

Post-Impact Downstream Flooding Hazards



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Humanity's level of asteroid impact mitigation and recovery planning partially relies on our knowledge of how this hazard has developed over time. This means that we need to understand both the immediate and delayed effects associated with such an event. This work focuses on potential downstream flooding risk post-asteroid-impact by adopting a timeline similar to the more common and well-documented wildfire-flood sequence. We examine four impact locations derived from the 2025 Planetary Defense Conference risk corridor: South Africa, Angola, DR Congo, and Romania. This analysis is conducted using GeoClaw, a physics-based flood model that solves the shallow water equations, to simulate flooding in each location at a most-likely and worst-case scenario (based on historical precipitation). This modeled flood risk is compared to population to estimate hazard exposure and loss of life in the various scenarios. Emphasis is placed on how location, thermal damage extent, and proximity to large population centers influence these estimates, and what that means for potential recovery paths.

Background

Previous research into asteroid impacts has been primarily focused on initial effects (blast wave, cratering, ejecta, seismic activity, tsunami, and thermal radiation), predicted from data derived from historical impacts and hydrocode modeling [1-4]. These first-order effects occur almost immediately and diminish in severity with distance. Due to our lack of empirical data on long-term recovery post-impact, potential cascading hazards are poorly understood and characterized (Fig. 1). Predictions for these effects can be made by comparing the well-researched initial impact effects to similar and far more common natural hazards [5]. This project investigates potential downstream flooding, which is hypothesized to occur based on increased flood risk post-wildfire. The first-order thermal radiation is proposed to have similar effects as the thermal damage caused by wildfires, which leads to hydrophobic soils, increased runoff, and therefore flooding downstream from the damaged area (Fig. 2) [5].

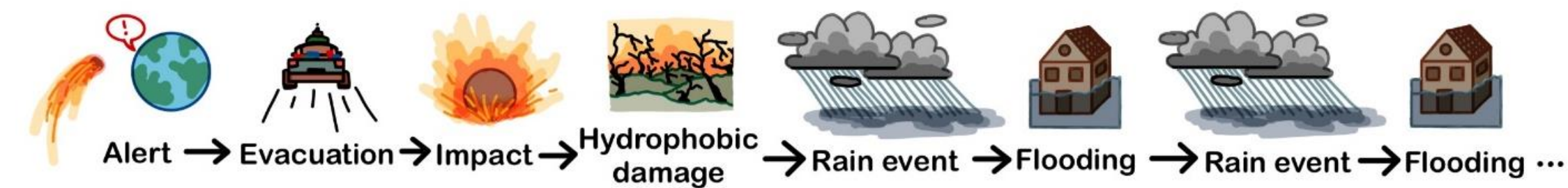


Fig. 2. Timeline of post-impact downstream flooding events demonstrating the repeating nature of this hazard.

