Damage assessment of Libya 2023 floods using Object-based and Pixel-based classifications

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Abstract

On September 11, 2023 the city of Derna in Libya experienced catastrophic flooding due to heavy rains from storm Daniel, The collapse of two dams led to widespread city flooding, causing extensive damage and loss of lives. This study employs a remote sensing approach, incorporating different methods, such as object-based image analysis (OBIA), pixel-based classification, and change detection, to assess flood damage in the city of Derna in the aftermath of Storm Daniel. The analysis focuses on post-flood changes in land cover classes, including built-up areas, roads, vegetation, bareland, and water bodies. Quantitative analysis revealed 111,400 m^2 of land cover alterations, with 30,350 m^2 of roads submerged in waterbodies—the most severely impacted infrastructure. Thematic maps and statistics (e.g., 19,624 m^2 of built-up areas submerged) provide actionable insights for prioritizing recovery efforts. This research provides valuable insights for decision-makers focusing on resilient urban recovery efforts. Using remote sensing, the study assessed damages to key urban elements, including residential structures, transportation networks, and vegetation cover. The findings highlight the widespread devastation caused by the floods, with roads and buildings identified as the most severely impacted infrastructure. The study's recommendations aim to support local and national governments in effectively allocating resources for both structural and non-structural flood mitigation strategies.

1. Introduction

1.1 Background and Rationale

On September 11, 2023, the coastal city of Derna, Libya, was devastated by severe flooding caused by Storm Daniel. Heavy rainfall exceeding 400 mm in 24 hours resulted in the collapse of two upstream dams, flooding the city, destroying infrastructure, and leading to a catastrophic loss of life. Preliminary estimates indicate over 10,000 fatalities, with extensive destruction of buildings and road networks.

Flooding has historically been one of the most destructive natural disasters, particularly in regions with vulnerable infrastructure and limited disaster preparedness. Coastal cities like Derna, situated at the confluence of mountainous terrain and the Mediterranean Sea, are uniquely exposed to extreme hydrological events. The failure of the upstream dams not only intensified the flooding but also highlighted weaknesses in structural resilience and urban planning. Understanding the full extent of such disasters requires rapid assessment methodologies that go beyond conventional field surveys.

Traditional ground-based damage assessments, while valuable, are often impractical in the immediate aftermath of large-scale disasters due to accessibility challenges and the time required for data collection. Consequently, remote sensing technologies have emerged as essential tools for rapid damage assessment, enabling near-real-time detection of affected areas and facilitating post-event mapping for effective emergency response, recovery planning, and informed decision-making. The application of satellite-based remote sensing allows for large-scale damage assessments, offering high-resolution insights that are crucial for governments, relief agencies, and urban planners in mitigating future risks.

1.2 Novelty and Research Objectives

Remote sensing-based flood damage assessment has been widely studied, with various methodologies applied to different geographic regions. Hussain et al. (2009) used Landsat imagery and object-based classification for flood damage assessment in Indiana, USA, while Zawadzka et al. (2021) integrated UAV imagery and tree-based classifiers to map flood impacts in urban European environments. Additionally, Matsuoka & Yamazaki (2004) employed remote sensing techniques to assess post-disaster building damage in Japan, focusing on structural collapse analysis. These studies emphasize the growing use of OBIA for disaster assessment.

Despite these advancements, few comparative studies have evaluated OBIA and pixel-based classification for flood damage assessment in North African urban environments. Most studies have focused on North America, Europe, and Asia, leaving a geographic gap in flood assessment applications for arid and semi-arid regions like Libya. Given Derna’s unique coastal and mountainous terrain, evaluating flood damage in such an environment presents new challenges, particularly in distinguishing flood-induced land cover changes from pre-existing landscape variations.

This study aims to fill these gaps by: (1) comparing OBIA and pixel-based classification in flood damage assessment for an urban, coastal, and semi-arid region; (2) providing insights into how geographic context influences classification performance, particularly in regions where terrain complexity, sparse vegetation, and urban infrastructure affect land cover differentiation; and (3) delivering a case study of flood-induced land cover changes in Derna, Libya, contributing to the global database of flood assessments. By addressing these issues, the research enhances discussions on optimal remote sensing methodologies for post-disaster assessments, particularly in regions where extreme flooding is an increasing threat.

