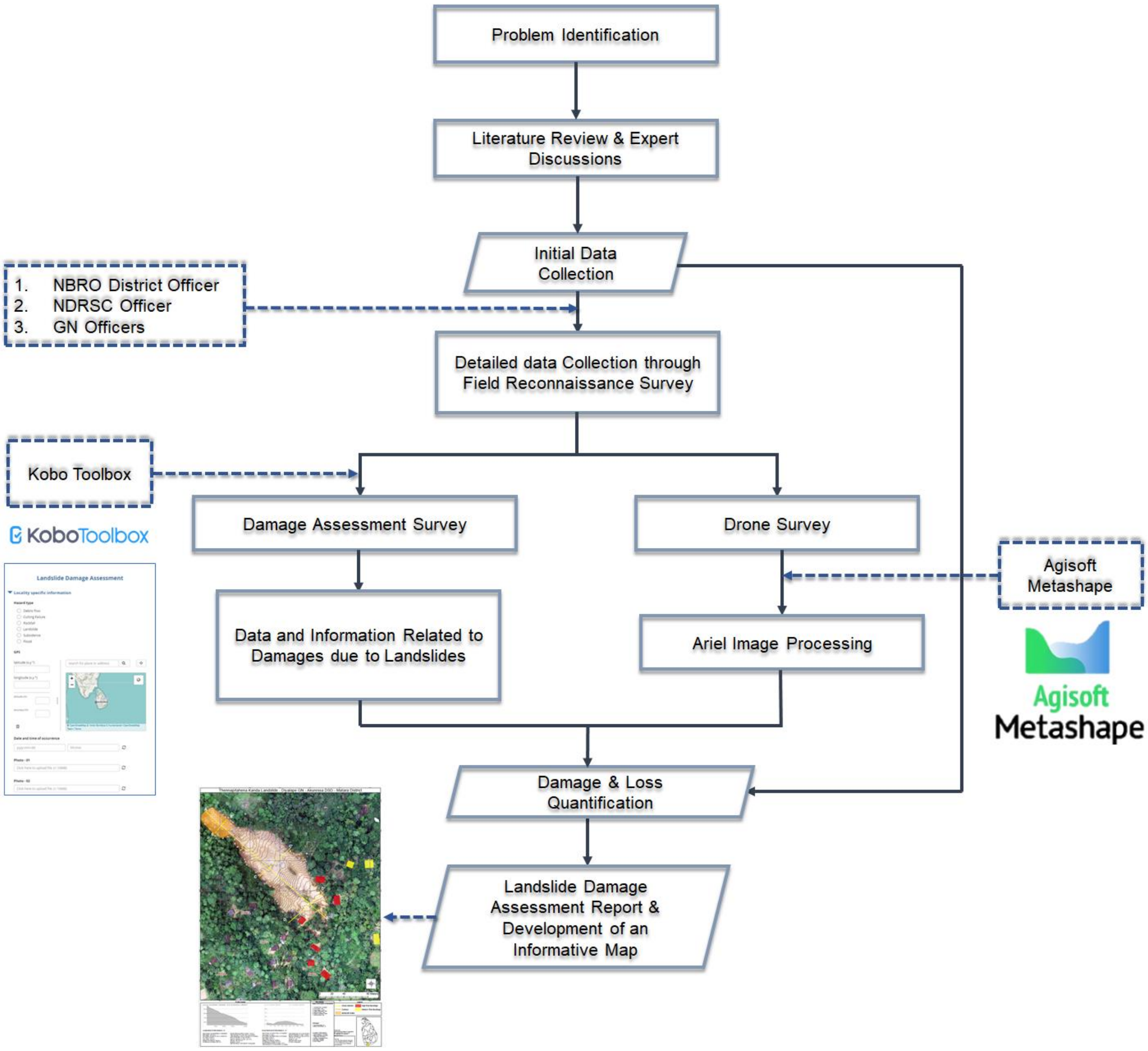
Traditional methods for landslide disaster damage assessments, include field surveys and visual inspections to manually assess and map landslides, photogrammetry using ground-based cameras for topographic mapping, geotechnical investigations to analyze soil and rock samples, and structural assessments to evaluate damaged infrastructure (Varnes, 1996; Guzzetti et al., 1999; Wolf & Dewitt, 2000). Additionally, interviews with local residents and historical data analysis provide insights into past landslide events, while Ground Penetrating Radar (GPR) is used to detect subsurface conditions (Keefer, 2002; Jol, 2009). These traditional techniques have formed the foundation of landslide assessments (Wieczorek, 1996).

