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Impacts of Floods on Urban Settlements and the Adjacent Marine Environment: Evidence from Derna City

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تأثير الفيضانات على التجمعات الحضرية والبيئة البحرية المجاورة: أدلة من مدينة درنة

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Abstract:
Floods are among the most lethal natural calamities, both for coastal urban areas and marine ecosystems. In September 2023, Derna city in Libya was hit by catastrophic flooding caused by Storm Daniel, registering immense human and material losses, as well as drastic environmental change to the adjacent marine ecosystem. This study discusses the impacts of flooding on marine environment and urban infrastructure in Derna City based on official reports, previous studies, satellite imagery, and post-disaster survey. It presents the degradation of infrastructure, increased coastal pollution, water quality fluctuation, and damage to marine habitats along the mouth of Wadi Derna. Recommendations are coastal disaster risk management plans and regular monitoring of flood impacts on the marine environment.

Keywords: Derna Flood, Storm Daniel, Failure of urban infrastructure, Marine, Environmental impact, Satellite imagery analysis.

الملخص:
تُعتبر الفيضانات من أخطر الكوارث الطبيعية، سواء بالنسبة للمدن الساحلية أو للنظم البيئية البحرية. في سبتمبر 2023، تعرضت مدينة درنة الليبية لفيضانات كارثية نتيجة عاصفة دانيال، مما أسفر عن خسائر بشرية ومادية هائلة، بالإضافة إلى تغييرات بيئية جذرية في النظام البيئي البحري المجاور.تُحلل هذه الدراسة آثار الفيضانات على البنية التحتية الحضرية والبيئة البحرية في مدينة درنة، استنادًا إلى الوثائق الرسمية والدراسات السابقة وصور الأقمار الصناعية والتحليل بعد الكارثة. وتُبرز الدراسة تدهور البنية التحتية، وارتفاع التلوث الساحلي، وتقلبات جودة المياه، وتضرر المواطن البحرية على طول مصب وادي درنة. تُوصي الدراسة بوضع خطط لإدارة مخاطر الكوارث الساحلية، والقيام برصد دوري لتأثيرات الفيضانات على البيئة البحرية.

الكلمات المفتاحية: فيضان درنة، عاصفة دانيال، انهيار البنية التحتية الحضرية، البيئة البحرية، الأثر البيئي، تحليل صور الأقمار الصناعية.

Introduction

Flooding has far-reaching and interconnected impacts on urban settlements and nearby marine environments. The combination of urbanization, climate variability, and inadequate infrastructure exacerbates flooding dangers, unleashing extensive social, economic, and environmental consequences. Floods in urban areas result in huge damage to structures like buildings, roads, and utilities and lead to significant economic loss and disruption of normal life [1-6].

Poor communities, particularly those residing in slums or low-lying zones, are disproportionately impacted with higher poverty and health risks due to water pollution and disrupted basic services [7-9].

Urbanization enhances these risks by higher impervious surfaces, which increase surface runoff and flood volume, especially when drainage infrastructure is old or in poor condition [9]. The secondary effects may include breakdowns of infrastructure and other essential systems, including loss of power, which complicates recovery even further and compounds socioeconomic challenges [6]. Transport networks are often disrupted, reducing access and exposing constraints in urban planning and resilience [5].

Floodwaters tend to carry sediments, hydrocarbons, and other contaminants from urban catchments into surrounding marine ecosystems, altering sediment quality and geochemical conditions [9,10]. These alterations can worsen already degraded marine ecosystems, leading to loss of biodiversity and altering the evolutionary process of marine life [10,11]. Urban runoff also alters habitat and introduces pollutants, thereby reducing genetic diversity and physiological stress in marine life [11]. Sea level increase and groundwater inundation add still to flood dangers in coastal cities, inflicting damage on both city infrastructure and marine habitats [12,13].

To prevent such effects, effective adaptation strategies should include structural measures of flood protection, nature-based solutions, and economic risk instruments [1,3]. Rehabilitation of natural systems and utilization of indigenous knowledge can be beneficial to enhance resilience, particularly in low-income and informal settlements [7,8]. Enhancing drainage systems in urban areas considering the interaction between climate change and urbanization is essential to reduce future flood risks [14,15].

The recent floods in Derna city and other Libyan cities illustrate the intricate nature of such disasters as infrastructure failure coinciding with high-scale environmental degradation. Heavy September 2023 rainfall caused catastrophic flooding and as much as -14 cm land subsidence in urban regions. Geological and meteorological instabilities caused them to increase the susceptibility of infrastructure to failure [16]. Urbanization played an important role in reducing infiltration, increasing surface run-off, and increasing flood peaks [17,18]. The extensive paving with concrete of pervious surfaces prevented groundwater recharge, resulting in quick surface water rising during storm events a behavior clearly observed in Derna and other coastal cities.

