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Age-specific flood risk management under climate change and population aging

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Climate change has intensified the frequency and severity of extreme floods, while global aging has disproportionately exposed the elderly (individuals aged 65 and above) to these escalating hazards. In North America, Canada's 2024 floods left 116 seniors trapped for 12 hours, and the US 2022 floods reported that nearly 60% of fatalities were the elderly. In Europe, more than 45% and 75% of victims were the elderly during Spain's 2024 floods and Germany's 2021 floods, respectively. In Asia, 87% of affected seniors in Pakistan's 2022 floods faced severe medical shortages, while Japan's 2020 floods resulted in the drowning of 14 nursing-home seniors. Under these circumstances, extreme floods severely threaten aging populations, exacerbate social inequalities, and challenge the United Nations Sustainable Development Goals (SDGs), making flood risk management for the elderly a pressing global issue.

Concerning this issue, although flood risk management strategies have been adequately developed, they mainly rely on generalized public interventions that fail to account for the age-specific challenges. As climate change and population aging converge, the disproportionate flood risk to the elderly is increasingly shaped by two critical mismatches, namely, the temporal mismatch between the climate-driven abrupt floods and the delayed warning message to the elderly, and the spatial mismatch between urban aging hotspots and emergency resources. These two mismatches reveal that the elderly's vulnerability is not merely an inherent attribute of aging, but a condition induced and amplified by the structural misalignment between existing flood management systems and the actual demands of elderly populations. In this commentary, we argue that addressing these mismatches requires moving beyond generic vulnerability descriptions, and incorporating age-specific measures into existing flood risk management systems, thereby enhancing the flood resilience of this vulnerable group under a changing environment.

FAILURE OF FLOOD WARNING DELIVERY UNDER CLIMATE EXTREMES

Global climate change has disrupted hydrological regimes, bringing more frequent extreme rainfall events over the past decades, accompanied by strong interannual variability and spatial heterogeneity (Figure 1A). Meanwhile, climate change has triggered compound events such as hot-dry extremes and dry-wet abrupt alternations. The hot-dry extremes severely damage soil infiltration capacity, and the following dry-wet abrupt alternations generate sudden floods with higher peaks and greater velocities than traditional gradual events. These factors jointly exacerbate the hazards, abruptness, and uncertainty of extreme floods, substantially compressing the window for emergency rescue, making precise and timely flood warning information essential.

However, the flood warning delivery for the elderly is constrained by an information barrier. Modern flood alerts are primarily disseminated through smartphones, social media, and mobile applications. While these channels offer higher technical precision and spatiotemporal coverage than television, radio, and newspapers, the elderly exhibit significantly lower utilization rates of modern digital tools. Beyond mere access, age-related cognitive and sensory declines further impede their ability to swiftly process and act upon digital alerts.[1] Consequently, despite the successful prediction of floods by advanced hydrological models, flood warnings often fail to translate into actionable knowledge for the elderly. This information delay further compresses the elderly's evacuation window, leaving them physically trapped in their residences when fast-moving, high-velocity floodwaters strike suddenly. The temporal mismatch thus reveals a systemic failure of the flood warning system to accommodate the limited information-seeking channels and declined cognitive capabilities of the elderly. In a context of increasingly abrupt floods under climate change, this failure transforms a manageable inconvenience for young people into a life-threatening information gap for the elderly.

MISMATCH OF RESCUE AND MEDICAL RESOURCES UNDER URBANIZATION

The synergistic convergence of rapid urbanization and population aging leads to a spatial mismatch between the elderly and flood rescue resources. Over the past decades, a parallel increase has been observed in both urbanization and aging rates (Figure 1B), particularly in major global economies (e.g., the US, Germany, China, and Brazil). This trend drives pronounced disparities among demographic groups within cities. Younger and higher-income populations migrate toward newly developed areas equipped with modern drainage infrastructure. However, the elderly are constrained by economic limitations, attachment to familiar neighborhoods, and mobility issues, thus increasingly concentrating in degraded urban cores, high-density older neighborhoods, and low-lying areas.[2] Such disparities inadvertently place the elderly in the exact high-risk zones where floods strike first and hardest. More critically, since emergency resources are traditionally distributed based on average population density rather than the concentration of elderly individuals,[3] this spatial mismatch leaves the aging hotspots facing a disproportionate shortage of rescue and medical support during floods.

Once the elderly in these high-risk zones are exposed to floods, their physiological limitations further compound the danger. Due to weakened immune functions, the elderly can be significantly vulnerable to post-disaster secondary hazards, such as water-borne diseases and respiratory infections that often emerge in damp, flood-affected environments.[4] Meanwhile, the elderly suffering from chronic health conditions (e.g., cardiovascular diseases, diabetes) rely heavily on life-sustaining medical equipment at home, such as respirators, oxygen concentrators, and insulin refrigerators. When extreme floods strike, infrastructure damage causes abrupt power outages, severing the electricity supply to life-sustaining equipment, and essential medications are often destroyed or contaminated by floodwaters. The disruption of medical support, compounded by the elderly's inherent physical limitations, rapidly escalates their life-threatening crises. The spatial mismatch reveals that such cascading medical failures are not a natural consequence of aging, but a foreseeable result of resource allocation logic that overlooks the spatial concentration of chronic health conditions and medical care dependency.