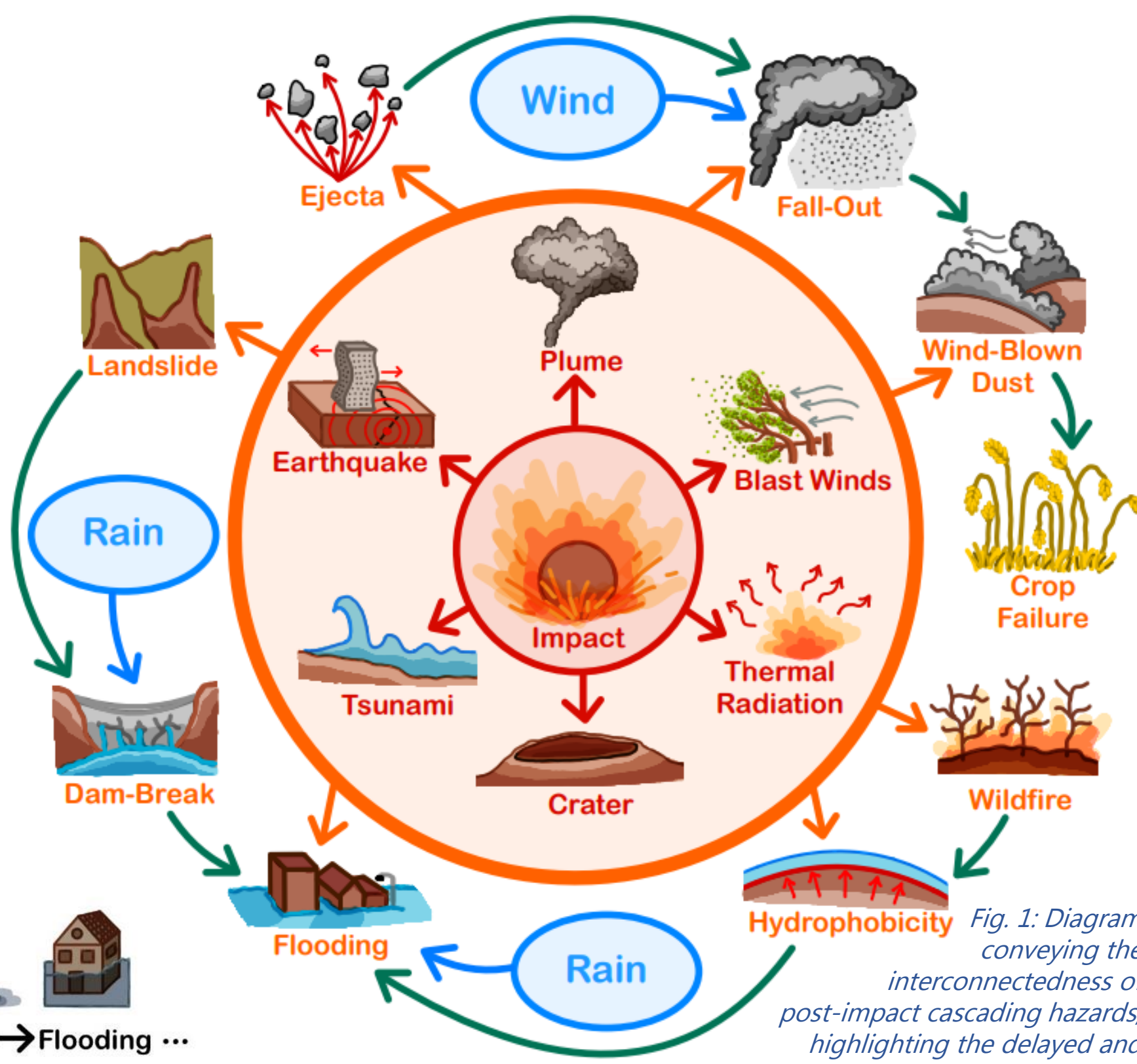


Fig. 1. Diagram conveying the interconnectedness of post-impact cascading hazards, highlighting the delayed and weather-triggered events.

Methodology

The flood model GeoClaw was used to simulate the potential post-impact downstream flooding for multiple hypothetical impact events. GeoClaw is an open-source model that solves the depth-averaged shallow water equations for flow [6]. It is a subset of the Clawpack software designed to solve hyperbolic systems of partial differential equations [7]. This model is not intended to simulate inundation due to precipitation, therefore we used a point source (a spring) over a given watershed, which could increase the uncertainty in our output. The examined asteroid scenario is predicted to impact with 3 to 720 Mt of energy, resulting in thermal damage radii ranging from 0 to 60 km [8]. Tested spring flow rates were determined based on local precipitation data [9] and hydrophobic radius size (25 km for the most likely and 50 km for the worst case), each spring ran for three days. We examined scenarios impacting near Cape Town, South Africa; Lucapa, Angola; Mwaka, DR Congo; and Bucharest, Romania, derived from the 2025 PDC Epoch 1 risk corridor (Fig. 3a) [8]. The low-resolution 90 arcsecond output was collapsed to a 30 arcsecond resolution, interpolating with "nearest-neighbor" values which may overestimate flooding levels in certain areas (Fig. 4). Mortality functions were then used to estimate hazard severity based on the interpolated depth and velocity values (Fig. 4) [10]. The exposed population is a value of how many people will experience any level of flooding (ranging from getting their feet wet to drowning) based solely on the GeoClaw output. The affected population is a metric for how many fatalities will occur, calculated using the mortality functions. These two metrics were compared across different scenarios to determine the influences of geography, precipitation, and population distribution on hazard severity. This information could be used to inform future evacuation policies and recovery planning.