Traditional landslide damage assessment methods are limited by their time-consuming and labor-intensive nature, often delaying critical responses (Varnes, 1958). They also suffer from limited accessibility in remote areas, subjectivity in visual inspections, and lower precision compared to modern technologies (Wieczorek, 1996; Guzzetti et al., 1999). Additionally, these methods struggle with large-scale assessments and data integration challenges, further hindering their effectiveness (Wolf & Dewitt, 2000; Jol, 2009). Hence, an advanced approach is required for rapid damage assessment on landslide disasters.

Landslide damage assessment methods using drone technology have revolutionized the field by offering rapid, high-resolution data collection and enhanced accessibility to hazardous or remote areas. Drones equipped with advanced sensors, such as LiDAR, multispectral, and thermal cameras, enable detailed topographic mapping, 3D modeling, and real-time monitoring of landslide-prone regions (Colomina & Molina, 2014). These technologies provide higher accuracy and efficiency compared to traditional methods, allowing for quick assessments and timely interventions (Giordan et al., 2017). Furthermore, Drones facilitate the integration of diverse datasets, improving the overall precision of landslide risk assessments and disaster management strategies.

Methodology

The methodology of this study obtains a systematic approach comprising six major steps to assess landslide damage and loss including problem identification, literature review and expert discussions, data collection, aerial image processing, damage and loss quantification and finally preparation of landslide damage assessment report and an informative map.



Source: Author

Figure 1: Research methodology

a. Problem Identification

During the monsoon and inter-monsoon periods, Sri Lanka experiences a significant increase in landslide incidents, which result in substantial damage and losses across various sectors, including property, agriculture, and infrastructure. According to reports from the National Building Research Organisation (NBRO), the landslides that occurred in May 2017 caused an estimated direct loss of LKR 1,077,672,218.72 (approximately LKR 1.08 billion) across the districts of Ratnapura, Kalutara, Kegalle, Galle, Matara, and Hambantota. This figure reflects the severe impact of landslides on the affected regions, underscoring the critical need for efficient assessment of damages to facilitate a timely and effective post-disaster recovery process. Current damage assessment methodologies, however, are often characterized by their time-consuming and resource-intensive nature (Varnes, 1958). These limitations can hinder the prompt evaluation and subsequent recovery efforts required in the aftermath of such disasters. Therefore, there is an urgent need to develop and implement rapid damage assessment techniques that can more effectively support post-disaster recovery processes by providing accurate and timely information on the extent of damage and losses.

b. Literature Review

A systematic literature review and expert discussions were undertaken to identify existing rapid damage assessment methodologies, the application of drone technology for damage assessment, and the most effective approaches for damage and loss quantification. These efforts also aimed to establish the key criteria for accurately assessing damage and loss. The primary criteria identified for damage and loss quantification include the following: the number of fatalities and injuries, the number of fully and partially damaged houses, the area of damaged homelands, and the area of damaged crops (including paddy, tea, rubber, coconut, and other crops). Additionally, the assessment criteria cover the area of damaged forest cover and the number of damaged social infrastructure facilities (such as hospitals, schools, and religious sites). For physical infrastructure, the criteria include the length of damaged assets, such as expressways, major and minor roads, gravel roads, railway lines, and networks for water supply, electricity, telecommunications, and sewerage systems.

c. Data Collection

Data collection of this research can be categorized into two main sections as initial data collection and detailed data collection.

The initial data collection was conducted by district officers from the National Building Research Organisation (NBRO), officers from the National Disaster Relief Services Centre (NDRSC), and Grama Niladhari (GN) officers. This phase focused on gathering basic information, including the location details of the affected areas, the number of fully and partially damaged houses, the number of fatalities, and the number of injuries reported.

The detailed data collection phase comprised two subsections: a damage assessment survey and drone surveys, both carried out through field visits. Building on the criteria identified through the systematic literature review, a comprehensive damage assessment survey questionnaire was developed using KoboToolbox (Figure 2). The questionnaire captured a wide range of damage indicators, including the number of fully and partially damaged houses, damage to homelands, damage to crops (such as paddy, tea, rubber, coconut, and other crops), damage to forest cover, and damage to social infrastructure (hospitals, schools, and religious sites). Additionally, the survey included assessments of damage to physical infrastructure, such as expressways, major and minor roads, gravel roads, railway lines, water supply networks, electricity networks, telecommunication networks, and sewerage systems. By employing these data collection methods, the research aims to provide a detailed and accurate quantification of damage and loss, which is essential for supporting efficient disaster response and recovery strategies.