2. Materials and Methods

2.1 Study Area

Derna, located at approximately 32°45′49″N, 22°38′10″E, is bounded by the Jebel Akhdar range and the Mediterranean Sea to the north. The city has an average elevation of about 65.5 meters and a population of roughly 100,000, based on data from recent topographic surveys and census reports.

the city’s topography and coastal setting expose it to flash floods and coastal storms figure (1) showcases the area of our study.

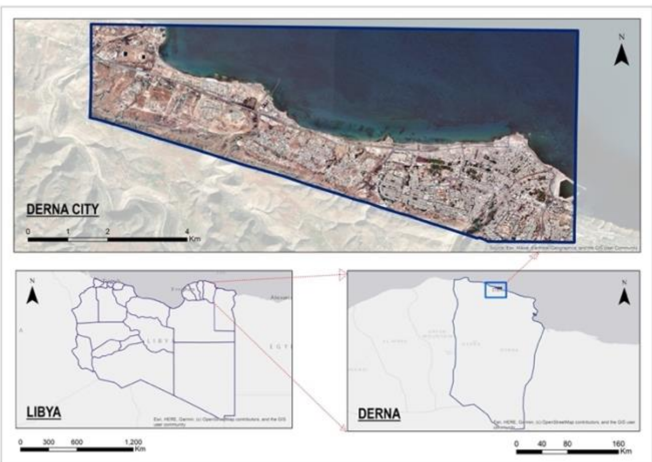

Figure 1. Study Area

2.2 Datasets

The first step was to acquire images of the study area before and after the occurrence of the event in September 2023. Pre-flood imagery from the GeoEye-1 satellite (1.65-meter spatial resolution, multispectral bands) was acquired on July 15, 2023, providing baseline land cover conditions. Post-flood imagery was captured on September 13, 2023, 48 hours after the dam collapse, to assess flood impacts. GeoEye-1’s 3-day revisit cycle ensured minimal temporal gaps. © MAXAR Technologies, 2023. The satellite imagery used in this study is provided under the MAXAR Open Data Program. The program offers freely accessible high-resolution satellite imagery for disaster response, environmental monitoring, and humanitarian research, supporting global efforts in crisis management and scientific studies.

2.3 Methodology

A hybrid classification approach was implemented, leveraging object-based image analysis (OBIA) and pixel-based classification to systematically assess flood-induced land cover changes.

The methodology follows a structured sequence comprising data acquisition, preprocessing, classification, change detection, and final damage assessment calculations.

Data acquisition involved obtaining high-resolution satellite imagery for both pre and post-flood conditions. Preprocessing included radiometric and geometric corrections to enhance image quality.

Classification was performed using OBIA and pixel-based techniques to categorize land cover types. Change detection was applied to analyze differences between the pre and post-flood datasets, identifying flood-impacted areas. Finally, damage assessment calculations quantified the extent of infrastructure loss, focusing on affected roads, buildings, and vegetation. to ensure a comprehensive evaluation of the flood's impact. The methodological workflow, depicted in Figure 2,

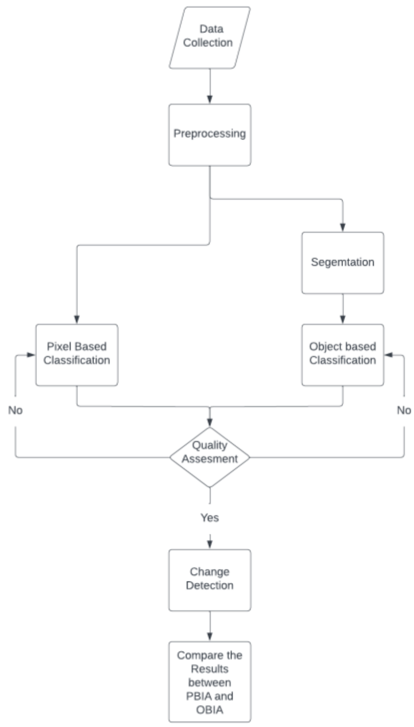

Figure 2. Methodology Workflow

The OBIA framework was implemented using a segmentation process, which grouped pixels into homogeneous objects based on spectral and spatial characteristics. A total of 100 training samples per class were selected to perform a supervised OBIA classification. In contrast, pixel-based classification involved manually selecting representative training data and applying a Maximum Likelihood Algorithm (MLA) to classify pixels into predefined land cover categories. The study classified land cover into five primary categories: built-up areas, roads, vegetation, Bareland, and water bodies.