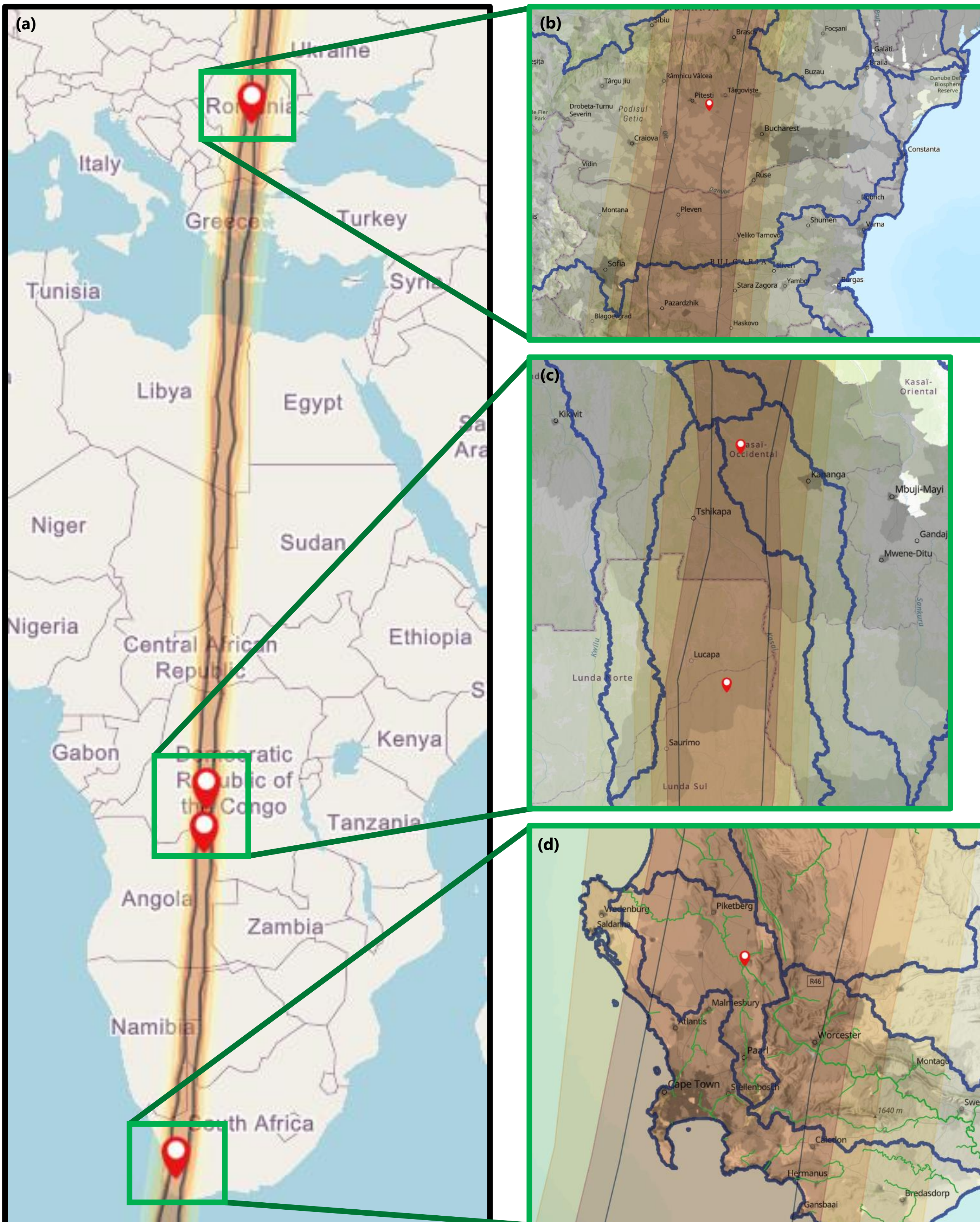


Fig. 3. (a) PDC 2025 Epoch 1 95% extent risk corridor through Africa and eastern Europe with locations in South Africa, Angola, DR Congo, and Romania highlighted. (b, c, d) Each location with impact shown in red, watershed boundaries in dark blue, population in black/white, and approximate river locations in green (only d).