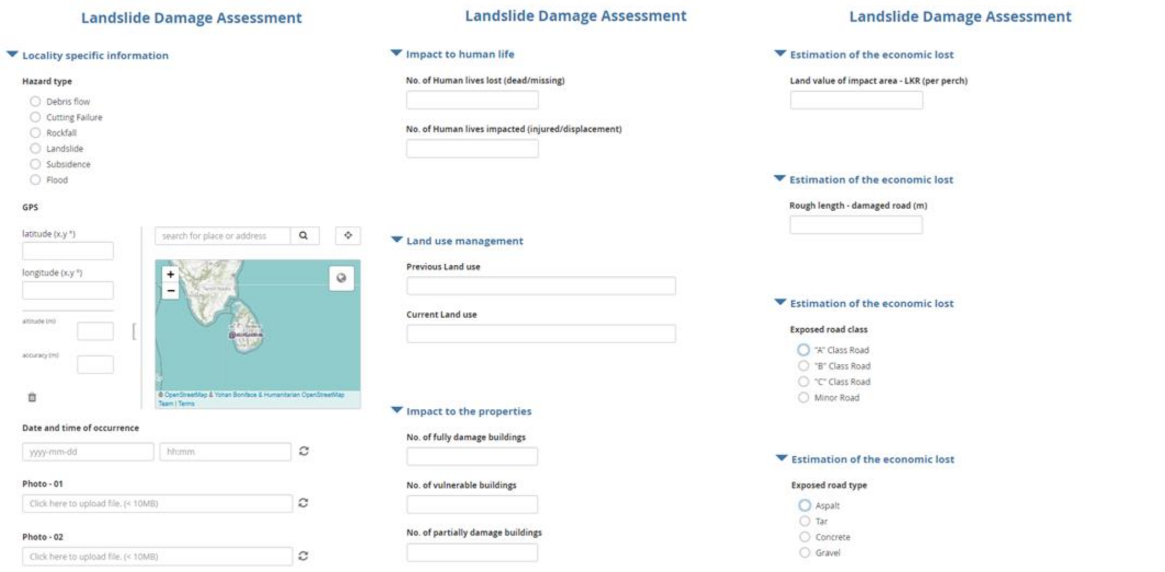


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Figure 2: Damage assessment survey questionnaire

A drone survey was conducted at each landslide site to obtain aerial imagery and gather additional information on the affected land areas. The drone survey facilitated the creation of detailed three-dimensional (3D) models, extraction of topographic contours, and development of cross-sections of the terrain. It also enabled the precise identification of landslide initiation areas, delineation of landslide boundaries, and extraction of building footprints for fully and partially damaged houses. Moreover, the survey was instrumental in identifying vulnerable buildings and categorizing them based on risk levels as high, medium, or low risk.

Source: Author

Figure 3: Drone flight plan

d. Ariel Image Processing

Following the drone survey, the captured images were processed using Agisoft Metashape software to produce several key outputs, including an orthomosaic image of the site, a digital surface model (Figure 7), and a three-dimensional (3D) model (Figure 6). These outputs were critical for further analysis and were utilized to extract topographic contours, develop cross-sections of the terrain (Figure 8), identify the landslide initiation area, and delineate the landslide boundary. Additionally, the processed images were used to extract building footprints of fully damaged houses and to assess and categorize vulnerable buildings based on their risk levels—high, medium, or low.

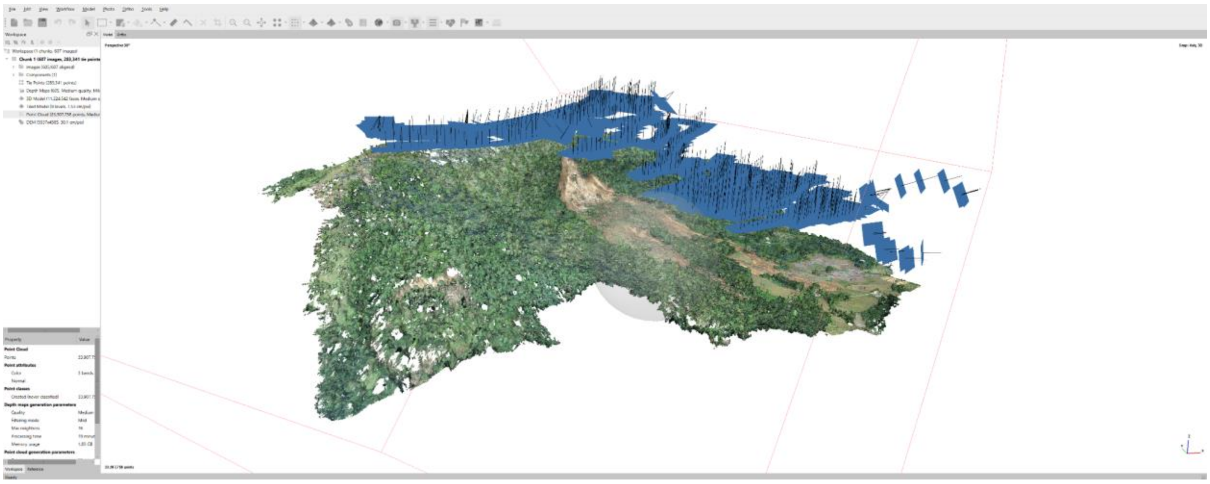

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Figure 4: Locations of captured images - Kelipanawela landslide

