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**The perspective of early career scientists of Modeling and Mitigating Unprecedented Flood Disasters in Data-Scarce Regions - Derna city flood case**

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**ABSTRACT:** In September 2023, northeastern Libya faced unprecedented flooding due to Storm Daniel, leading to substantial human casualties and considerable damage to infrastructure of the city of Derna. This essay delves into the causes, impacts, and modeling initiatives undertaken in the aftermath of this catastrophe. Climate change exacerbated the storm, causing severe rainfall and the collapse of two embankment dams, inundating Derna. Libya's lack of proper infrastructure maintenance and political instability further amplified the disaster. In response, researchers from the Water Adaptive Design & Innovation Laboratory (WadiLab) at the University of São Paulo developed a participative simulation model, HydroPol2D, to understand the event and propose mitigation strategies. Utilizing diverse data sources including satellite imagery, weather forecasts, and soil databases, the team established a framework for physically-based fully distributed hydrodynamic modeling. In this essay, we aim to discuss the challenges and opportunities of modeling flood disasters in data scarce region from an early career scientist perspective. Despite data accuracy and resolution challenges, the iterative simulation process yielded valuable insights. The participative simulation model enhanced comprehension of the Derna disaster and provided a versatile framework for future disaster scenarios.  In this essay, we discuss how early career scientists can unveil overarching problems related to modeling flood disasters in poorly monitored

areas and provide our perspective in the challenges and opportunities that can help the community in advancing disaster risk reduction and natural hazards monitoring in vulnerable areas.
**KEYWORDS:** Early career scientist perspective. Hydrodynamic modeling. Natural Hazards. HydroPol2D. Disaster Risk Reduction.

**A perspectiva dos cientistas do início da carreira de Modelagem e Mitigação de Desastres de Inundações Sem Precedentes em Regiões Escassas de Dados - Caso de Inundação da Cidade de Derna**

**RESUMO:** Em setembro de 2023, o nordeste da Líbia enfrentou inundações sem precedentes devido à Tempestade Daniel, resultando em consideráveis perdas humanas e danos significativos à cidade de Derna. Este artigo investiga as causas, impactos e iniciativas de modelagem empreendidas na sequência dessa catástrofe. As mudanças climáticas exacerbaram a tempestade, causando fortes chuvas e o colapso de duas barragens de diques, inundando Derna. A falta de manutenção adequada da infraestrutura e a instabilidade política na Líbia amplificaram ainda mais o desastre. Em resposta, pesquisadores do Laboratório de Design Adaptativo de Água e Inovação (WadiLab) da Universidade de São Paulo desenvolveram um modelo de simulação participativa, HydroPol2D, para compreender o evento e propor estratégias de mitigação. Utilizando diversas fontes de dados, incluindo imagens de satélite, previsões meteorológicas e bancos de dados de solo, a equipe estabeleceu um quadro de análise para modelagem hidrodinâmica distribuída totalmente baseada em princípios físicos. Neste ensaio, pretendemos discutir os desafios e oportunidades de modelagem de desastres de inundação em regiões carentes de dados, do ponto de vista de um cientista em início de carreira. Apesar dos desafios na precisão e resolução dos dados, o processo iterativo de simulação proporcionou insights valiosos. O modelo de simulação participativa não apenas aprimorou a compreensão do desastre em Derna, mas também oferece um quadro de análise versátil para cenários futuros de desastres. Neste ensaio, discutimos como cientistas em início de carreira podem desvendar problemas abrangentes relacionados à modelagem de desastres de inundações em áreas mal monitoradas e fornecer nossa perspectiva sobre os desafios e oportunidades que podem ajudar a comunidade a avançar na redução do risco de desastres e monitoramento de riscos naturais em áreas vulneráveis.

**PALAVRAS-CHAVE:** Perspectiva de cientista em início de carreira. Modelagem hidrodinâmica. Ameaças naturais. HydroPol2D. Redução do risco de desastres.

## Unraveling the catastrophic Derna flood: causes, impacts, and modeling initiatives

On September 10th, Storm Daniel caused extensive damage in northeastern Libya, resulting in heavy rainfall and sudden flooding that impacted numerous urban and rural areas. The human casualties have been substantial, and the numbers are anticipated to increase. According to the Office for the Coordination of Humanitarian Affairs (OCHA), around 884,000 individuals residing in five regions (Mantikas) are situated in locations directly impacted by the storm and flash floods in Libya, with varying degrees of impact (OCHA, 2023).