Apart from that, Derna floodwaters brought pollution and garbage into the Mediterranean Sea, greatly degrading water quality and exposing coastal systems to hydrocarbons, heavy metals, and organic pollutants. These pollutants hinder biodiversity, upset food webs, and demilitarize fisheries, causing long-term economic and livelihood loss [19,18]. Uncertainty of income, public health hazard, displacement, and psychological trauma were among the other human impacts.

Advanced technologies, such as satellite interferometry, played a key role in the detection of land deformation and enabling risk reduction [1]. Such equipment enabled early warning systems and informed timely interventions. The Derna case accentuates the need for integrated urban planning and protection of the environment to reduce the adverse effects of flooding [18-16].

This study contributes to existing knowledge by giving a comprehensive assessment of the twin impacts of city floods on onshore infrastructure and offshore marine ecosystems. By integrating satellite imagery with environmental and socioeconomic factors, it provides data on spatiality of damage, highlights terrestrial-disaster and marine-interconnectedness, and presents pragmatic recommendations for disaster risk reduction particularly in the Libyan coastal ecosystem.

Material and methods

To acquire a multi-dimensional understanding of the flood impacts in Derna, the study utilized a desk-based methodology that combines geospatial software, government reports, and peer-reviewed literature. The research design was cleverly designed to compensate for the constraints resulting from the absence of fieldwork, while simultaneously offering an evidence-based, overarching analysis of the impact of the disaster on urban infrastructure as well as the coastal marine ecosystem.

This field-independent research utilized the following sources and tools:

- Libyan official reports, including papers presented by the Ministry of Environment and Civil Defense officials.
- Data from international organizations, including the United Nations (UN), the Red Cross, and the United Nations Environment Programme (UNEP).
- Satellite imagery and geospatial software, primarily Google Earth, with pre- and post-disaster imagery to analyze spatial deformation and inundation area.
- Peer-reviewed scientific literature pertinent to urban coastal flooding, risk estimation, and disaster effects on marine ecosystems.
- Qualitative and quantitative evaluation of available post-disaster data based on damage to infrastructure, movement of contaminants, and socio-environmental effects.

Results and Discussion

The results provide a detailed analysis of data collected from high-resolution satellite imagery, institutional reports, and analytical tools, with a particular emphasis on the September 2023 catastrophic flood event in Derna, Libya. The satellite imagery as demonstrated Figures 1–5, and Tables 1–4, collectively document the scale of urban damage, infrastructural collapse, environmental loss, socioeconomic effects, and governance failure. The pre- and post-disaster comparison enables this research to inform how the disaster happened and its multifaceted effects.

Figure 1 provides a close-up of the urban structure of Derna prior to the flood event, with clearly intact streets, buildings, and natural watercourses. This image provides a necessary baseline for assessing the extent of damage and change present in subsequent imagery**.**

Figure 1: Pre-flood Derna City, 2 September 2023 (Planet Labs PBC).

Figure 2, photographed ten days after Figure 1, indicates extensive inundation of central Derna. There is significant increase in water cover from the pre-flood situation with extensive building collapse. The severity of the flood and the level of urban submergence are clearly indicated by this photo.

Figure 2: Flooded Derna City, 12 September 2023 (Planet Labs PBC).

Figure 3 is the image of the southern dam in its original state, its structural form and containment ability are demonstrated, and it will be used as the basis for measuring how much damage can be observed from the subsequent images.

Figure 3: Dam on Southern Periphery of Derna Prior to Floods (Maxar Technologies).

Figure 4: Dam after the Flood with Severe Damage (Planet Labs PBC).

The post-flood Figure 4 depicts disastrous failure of the dam, with breaches, erosion of embankments, and disrupted flow channels. This reinforces the failure of the dam and its central importance in increasing flood dynamics. Figure 5 indicates massive urban devastation, e.g., collapsed buildings and widespread land subsidence. Land deformation, with its values of land subsidence up to -14 cm, also contributed to infrastructure failure and extensive devastation.

Figure 5: Urban Flooding and Land Deformation in Central Derna (Maxar Technologies).

Collectively, Figures 1-5 document the sequence from normal urban conditions to record flooding and infrastructure collapse, validating the cited flooding of the city, dam failure, and geomorphic modification. Quantitatively captures the scale of the disaster, with widespread damage on two-thirds of the city's area, one thousand buildings flooded or ruined, prolonged power cuts, and large land subsidence. The damage multiplier captures the mechanism by which the impact was amplified through cascading failures as illustrated in Table 1.

Table 1: Infrastructure Damage in Derna.