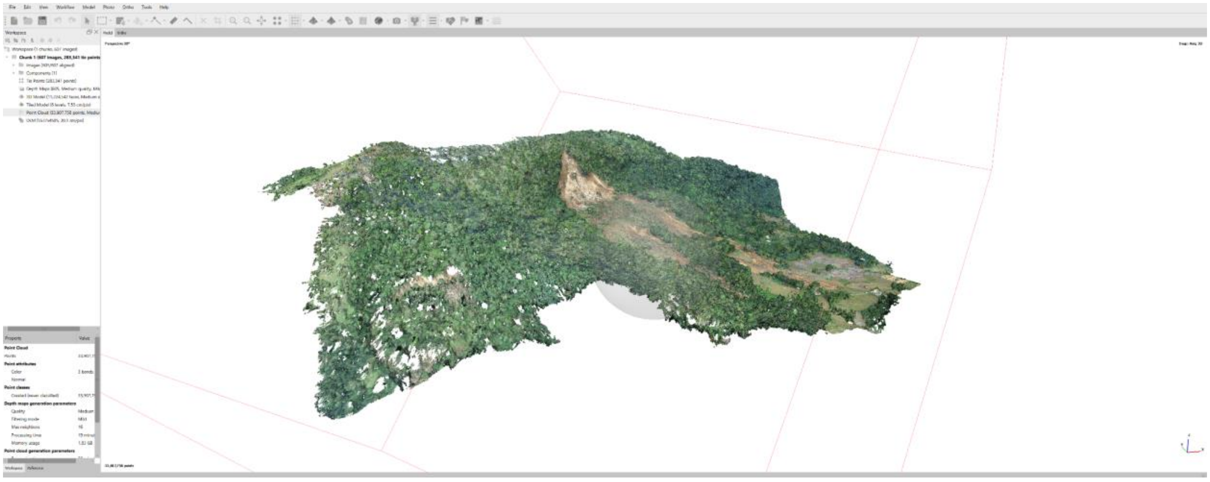

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Figure 5: Point cloud - Kelipanawela landslide

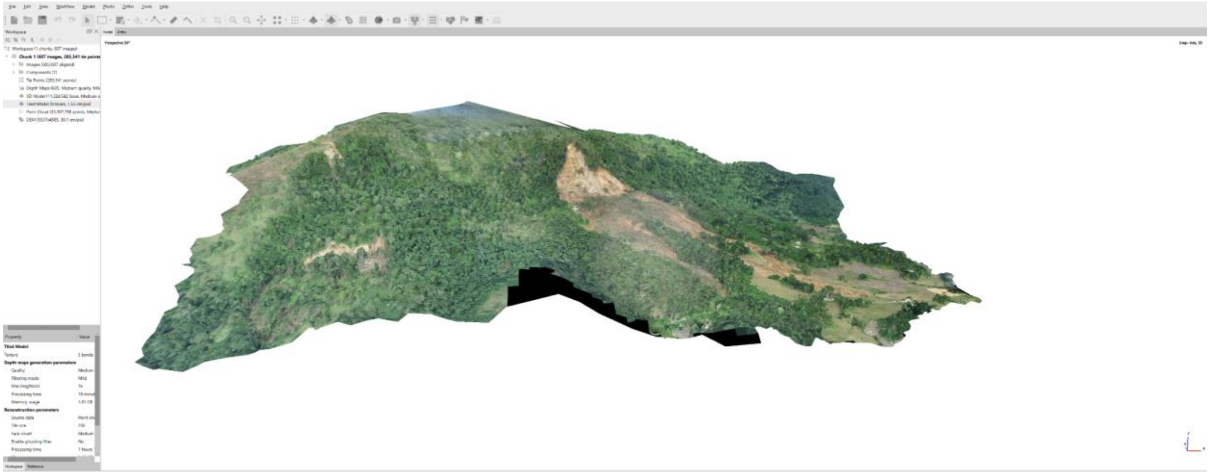

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Figure 6: 3D model - Kelipanawela landslide