Intergovernmental Panel on Climate Change (IPCC) reports show that more frequent and severe extreme events like heavy storms would be linked to climate change caused by temperature increases, due to our non-sustainable life patterns (IPCC, 2022). Although no one can say for certain that a given climatic event was caused or worsened by climate change, attribution studies can estimate the probability that climate change affected Storm Daniel, says Günter Blöschl, a hydrologist at the Vienna University of Technology. “The answer to that is, at this stage, without detailed analysis, yes. There is quite a clear causal link.” (Marshall, 2023, p. 452).

Storm Daniel has the characteristics of a tropical depression; approximately 170 millimeters of rainfall fell in Libya. Torrential rains of between 150 - 240 mm caused flash floods in cities including Al-Bayda, which recorded the highest rainfall rate of 414.1 mm in 24 hours (Marshall, 2023). Flooding specialists say the rainfall was unusually severe, and climate change would have intensified it by supercharging Storm Daniel, a low-pressure weather system that formed over the Mediterranean Sea around 4 September.

As a result of such huge rainfall, two dams collapsed, Derna and Mansour (a pair of dams positioned further up the river valley with the same name, situated at one and twelve kilometers' distance), releasing an estimated 30 million cubic meters of water into the city of Derna (Global Security, 2023). Other towns and cities of the Jabal al-Akhdar region and the suburbs of Al-Marj also suffered the storm consequences, but what occurred to Derna was the worst event cataloged. In an average year, Derna gets 274 millimeters of rain, according to the German Weather Service (2023).

Although the actual preoccupation around the disaster, the problem of floods in that region is not recent. In a research paper published in November 2022 (Ashoor, 2022), the author warned that the dams holding back the seasonal waterway needed urgent attention, because of the repeated floods on the river basin since World War II. The results demonstrated that the study area has a high potential for flood risk, and the dams needed periodic maintenance with necessary increasing in vegetation cover to reduce the phenomenon of desertification (Ashoor, 2022). Once one dam collapsed, the second one faced adverse conditions to maintain its integrity. [...] the current situation in the Derna Valley basin requires officials to take immediate measures, carrying out regular maintenance of the existing dams, because, in the event of a huge flood, the result will be disastrous for the residents of the valley and the city (Ashoor, 2022, p. 93).

Whilst details are lacking, they were embankment dams of soil and rock (Ashoor, 2022; Global Security, 2023) constructed to control the floods. The two dams were clay-filled embankment dams (the core is made of compacted clay, and the sides are made of stones and rocks) with Derna and Mansour capacities between 18-22.5 and 1.5 million cubic meters of water, respectively. They were designed to attend to the climate conditions in the mid-20th Century, not those of the early 21st Century. Because of these characteristics, continuous monitoring was essential, and the rapid understanding of the mechanisms led to the disaster.

As reported by ABC News, even though the risks facing the city were raised long before the disaster struck, Ashoor warned of the potential for destruction if the dam's infrastructure was not supported. It is not yet clear whether the degradation of infrastructure or decisions by authorities contributed to the scale of the destruction, but Derna has been the scene of battles between rival powers for years. Since the 2011 Arab Spring uprising, Libya has been subject to a decade of chaos, which ousted Libya's then leader who had been in power for more than four decades.

Since then, Libya has been divided into two rival administrations in the east and west of the country. Derna, which is in the East, was seriously impacted by the fighting between the two administrations and was held for some time by Islamic extremists who left its infrastructure devastated. Nonetheless, a ceasefire was proposed in 2020 and Libyans have more freedom between the two sides, eastern factions reinforce their discontent over not receiving their share of Libya's oil wealth. A finance committee created in 2023, with members from across political divides, is intended to ensure that funds are distributed fairly. However, many ordinary Libyans say corruption impedes the infiltration of wealth.

Given the unprecedented impact of the floods in Derna City, a group of researchers from the Water Adaptive Design & Innovation Laboratory (WadiLab), São Carlos School of Engineering at the University of São Paulo (EESC-USP) led a modeling study using satellite data and a physically-based fully distributed hydrodynamic model for flood modeling and damage estimation in data scarce regions. The aforementioned study is being prepared for a separate submission in a specialized peer-review journal with all the descriptions of the model, data acquisitor and processing, procedures, calibration, and validation.