Indicator	Value	Reference
Confirmed deaths	>5,000	[20]
Displaced population	>43,000	[21]
Urban area affected	~66%	[22]
Buildings submerged	>5,800	[23]
Buildings damaged/destroyed	~2,000	[24]
Electricity loss	>90%	[25]
Ground subsidence	Up to -14 cm	[14]
Damage multiplier	20x	[1,9]

The floodwaters transported enormous volumes of sediment and contaminants into the coastal ocean, significantly increasing turbidity, reshaping seabed morphology, and depositing toxic heavy metals. These changes pose significant threats to seagrass ecosystems and benthic communities, which require habitat and light stability as presented in Table 2.

Table 2: Marine Environmental Impacts.

Impact	Description	Reference
Turbidity	Significantly increased	[22]
Seabed alteration	Sediment changes and erosion	[22]
Pollutant inflow	Presence of heavy metals (e.g., mercury)	[28]
Light availability	Reduced light penetration	[22]
Ecosystem risk	Habitat instability and degradation	[22]

The tragedy caused a dire humanitarian emergency, displacing tens of thousands and overburdening healthcare and education infrastructure. The economic toll also worsened poverty and unemployment, and psychological trauma affected community well-being as shown Table 3.

Table 3: Socioeconomic and Health Impacts.

Indicator	Impact	Reference
Displacement	>43,000 people displaced	[21]
Healthcare	Collapse; increased disease risk	[21]
Education	Schools repurposed as shelters	[29]
Economy	Livelihood disruption, unemployment rise	[25]
Mental health	Elevated psychological distress	[29]

Institutional failures contributed to the devastation caused by the disaster, such as ignored warnings, faulty dam safety assessments, uncoordinated emergency responses, and the neglect of civil liberties. Lack of accountability hindered effective crisis management and had an impact on recovery as shown in Table 4.

Table 4: Governance Failures.

Issue	Description	Reference
Early warning ignored	Failure to act on 72-hour advance alerts	[30]
Dam safety misjudged	Declared safe shortly before catastrophic failure	[30]
Response delays	Conflicting evacuation orders and poor coordination	[31]
Civil rights violations	Arrests and media restrictions during crisis	[30]
Lack of accountability	No formal charges or investigations initiated	[18]

The integration of satellite imagery and quantitative data presents a multifaceted disaster portrait of apocalyptic infrastructure failure, pure environmental devastation, widespread socioeconomic upheaval, and systemic governmental breakdown. The time-series images bear witness to the abrupt shift from stable urban systems to record-breaking flooding and infrastructural breakdown. In contrast, the tabular data quantify the daunting human, environmental, and institutional losses. Floods greatly impact urban coastal cities, causing widespread destruction to infrastructure, roads, and buildings, and interfering with the socio-economic life of residents especially those in informal settlements and low-income residential areas [7,1,6]. The severity of floods is increased by rapid urbanization and climate change, which leads to more impervious surfaces and greater volumes of surface runoff [2,32,15]. Additionally, floodwaters transport sediments and pollutants from urban areas to the surrounding marine ecosystem, which alters sediment characteristics and damages marine ecosystems [10,33]. These changes result in biodiversity loss and ecological balance disruptions for marine organisms. To address these challenges, there is a necessity to develop efficient drainage systems, nature-based solutions, and promote integrated urban planning to render cities resilient to flooding and protect surrounding marine environments [10,32]. This study underscores the paramount importance of maintaining infrastructure resilience, effective early warning systems, governance transparency, and coordinated response systems for disasters to mitigate the impacts of future megadisasters.

Conclusion

The catastrophic floods that struck Derna in September 2023 exhibit the havoc caused by extreme weather events when coupled with urban infrastructure failure, unpreparedness, and environmental mismanagement. This study provides stark illustration of the double impact of flooding on both urban systems and marine ecosystems. On the urban side, infrastructure collapse, land subsidence, mass displacement, and governance failures spawned an acute humanitarian and economic crisis. Meanwhile, the floodwaters released enormous loads of sediments, pollutants, and debris into the surrounding Mediterranean marine ecosystem, resulting in habitat disruption, loss in biodiversity, and long-term ecological degradation. By integrating satellite information, geospatial analysis, and official and scientific data, the study stresses the necessity of adopting holistic risk reduction strategies. These include enhancing early warning systems, investing in drainage and dam infrastructure, promoting nature-based solutions, and enforcing integrated urban-marine planning. The Derna case highlights the interlinkage of terrestrial and marine systems and needs coherent policies linking urban development, climate adaptation, and marine protection. Without such proactive measures, seaside cities like Derna remain dangerously exposed to the amplifying impacts of climate-fueled catastrophes.

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