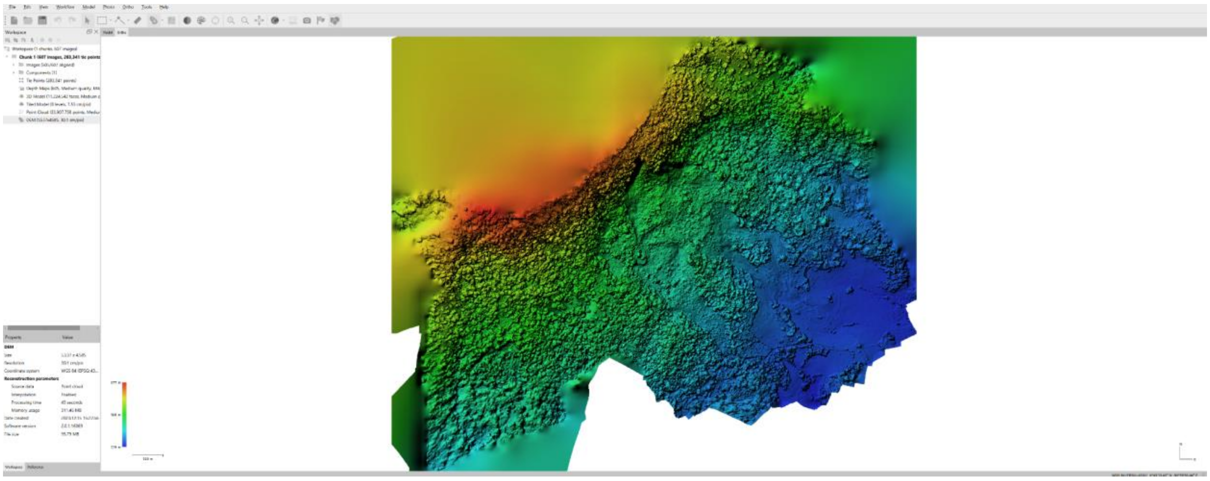

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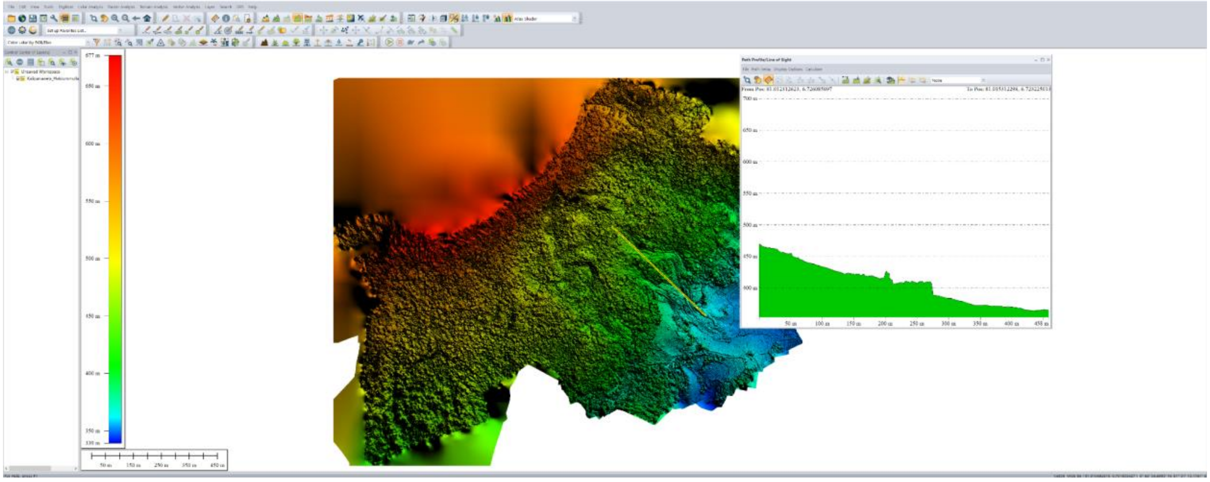
Figure 7: Digital surface model (DSM) - Kelipanawela landslide



Source: Author

Figure 8: Cross section - Kelipanawela landslide

e. Damage and Loss Quantification

The areas of fully and partially damaged houses, damaged homelands, damaged crops (including paddy, tea, rubber, coconut, and other types), damaged forest cover, and damaged social infrastructure (such as hospitals, schools, and religious sites) were measured using the processed orthomosaic images and data obtained from the developed damage assessment survey questionnaire. Similarly, the lengths of damaged physical infrastructure—comprising expressways, major roads, minor roads, gravel roads, railway lines, water supply networks, electricity networks, telecommunication networks, and sewerage systems—were also quantified. Subsequently, the unit costs associated with the measured areas and lengths of the above criteria were calculated as outlined in table 1.