The curiosity to solve the lack of information and to understand how the catastrophic event took place in Derna City was the motivation to propose an effective modeling framework. The phases to analyze the Derna flood disaster are presented in the following sections of this document, as well as the description of each step and decision taken to integrate the complete study and modeling of the extreme event. Using the curiosity and motivation from early career scientists in developing countries that are involved in natural hazards, disaster risk reduction and hydrology studies, in this essay, we focus on discussing the main lessons that we have learned from the experience of modeling flood disaster in a poorly gauged region.

**Description of the Framework**

Analyzing Derna's flood disaster was possible by following the steps presented in Figure 1. This approach consisted of a deliberative and collaborative group analysis, which gathered information, raised hypotheses, and feasible simulations to achieve preliminary results. After these steps, there was a rethinking about how to improve the preliminary results according to the real scenario. Hence, after refining the results, it was made recommendations for knowledge sharing to understand and mitigate the event and suggestions for procedures in the context of future disasters.

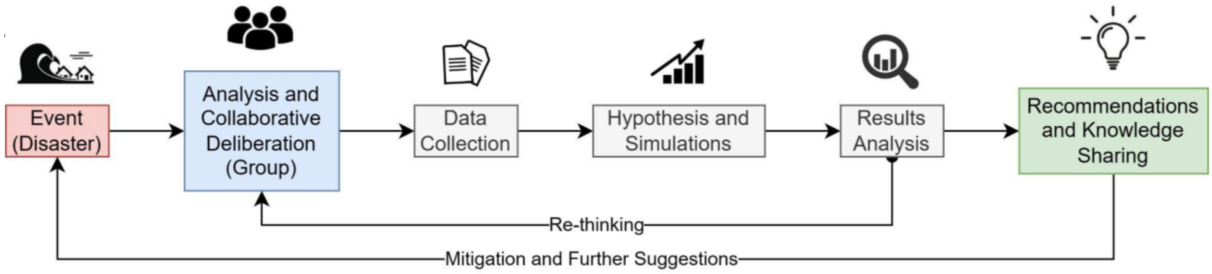


Figure 1 - Flowchart summarizing the following steps to analyze Derna's flood disasters.

<u>Analysis of the disaster event and collaborative deliberation</u>

The analysis of disasters consisted in discussing how Derna's flooding disaster event happened and its casualties, assembling information through news on the internet and mass media. After that, it was considered the possibilities of applying a hydrodynamic model (HydroPol2D) (Gomes et al., 2023) to assess the flood extent. Here, we considered all the border conditions of the precipitation event and dams breaking, delimiting the study areas and procedures to information collecting about the Daniel storm (the extreme event responsible for the disaster in Derna's city).

<u>Data collection</u>

The Hydropol2D model works with data in raster format. The model requirements: Digital Elevation Modeling (DEM), Land Use Land Cover (LULC), Soil type, and the rain data. Thus, it was examined and collected data from different official and institutional platforms. Also, the information about the dams was available by Yugoslav construction company Hidrotehnika-Hidroenergetika (Maksin, 2016). Below, as presented in Table 1, there will be a brief description of all data used in this simulation.

| Data | Description |
|---|---|
| Digital Elevation Modeling (DEM) | The dataset employed is the Copernicus Digital Surface Model (DSM), characterized by a 30-meter resolution capturing Earth's surface, encompassing buildings, infrastructure, and vegetation. It originates from the WorldDEM, an edited DSM that incorporates features like flattened water bodies and consistent river flow. This refinement ensures a more accurate representation, reducing inconsistencies in the model output (OpenTopography , 2021). |
| Land Use Land Cover (LULC) | The dataset employed, known as The Dynamic World, utilizes a near real-time (NRT) methodology for mapping land use and land cover (LULC) via 10-meter Sentinel-2 imagery. By leveraging advanced techniques such as deep learning and a cloud-based system, it provides continuous and high-resolution predictions parallel to Sentinel-2 acquisitions (Veter, 2022; Brown, 2022). |
| Soil type | The utilized data file was The Harmonized World Soil Database version 2.0 (HWSD v2.0), a collaborative effort by FAO and IIASA. This global soil inventory offers comprehensive details on the morphological, chemical, and physical properties of soils at an approximate 1 km resolution. Primarily designed to support prospective studies related to agro-ecological zoning, food security, and climate change, it was specifically selected for the modeling of the Wadi's basin to address these critical considerations (FAO, 2023). |
| Rain Data | The selected data comes from ICON (ICOsahedral Non-hydrostatic NWP and climate model ICON) weather forecast model, part of the DWD Database Reference for the Global and Regional ICON and ICON-EPS Forecasting System. This global model is designed to effectively capture atmospheric blocking, a |

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|---|---|
| | phenomenon posing challenges for existing numerical weather prediction models. Extensive evaluations, including ensemble simulations and verification against reanalysis data, indicate a commendable representation of annual blocking frequencies. While some deviations surface in individual seasons, the insights from this model provide valuable perspectives, particularly for regions lacking their own predictive systems or models (Attinger et al., 2019). |

Table 1 - Description of the data used in the model.