To analyze flood-induced land cover transformations, various change detection techniques were applied to OBIA and pixel-based classification results. Since Pixel-based classification processes vector data, the intersect tool was utilized to link pre-flood and post-flood features in a structured table using SQL-based expressions. Meanwhile, the OBIA relied on raster-based analysis, employing the built-in change detection tool in ArcGIS Pro to compare pre and post-flood conditions. The results from both methods were then compared, highlighting the strengths of each approach: OBIA’s ability to accurately define object boundaries and pixel-based classification’s ability to detect subtle spectral variations. By integrating these approaches, the classification process minimized misclassification errors and improved the accuracy of change detection.

Using Unique symbologies provided enhanced visualization capabilities by allowing classification results to be displayed with customized color schemes and symbolization, making it easier to interpret spatial patterns and flood impact areas, the classified change detection results were organized into key transitions to highlight the most significant flood impact zones, including Built-up to Bareland, Built-up to Water body, Roads to Bareland, Roads to Water body, Vegetation to Bareland, Vegetation to Water body, Bareland to Others, Water body to Others, and No change. The combined OBIA and pixel-based analysis allowed for a more refined assessment of how different land cover types were affected by flooding, ensuring a higher level of detail in the spatial representation of damage.

To quantify the flood impact, post-classification analysis measured the extent of land cover changes and was validated using an accuracy assessment approach. A confusion matrix was generated to compare classified results with ground truth data, using equalized stratified random sampling to ensure representative accuracy assessment points, calculating key metrics such as overall accuracy, user’s accuracy, producer’s accuracy, and the kappa coefficient. This ensured the reliability of the classification outcomes and minimized potential misclassification errors. between the pre-flood and post-flood imagery. This involved calculating the area of damaged buildings and the percentage of affected roads to provide a spatially explicit assessment of the flood’s destruction in Derna. The comparison between OBIA and pixel-based classification provided an evaluation of urban and environmental damage, offering insights that can support future risk mitigation and disaster response strategies.

3. Results

The results of the flood damage assessment are presented based on the two classification approaches: Pixel-Based Classification and Object-Based Image Analysis (OBIA). Each approach was used to detect land cover changes and evaluate the extent of flood impact. The classification accuracy and identified transitions are detailed below.

3.1 Pixel-based Results

Pixel-based classification was applied to identify land cover changes using a Maximum Likelihood Algorithm (MLA) on pre and post-flood satellite imagery. The classification process detected significant changes in urban infrastructure, vegetation, and roads, as illustrated in Figure 3 below.

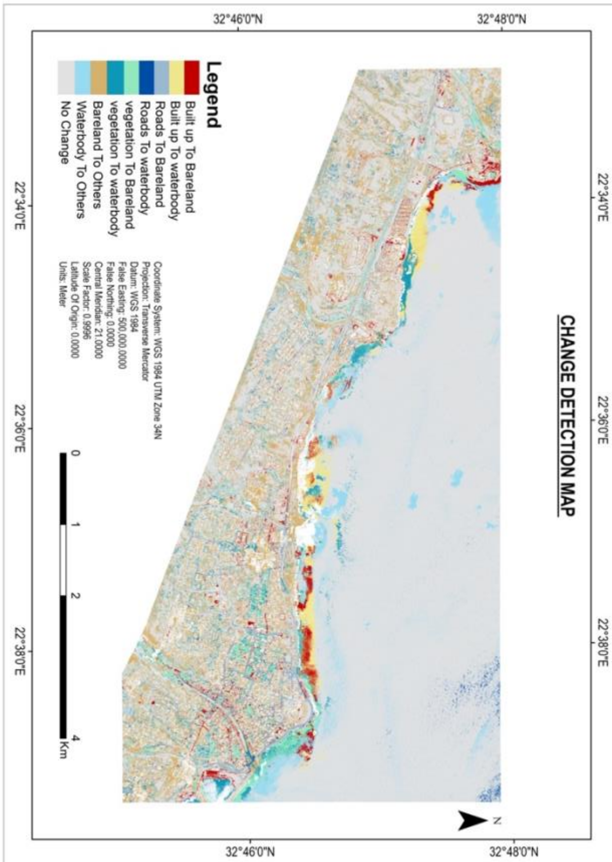

Figure 3. Change Detection Based on Pixel-Based Classification

A confusion matrix was used to assess the accuracy of this method, resulting in an overall classification accuracy of 46%. The primary limitations of the pixel-based approach stem from its reliance on spectral information alone, which can lead to misclassification of mixed pixels and reduced precision in delineating object boundaries, particularly in dense urban areas and arid environments where spectral similarities can cause misclassification errors.