Table 1: Cost calculations for damaged properties

Damaged Property	**Unit**	**Cost quantification method**
Damaged houses, partially damaged houses	sqm	Construction cost per sqm
Damaged homelands	perch	Land value of the area
Damaged crops	ha	Cost of crop cultivation can be produced per ha
Damaged forest	ha	Land value of the area
Damaged social infrastructure	sqm	Construction cost per sqm
Damaged physical infrastructure	m	Construction cost per m

Source: Author

The total damage and loss were quantified by multiplying the unit costs by the respective measurements of actual damages. This approach allowed for a precise calculation of the economic impact across various affected sectors, based on the established criteria.

f. Preparation of Landslide Damage Assessment Report and an Informative Map

The final output of this research included a comprehensive damage assessment report and an informative map. The report provides detailed information on the location of each landslide incident, along with fundamental characteristics of the landslides, such as the crown, boundary, initiation points, and cross-sections. It also presents an analysis of the damage caused, including the quantified losses and damages, as well as the identification of vulnerable buildings. Additionally, the report features an informative map that consolidates all the gathered data, offering a visual representation of the findings (Figure 9).

Results and Discussion

The activation of the Second Inter-Monsoon of 2023 led to increased rainfall in specific areas within the Badulla, Galle, Kegalle, Matara, and Ratnapura districts. This heavy rainfall triggered five significant landslides across the districts of Badulla, Kegalle, Matara, and Ratnapura. Table 2 presents the basic details of these reported landslide incidents.

Table 2: Basic details of reported landslide incidents

Landslide	**District**	**DSD**	**No. of deaths**	**No. of damaged buildings**		**Crop damage (ha)**
				fully	**partially**	
Gawarahena landslide	Ratnapura	Balangoda	4	2	-	4.4
Bellankanda landslide	Ratnapura	Kalthota	-	-	2	-
Kelipanawela landslide	Badulla	Haldummulla	-	6	-	16.55
Ambalapitiya landslide	Kegalle	Aranayake	-	-	-	1.3
Thennapitahenakanda landslide	Matara	Akuressa	-	-	3	1.45

Source: Author

Based on the information collected for the landslide loss and damage assessment, a total of four fatalities were reported in the landslide-affected areas. The overall damage to property and crops, as recorded for the landslides detailed in table 2, amounted to LKR 160.1 million.

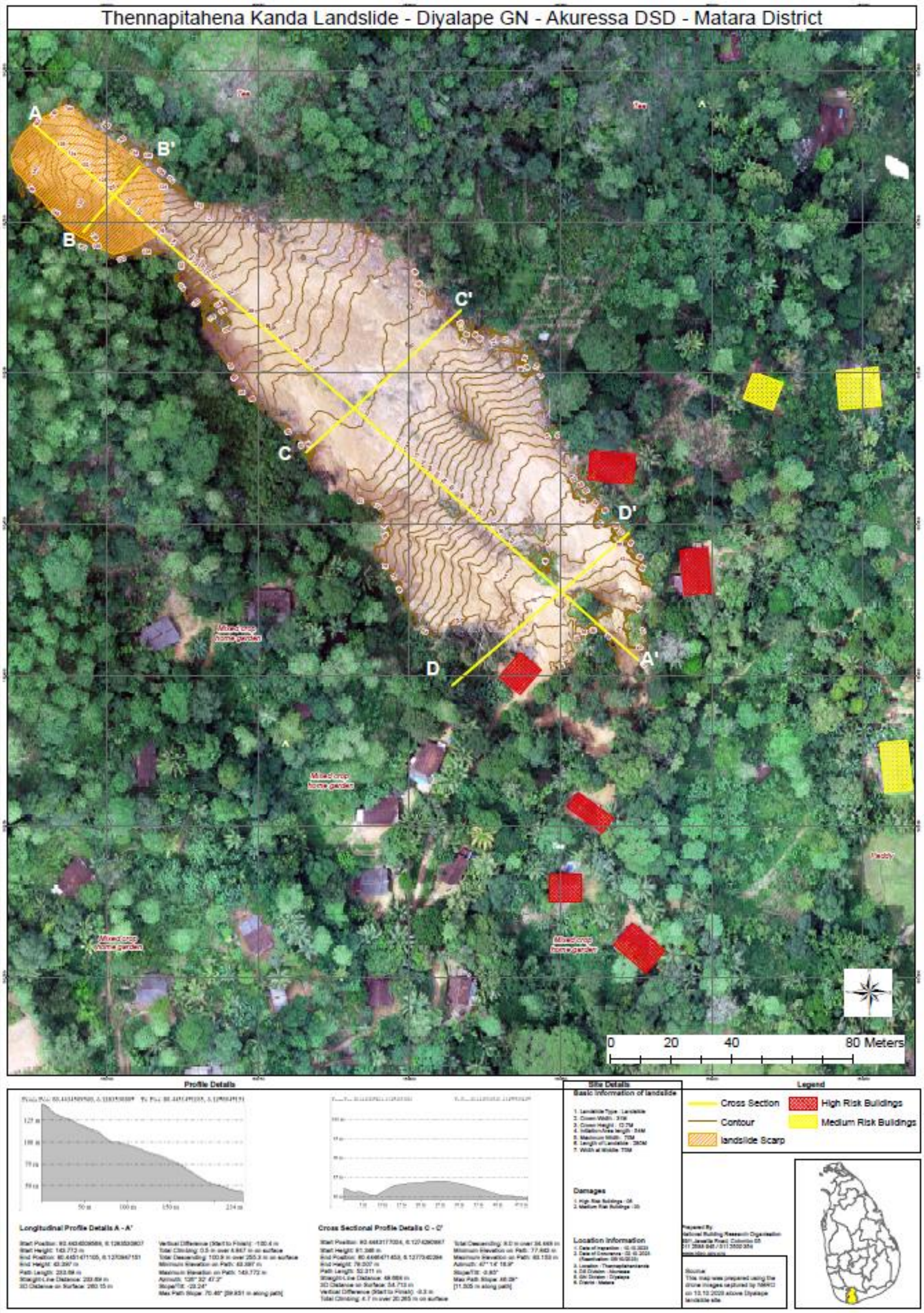
A detailed analysis of the damages to property and crops is presented in table 3.