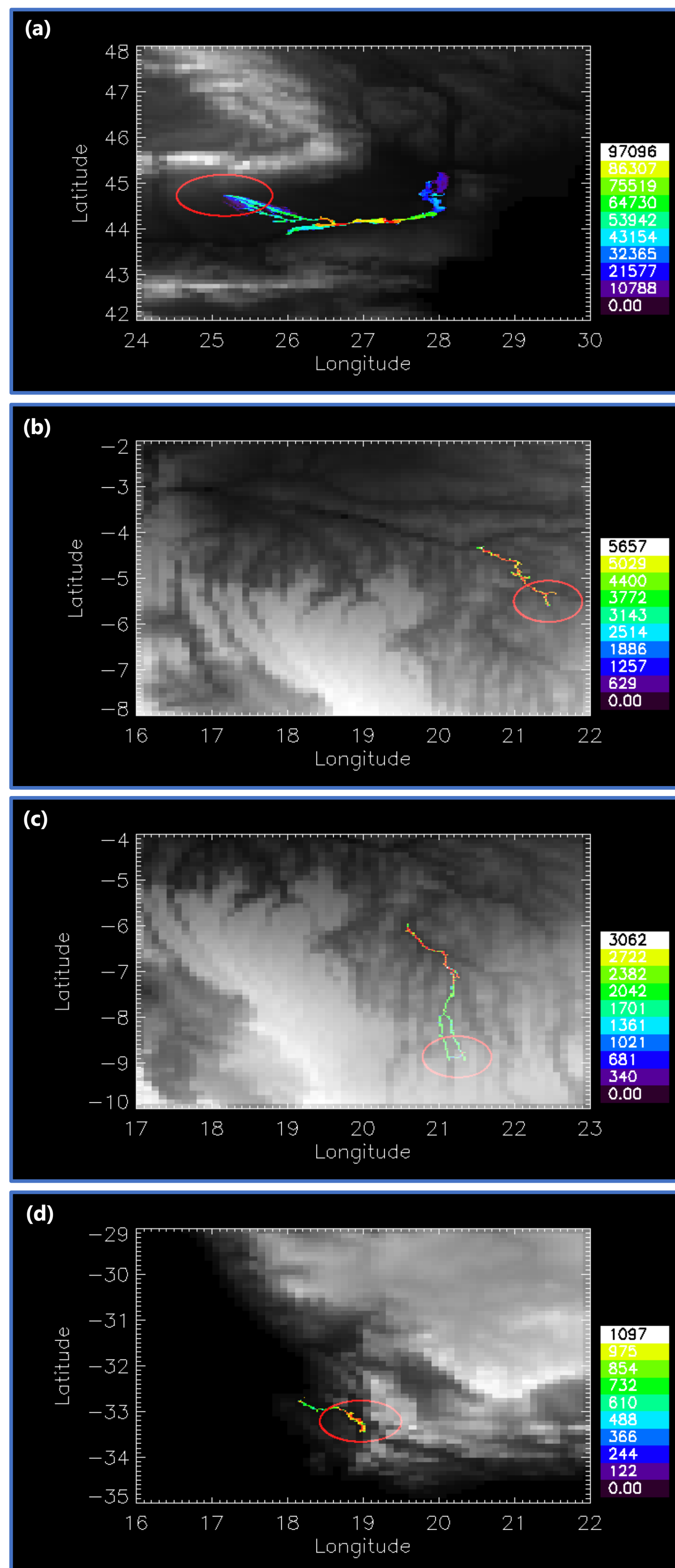


Fig. 5. Worst case scenario affected population shown in color overlaying a gray-scale topography map for (a) Romania, (b) DR Congo, (c) Angola, and (d) South Africa.