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3.2 OBIA Results

Object-Based Image Analysis (OBIA) was employed to improve the accuracy of change detection by incorporating spatial and contextual information alongside spectral characteristics. The segmentation process allowed for a more precise identification of flood-affected areas, as illustrated in Figure 4 below.

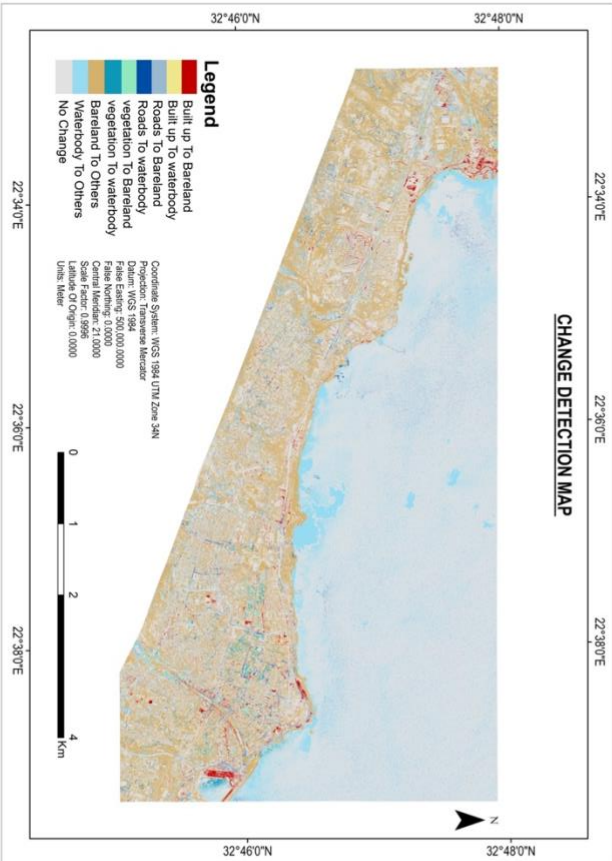

Figure 4. Change Detection Based on (OBIA) Classification

To further illustrate the impact on critical infrastructure, a zoomed-in view of a specific area is provided in Figure 5. This area was chosen due to its strategic importance in urban connectivity, as it highlights a bridge where Roads class features transitioned to Waterbody class, indicating severe structural failure. Bridges are critical for emergency response and post-disaster recovery, making their failure a significant concern for urban resilience planning.

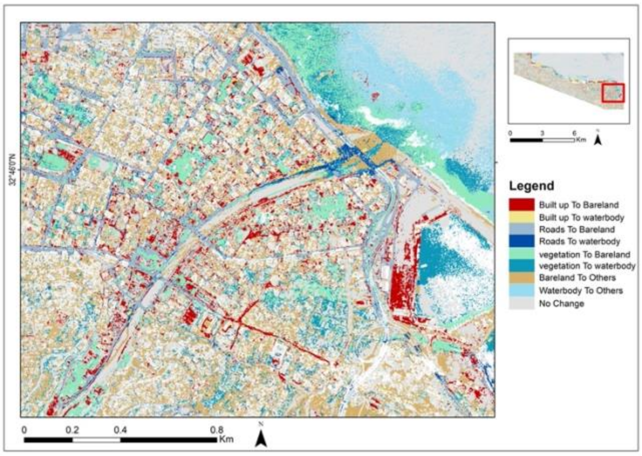

Figure 5. Zoomed-In View of Roads to Waterbody Class Change on a Bridge

3.3 Quantification of Flood Damage

The flood damage assessment reveals significant land cover transitions, with roads suffering the highest impact, with over 30,000 m² submerged, and vegetation loss affecting more than 23,000 m². Figure 6 illustrates the total flood damage area categorized by land cover transition, highlighting the scale of destruction.