Table 3: Detail analysis on property and crop damages

Landslide	**Property loss (LKR)**	**Crop loss (LKR)**	**Environment loss (LKR)**
Gawarahena landslide	1,584,800.00	509,400.00	10,414,400.00
Bellankanda landslide	1,584,800.00	NA	4,426,120.00
Kelipanawela landslide	44,572,500.00	2,396,090.25	37,231,480.00
Ambalapitiya landslide	NA	492,420.00	2,863,960.00
Thennapitahenakanda landslide	22,286,250.00	382,050.00	3,384,680.00

Source: Author

An informative map was produced for each landslide incident by incorporating all the relevant information (Figure 9).



Source: Author

Figure 9: Informative landslide incident map for Thennapitahenakanda landslide

Conclusion and Recommendation

This research underscores the significant potential of drone technology in conducting rapid damage assessments for landslide incidents. Through a systematic approach combining initial and detailed data collection, including drone surveys, this study demonstrates that drones can serve as an effective and efficient tool for gathering critical data on landslide-affected areas. The deployment of drones enabled the creation of high-resolution orthomosaic images, 3D models, and digital surface models, which facilitated the precise identification of landslide boundaries, the extent of damage, and the classification of vulnerable buildings based on their risk levels. Compared to traditional damage assessment methods (table 5), which are often time-consuming and resource-intensive, the use of drones increased the speed of data collection by 80% thereby enhancing the overall efficiency of the assessment process.

Table 5: Comparison of data collection

Method	**Human resource (no of people)**	**Time (no of days)**	**Financial requirement (LKR)**
Traditional methods (by field surveys)	5	1	39,000.00
Utilizing drones	2	1/2	7,800.00

Source: Author

The findings also highlight that drone technology can significantly reduce the time required for data processing and analysis, providing timely and accurate information essential for informed decision-making during disaster response and recovery efforts. The quantitative analysis revealed that the integration of drone technology reduced the assessment time from weeks to just a few days, with a cost reduction of approximately 60%. This efficiency gain underscores the value of drones as a complementary tool to traditional methods, particularly in challenging terrains where ground access is limited or hazardous.

Based on the findings of this research, several recommendations are proposed:

1. Adopt Drone Technology as a Standard Tool for Rapid Damage Assessment: Relevant authorities, such as disaster management agencies and local governments, should consider incorporating drone technology into their standard operating procedures for rapid damage assessments. This adoption could enhance the speed and accuracy of data collection and improve the overall effectiveness of disaster response strategies.
2. Invest in Capacity Building and Training: To maximize the benefits of drone technology, there should be targeted investments in capacity building and training

for personnel involved in disaster management. Training programs should focus on drone operation, data analysis, and interpretation to ensure that the technology is used effectively and efficiently in real-world scenarios.