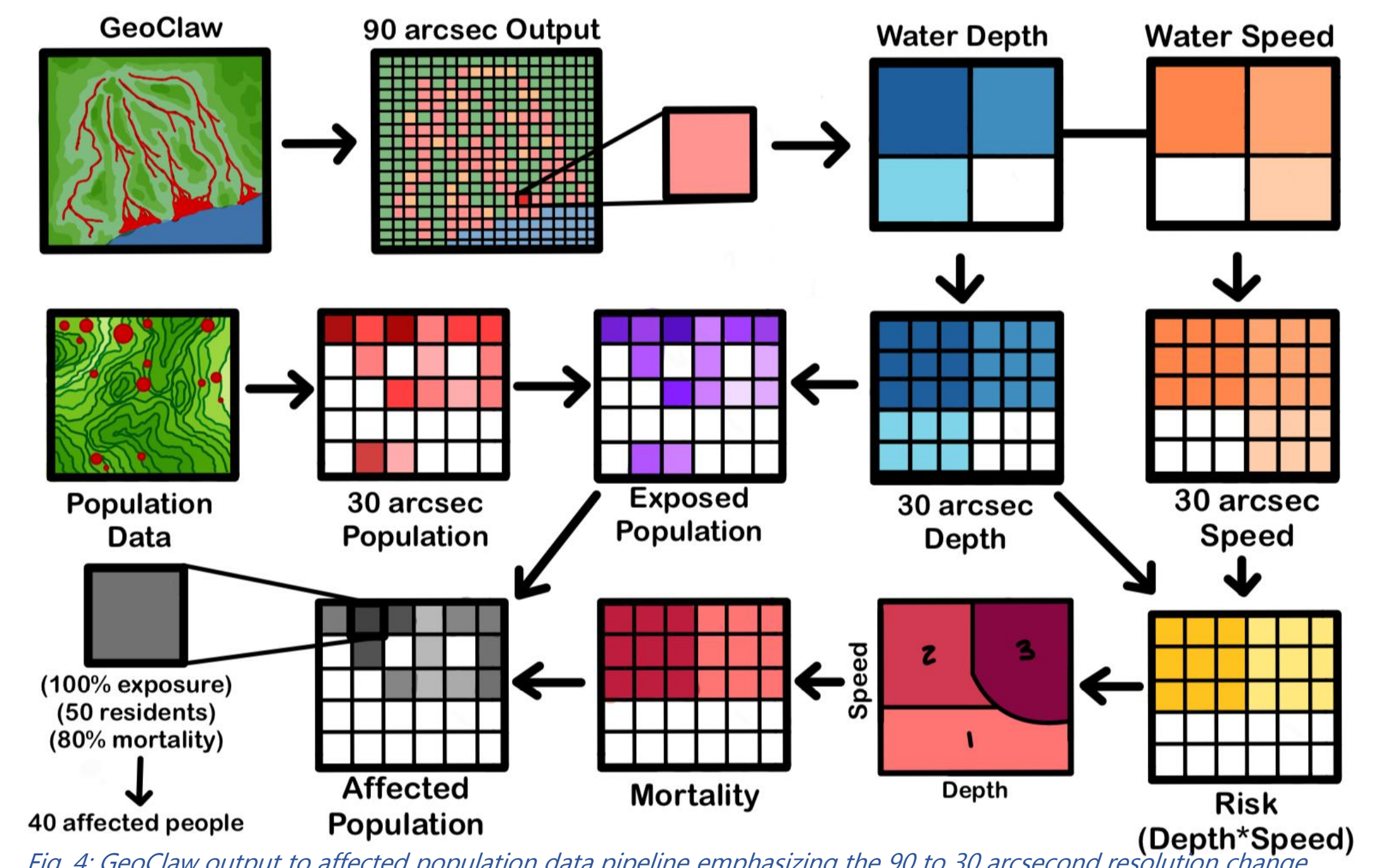


Fig. 4. GeoClaw output to affected population data pipeline emphasizing the 90 to 30 arcsecond resolution change.

Results

In South Africa, the simulated runoff did not reach Cape Town and only flooded the surrounding rural areas, leading to low severity results with a worst-case scenario estimate of around 63,000 people exposed and 56,000 people affected (Table 1). A vast majority of those exposed live within the hydrophobic radius, partially because the water did not extend far past the damage boundaries (Fig. 5d) and because the highest-density settlements are within the radius (Fig. 3d). A small percentage, approximately 14%, of those who live within the damaged area may be exposed.

Central Africa receives higher-intensity precipitation events compared to South Africa, and the locations we examined have populated downstream riverbanks. The simulated runoff in Angola extended far outside the damaged radius (Fig. 5c), flooding up to around 980,000 people and affecting 914,000 people (Table 1). The DR Congo is even more hazardous than Angola, with a worst-case scenario of 1,236,000 people exposed and 1,221,000 people affected (Table 1). Both events have a majority of the exposed population outside of the hydrophobic radius and tend to expose at least half of the residents within the radius. These are high severity events; the likelihood of being affected if you are exposed is generally over 90% for all scenarios.