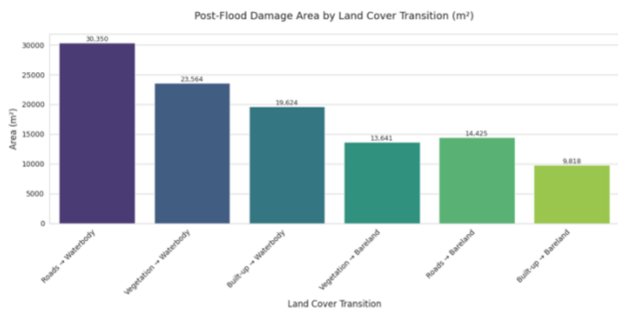

Figure 6. Post-Flood Damage Area by Land Cover Transition

The conversion of roads to water bodies represents the most extensive damage, indicating severe infrastructure failure and transportation network disruption. This suggests that bridges and main roadways in low-lying areas were highly vulnerable, leading to connectivity loss and hindering disaster response efforts. Such disruptions have long-term economic consequences, delaying reconstruction and affecting daily mobility.

The loss of critical road networks obstructs supply chain operations, restricting the movement of goods and services essential for local economies. Emergency response efforts are also hindered, delaying medical aid and evacuation procedures. Additionally, the destruction of transportation infrastructure can

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increase long-term economic instability, as businesses struggle to regain access to markets, and residents face difficulties commuting to work or relocating to safer areas.

A comparison of class change percentages demonstrates that roads experienced the highest percentage of transformation into water bodies, while vegetation showed a significant shift toward both water bodies and Bareland, as illustrated in Figure 7.

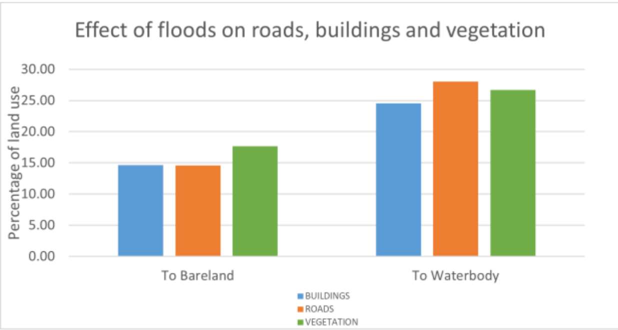

Figure 7. Effect of Floods on Roads, Buildings, and Vegetation

4. Conclusion

This study assessed the flood damage in Derna, Libya, using a comparative analysis of Object-Based Image Analysis (OBIA) and pixel-based classification. The results demonstrated that OBIA outperformed pixel-based classification in identifying flood-affected areas, with a higher accuracy of 62% compared to 46%. This improvement can be attributed to OBIA's ability to incorporate spatial and contextual information, enabling more precise object boundary detection and reducing spectral confusion, which are common challenges in pixel-based classification. The findings highlighted that roads and vegetation were the most impacted land cover types, with significant portions submerged or converted into Bareland.

The integration of remote sensing techniques and change detection analysis provided valuable insights into the spatial extent and severity of flood-induced damage. The transition of built-up areas to water bodies underscored the direct impact on urban infrastructure, emphasizing the need for improved flood resilience strategies in vulnerable regions. Additionally, the study confirmed that OBIA's ability to incorporate spatial and contextual information resulted in more precise delineation of affected areas compared to pixel-based classification.

While the study demonstrated the effectiveness of OBIA over pixel-based classification, the accuracy of both methods could potentially be improved by incorporating a larger set of training samples. Increasing the number of training samples would enhance the classification process by reducing misclassification errors, improving differentiation between similar land cover types, and strengthening the model's ability to generalize across varied flood-affected landscapes. Due to time constraints, extensive sample refinement was not feasible. Future studies with a longer timeframe could enhance classification precision by optimizing training data selection and incorporating additional ground truth validation.

These findings have important implications for post-disaster recovery planning, enabling authorities to prioritize infrastructure restoration and urban resilience measures. Future research could explore the use of deep learning models to further enhance classification accuracy and automate flood impact assessments.

By leveraging high-resolution remote sensing and advanced classification methods, this study contributes to the broader discourse on disaster management and rapid damage assessment in arid and coastal environments like Derna, Libya, where flooding poses a recurrent threat. The findings can aid policymakers and emergency response teams in designing more effective flood mitigation strategies, improving resource allocation for disaster recovery, and enhancing early warning systems to minimize future flood risks. The findings reinforce the need for continued advancements in geospatial analysis to support effective decision-making in flood-prone urban areas.

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