Hypothesis and Modeling

During the phase of mining data, the information in the journals, engineering blogs and precipitation models that tracked the storm Daniel helped to establish a hypothesis about how the disaster happened in Derna City. The storm descended through the Mediterranean Sea and when it arrived in the Cyrenaica region, it traveled from west to east, which corresponds to the drainage direction of the Wadi Derna River. Therefore, the basin receives precipitation from upstream to downstream during the three days of the storm, accumulating enough water to cause the failure of the two dams and the flood in Derna city. Taking into account the satellite images of how the dams remained and the found information about its characteristics, the supposition was that the water accumulated in the reservoir overflowed the dam (that shows the characteristics of an Embankment Dam) and started to erode the compacted rockfill. At a certain point, a large percentage of the rockfill was eroded and the core of the structure lost its momentum resistance, causing the first dam failure. Moments later, the accumulated water upstream reached the second dam (that was 1 km from the city), and, as its capacity was much lower than the first dam, had a faster failure.

After collecting data, the next step is its treatment, it means delimiting the basin in the base of the DEM and clip, rescaling (if necessary), reprojecting, and ailing the raster information to the extent of the basin. The team's second section executed the process using GIS software. Subsequently, preliminary values required by the software for infiltration and manning parameters were incorporated. The suggested values were derived from the participants' experiences in the field of hydrologic modeling. Finally, after the preprocessing data, the components of the model were set. The results of the first model run were ready on the 16th of September.

Results analysis

Following the completion of the initial modeling phase, the team collectively reviews the first results. The outputs generated by the Hydropol2D program manifest as raster maps, depicting parameters such as maximum velocity flow and maximum water depth in the basin, along with hydrographs observed at specific gauges and the outlet. Identified within the modeling results are certain instability issues, attributed to elevated values (approximately 40 m/s) in the raster of maximum velocity during the reservoir filling stage. Additionally, the hydrographs at the outlet exhibit peaks post-event. Conclusively, irregularities in the acquired topographical data suggest the necessity of rescaling information to enhance the model's response quality. The iterative process of data mining, modeling, and result analysis persists cyclically until achieving a stable numerical simulation.

Recommendation and Knowledge Sharing

The recommendations extend to future endeavors, highlighting the potential of participative simulations as a versatile tool applicable to various disaster scenarios related to floods. By leveraging participatory approaches in simulations, not only can enhance our understanding and preparedness for floods but also extrapolate these methodologies to address different types of disasters. Citizen science is one example participatory approach that can use information collected from people who live in vulnerable areas that can be used to validate models and improve disaster risk reduction management by incorporating local knowledge (Fava, 2019).

The participative simulation model serves as a dynamic framework that can be adapted and customized for diverse disaster scenarios such as hurricanes, earthquakes, or wildfires. This approach encourages active involvement from communities, stakeholders, and experts, fostering a collective understanding of potential risks and effective response strategies.

Moreover, the utilization of participatory simulations promotes a culture of resilience, empowering communities to proactively engage in disaster management. This adaptive approach ensures that the benefits derived from participatory simulations extend beyond the immediate context of flood-related disasters, providing a comprehensive and flexible tool for addressing a spectrum of challenges posed by various natural disasters.

**Discussion and lessons learned**

For poorly gauged basins, the lack of observational data is a key limitation in hydrological modeling from an international research perspective. However, quasi-global rainfall products like PERSIANN and numerical weather prediction models like ICON can help address this issue. Still, uncertainties remain; ICON likely provides more accurate rainfall estimates than PERSIANN, which showed low precipitation rates for a ~780 km2 basin.

Additionally, the basin's shape acts as a bottleneck, preventing upscaling of the digital elevation model's resolution without losing connectivity - higher resolution was needed to maintain flow routing. The complex topography, with meanders and reservoirs, also caused numerical instabilities from high-velocity flows, requiring longer simulations. This indicates that for a future flood forecasting system, these conditions should be accounted for if sufficient lead time is needed.