Romania provides contrast to the Africa scenarios because the impact location is upstream of the highly-populated cities of Bucharest and Constanța (Fig. 3a). Estimates range to over 20,000,000 people exposed and 13,000,000 people affected in the worst case (Table 1). Over 99% of those exposed live outside of the damaged radius (Fig. 5a), and only up to 10% of those living within the radius may be exposed. Although this scenario has the highest estimates for exposed population, it is also the least severe: as low as 15% of those exposed will be affected by a single flooding event.

Location	Worst Case (max precipitation, R = 50 km)					Most Likely Case (average precipitation, R = 25 km)				
	Total Exposed Population	% Total Exposed Outside R	% Exposed of Total Pop Within R	Total Affected Population	% Affected of Total Exposed	Total Exposed Population	% Total Exposed Outside R	% Exposed of Total Pop Within R	Total Affected Population	% Affected of Total Exposed
South Africa	63,361	4.40 %	14.59 %	56,038	88.44 %	11,470	0 %	14.01 %	7,929	69.13 %
Angola	979,131	94.58 %	43.78 %	914,329	93.38 %	60,133	50.28 %	85.74 %	53,237	88.53 %
DR Congo	1,236,770	70.71 %	55.55 %	1,221,140	98.74 %	242,795	55.50 %	67.53 %	229,882	94.68 %
Romania	20,033,700	99.54 %	10.15 %	13,064,700	65.21 %	2,240,640	99.86 %	1.76 %	338,666	15.11 %

Table 1. Results for the worst case, using 10 times the average precipitation over a 50 km radius, and the most likely case, using the average precipitation over a 25 km radius, at each impact location. Includes total exposed and affected population, percentage of the total exposed population outside the hydrophobic radius, percentage of the total residential population within the hydrophobic radius that will be exposed, and the percentage of the exposed population that will be affected.

Discussion

Our methodology simplifies a very complex situation, which requires many assumptions to be made. For example, GeoClaw does not account for river basin base flow, soil infiltration, sediment flux, evaporation, or transpiration, and our use of a point source does not perfectly replicate precipitation. Additionally, we only modeled flooding in a single watershed at each location, potentially missing effects in other downstream areas. Although these assumptions may reduce the accuracy of our results, they provide enough latitude for a feasible and replicable downstream risk data pipeline.

The results vary significantly between location and event severity. Estimates for exposed and affected populations are lowest at the southern-most location, South Africa. This is due to a combination of factors: the geography of the area, which is composed of short coastal watersheds; the climate, as this is the driest location examined; and the lack of high-density settlements along the downstream riverbank. The population in this area is fairly spread out within the low-lying area surrounding Cape Town, not clustered around water sources. The water does not flow very far and not many people are exposed; thus, this location is at low risk. Moving north, the cases in Angola and the DR Congo can be grouped together, they share similar topography and have large populations located along riverbanks. However, the DR Congo receives over twice the amount of rain compared to Angola (it's the wettest location examined), leading to higher exposed, affected, and hazard severity estimates. At both sites, roughly half of the residents within the hydrophobic radius may be exposed, which could influence post-impact recovery plans to move evacuees back to the damaged area. Finally, the highest estimates for exposed and affected populations are in Romania. In contrast to the Central African cases, almost all the exposure occurs outside of the hydrophobic radius, which is unsurprising due to the impact being in a rural area upstream of significant population centers. Even in the most likely case, this scenario sees at least 2 million people exposed to flooding. The impact also occurs in a mountainous region, potentially channelizing the flow as it approaches Bucharest and Constanța.

References

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Highlights

- Post-asteroid-impact cascading hazards are significant to the impact risk data pipeline, and downstream flooding could be a repeating hazardous event.
- Using the flood model GeoClaw, we can estimate potential downstream flooding risk in various scenarios. This work compares these risks in four locations: South Africa, Angola, DR Congo, and Romania at both a most likely and worst-case scenario varying precipitation and hydrophobic radius size.
- Estimates of people who were exposed range from just over 11,000 in the best scenario to over 20,000,000 in the worst.
- Local geography, population distribution and proximity to riverbanks, and climate/precipitation amount have been determined to greatly influence this hazard.
- Depending on the scenario, post-impact recovery planning may need to consider downstream flooding hazards.