3. Develop Integrated Assessment Frameworks: Future studies should aim to develop integrated assessment frameworks that combine drone-based data collection with other advanced technologies, such as Geographic Information Systems (GIS) and remote sensing, to further enhance the accuracy and comprehensiveness of damage assessments.
4. Encourage Continuous Technological Advancements: Ongoing research and development efforts should be encouraged to refine drone technology and its applications in disaster management. Innovations such as automated data processing algorithms and machine learning techniques could further streamline the damage assessment process and provide even more rapid and reliable results.

By implementing these recommendations, stakeholders can leverage the advantages of drone technology to improve rapid damage assessments and enhance disaster preparedness and response in landslide-prone areas.

References

1. Perera, E. N. C., Jayawardana, D. T., Ranagalage, M., Dissanayake, D. M. S. L. B., & Wijenayaka, H. M. D. S. (2020). Introduce a framework for landslide risk assessment using geospatial analysis: a case study from Kegalle District, Sri Lanka. Modeling Earth Systems and Environment, 6, 2415-2431.
2. Varnes, D. J. (1958). Landslide types and processes. Landslides and engineering practice, 24, 20-47.
3. Schuster, R. L., & Highland, L. M. (2001). Socioeconomic and environmental impacts of landslides in the western hemisphere (No. 2001-276)
4. Varnes, D. J. (1978). Slope movement types and processes. Special report, 176, 11-33
5. Wieczorek, G. F. (1996). Landslides: investigation and mitigation. Chapter 4-Landslide triggering mechanisms. Transportation Research Board Special Report, (247)
6. Fell, R., Ho, K. K., Lacasse, S., & Leroi, E. (2005). A framework for landslide risk assessment and management. In Landslide risk management (pp. 13-36). CRC Press
7. Guzzetti, F., Carrara, A., Cardinali, M., & Reichenbach, P. (1999). Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy. Geomorphology, 31(1-4), 181-216
8. DeWitt B. A., & Wolf, P. R. (2000). Elements of Photogrammetry (with Applications in GIS). McGraw-Hill Higher Education

9. Keefer, D. K. (2002). Investigating landslides caused by earthquakes–a historical review. Surveys in geophysics, 23, 473-510
10. Jol, H. M. (Ed.). (2008). Ground penetrating radar theory and applications. elsevier
11. Colomina, I., & Molina, P. (2014). Unmanned aerial systems for photogrammetry and remote sensing: A review. ISPRS Journal of photogrammetry and remote sensing, 92, 79-97
12. Giordan, D., Manconi, A., Remondino, F., & Nex, F. (2017). Use of unmanned aerial vehicles in monitoring application and management of natural hazards. Geomatics, Natural Hazards and Risk, 8(1), 1-4
13. CIC Institute of agribusiness. (November 2010), Cost of production for selected vegetables, pulses and grains. Handbook, Department of Agriculture
14. Ministry of Mega Polis and Western Development and NBRO (2016), Consultancy services for conducting a detailed flood risk assessment for Colombo metropolitan region
15. Petrucci, O. & Gullà, G., (2009). A simplified method for assessing landslide damage indices. Natural Hazards, 52(3), pp.539–560.
16. Priyantha, N.A.A (2010). "Guidelines for construction of low volume concrete roads in Sri Lanka" MS thesis, Department of Civil Engineering, University of Moratuwa.
17. R.L. Senanayake, U.R. Sangakkara, D.K.N.G. Pushpakumara and P. Stamp (2009), Vegetation Composition and Ecological Benefits of Home Gardens in the Meegahakiula Region of Sri Lanka. Tropical Agricultural Research Vol. 21
18. Zwęgliński, T. (2020). The use of drones in disaster aerial needs reconnaissance and damage assessment–three-dimensional modeling and orthophoto map study. Sustainability, 12(15), 6080.
19. Greenwood, F., Nelson, E. L., & Greenough, P. G. (2020). Flying into the hurricane: A case study of UAV use in damage assessment during the 2017 hurricanes in Texas and Florida. PLoS one, 15(2), e0227808.
20. Restas, A. (2015). Drone applications for supporting disaster management. World Journal of Engineering and Technology, 3(3), 316-321.
21. Hanifa, N. R., Gunawan, E., Firmansyah, S., Faizal, L., Retnowati, D. A., Pradipta, G. C., ... & Lassa, J. A. (2022). Unmanned Aerial Vehicles for geospatial mapping of damage assessment: A study case of the 2021 Mw 6.2 Mamuju-Majene, Indonesia, earthquake during the coronavirus disease 2019 (COVID-19) pandemic. *Remote Sensing Applications: Society and Environment*, 28, 100830.
22. Whitehurst, D., Joshi, K., Kochersberger, K., & Weeks, J. (2022). Post-flood analysis for damage and restoration assessment using drone imagery. *Remote Sensing*, 14(19), 4952.