Uncertainty sources have been identified and warrant consideration for future endeavors. To mitigate uncertainty in a flood forecasting system, leveraging numerical weather prediction products such as ICON or GFS could offer valuable lateral boundary conditions for enhanced resolution in hydrologic predictions. Additionally, expert judgment plays a crucial role in discerning potential scenarios of hydraulic infrastructure failure, as assuming worst-case failures might lead to an increase in false alarms.

Additional steps could include assimilating remote sensing data into hydrologic models to improve streamflow estimates and using ensemble or probabilistic methods to quantify rainfall prediction uncertainties. Detailed surveys of basin topography and hydraulics would also help constrain model parametrization and instability issues. Ultimately, addressing uncertainties will be key to developing robust flood forecasting systems for poorly gauged basins.

**Bibliography**

Ashoor ع. ع. ر. (2022). **Estimation of the surface runoff depth of Wadi Derna Basin by integrating the geographic information systems and Soil Conservation Service (SCS-CN) mode**l. Journal of Pure & Applied Sciences, 21(2), 90–100. https://doi.org/10.51984/jopas.v21i2.2137

ATTINGER, R. et al. Representation of atmospheric blocking in the new global non-hydrostatic weather prediction model ICON. **Meteorologische Zeitschrift**, v. 28, n. 5, p. 429–446, 2019. Doi:10.1127/metz/2019/0967.

BROWN, C. F. et al. Dynamic World, Near real-time global 10 m land use land cover mapping. **Scientific data**, v. 9, n. 1, 2022. Available in: <https://doi.org/10.1038/s41597-022-01307-4>

Gomes, M. N., Jr., do Lago, C. A. F., Rápalo, L. M. C., Oliveira, P. T. S., Giacomoni, M. H., & Mendiondo, E. M. (2023). HydroPol2D — Distributed hydrodynamic and water quality model: Challenges and opportunities in poorly-gauged catchments. In **Journal of Hydrology** (Vol. 625, p. 129982). Elsevier BV. https://doi.org/10.1016/j.jhydrol.2023.129982

**Fava, M. C., Abe, N., Restrepo-Estrada, C., Kimura, B. Y. L., & Mendiondo, E. M. (2019).** Flood modelling using synthesised citizen science urban streamflow observations. Journal of Flood Risk Management, 12(S2). https://doi.org/10.1111/jfr3.12498

**Harmonized World Soil Database version 2.0**. FAO; International Institute for Applied Systems Analysis (IIASA); 27 jan. 2023. Available in: <http://dx.doi.org/10.4060/cc3823en>

IPCC, 2022: **Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change** [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., Doi: https://doi.org/10.1017/9781009325844.

MAKSIN, B. **Wadi Derna**. Available in: <https://www.hidrotehnika.rs/en/libya/wadi-derna/>. Access in: 30 set. 2023.

MARSHALL, M. Libya floods: how climate change intensified the death and devastation. **Nature,** v. 621, n. 7979, p. 452–453, 15 set. 2023.

OCHA. **Libya Flood response Flash Appeal, Sept 2023 - Dec 2023 (Issued September 2023) [EN/AR]** - Libya | ReliefWeb. Disponível em: <https://reliefweb.int/report/libya/libya-flood-response-flash-appeal-sept-2023-dec-2023-issued-september-2023-enar?_gl=1>. Access in: 28 set. 2023.

OPENTOPOGRAPHY. **Copernicus GLO-90 Digital Surface Model**. OpenTopography, 2021. Available in: <http://dx.doi.org/10.5069/G9028PQB>

PIKE, J. **Derna**. Disponível em: <https://www.globalsecurity.org/military/world/libya/derna.htm>. Access in: 28 set. 2023.

SAARINEN, N. How political chaos and collapsed dams created the perfect storm in the Libyan city of Derna. **ABC News**, 14 set. 2023. Avaiable in: <https://www.abc.net.au/news/2023-09-14/political-chaos-and-burst-dams-devastate-derna-libya/102854638>. Access in: 29 set. 2023.

VENTER, Z. S. et al. Global 10 m Land Use Land Cover datasets: A comparison of Dynamic World, World Cover and Esri Land Cover. **Remote sensing**, v. 14, n. 16, p. 4101, 2022. Available in: <https://doi.org/10.3390/rs14164101>

**Wetter und Klima - Deutscher Wetterdienst - Startseite**. Available in: <https://www.dwd.de/DE/Home/home_node.html>. Access in: 29 set. 2023.

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