AGE-SPECIFIC FRAMEWORK FOR TARGETED WARNING AND FLOOD ADAPTATION

The synergy of temporal and spatial mismatches generates a compounding effect that amplifies flood risk. The temporal mismatch shortens the evacuation window for the elderly, while the spatial mismatch leaves them in high-risk

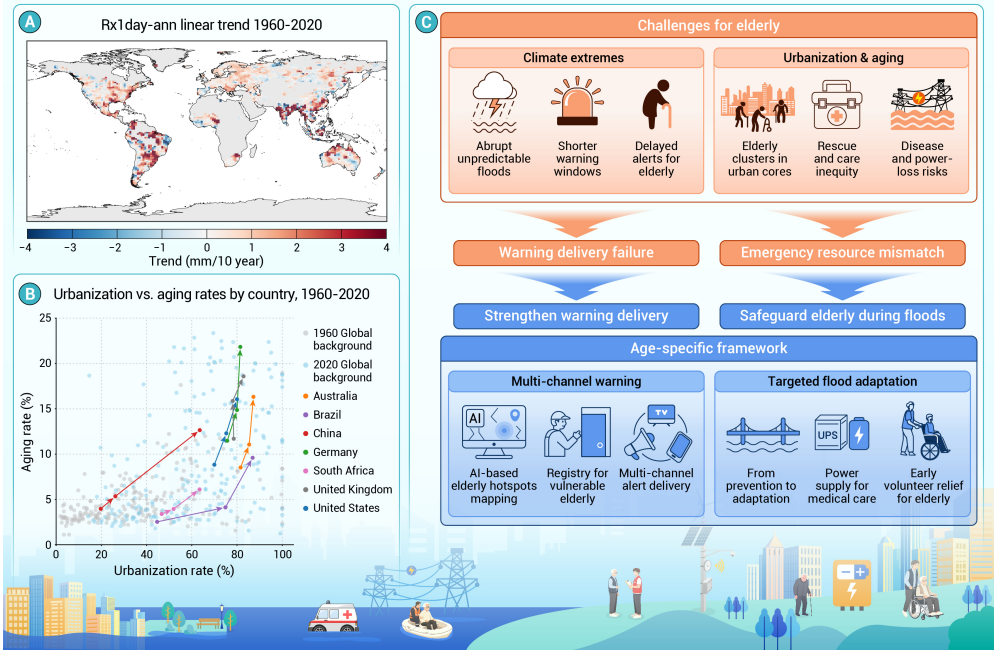

Figure 1. The (A) annual trend of maximum 1-day rainfall from the 1960s to the 2020s, (B) decadal trends of urbanization and aging rates from the 1960s to the 2020s, and (C) conceptual diagram of challenges faced by the elderly and an age-specific framework for flood resilience enhancement.

zones with insufficient medical support. This synergy transforms individual vulnerabilities into fatal crises. In response to these compounding crises, we propose an age-specific framework that translates the temporal and spatial mismatches identified above into actionable pathways (Figure 1C), thereby bridging general strategies with age-specific needs, and enhancing flood resilience for the elderly group. First, the warning system must complement its existing capacity for hazard prediction with a strengthened emphasis on targeted information delivery. Although coupling hydrological models with artificial intelligence (AI) has significantly improved the accuracy of flood prediction,[5] effectively delivering these forecasts to vulnerable populations remains a critical challenge, which demands precise spatial mapping of the elderly. In this regard, advanced machine learning algorithms can map the spatial correlations between demographic profiles and socioeconomic variables (e.g., income per capita, housing conditions, public health records), enabling the identification of elderly aggregation hotspots. Upon this foundation, community volunteers can be mobilized to establish a dynamic priority contact registry, prioritizing the registration of disabled and chronically ill seniors to ensure information physically reaches this most vulnerable subgroup. Once a flood is forecasted, the system triggers targeted and multi-channel delivery, combining traditional acoustic broadcasts with door-to-door notifications by assigned volunteers. By sequentially linking spatial mapping (identification), dynamic registration (targeting), and door-to-door notification (confirmation), this system transforms the flood warning process from passive, unidirectional broadcasting into an active, bidirectional closed-loop, ensuring that the information is not merely issued but verified as received and acted upon.

Second, in addition to foundational flood defense, targeted adaptation measures are increasingly essential. Although a series of engineering-based facilities and nature-based solutions (NbS) are employed for the physical defense against extreme floods, intermittent flood inundation in certain spatial areas may be inevitable within the context of intensifying extreme events and aging infrastructure. Therefore, we advocate shifting the focus from flood prevention to flood adaptation. In identified vulnerability hotspots, adaptation measures must provide a safety net for those identified as unable to evacuate, particularly to those in the contact registry. On the one hand, uninterruptible power supplies (UPS) and localized microgrids within residential buildings, to protect medical equipment from power outages and safeguard the chronically ill seniors dependent on life-sustaining devices. On the other hand, localized waterproof medical cabinets should be implemented to ensure that temperature-sensitive medications are not affected by floods. Furthermore, community volunteers can serve as a frontline response, offering preliminary relief to the disabled individuals before the arrival of professional rescue forces. Such closed-loop mechanisms are exemplified by recent flood responses in China, where community volunteers maintained dynamic lists of vulnerable seniors, issued door-to-door warnings, and provided immediate rescue assistance to those trapped, effectively bridging the gap between early warning and last-mile adaptation.

In conclusion, addressing the flood risk for the elderly requires shifting the focus from their inherent vulnerability to the temporal and spatial mismatches that structurally marginalize them. By synchronizing warning delivery and bridging the resource gap, this framework enhances the flood resilience of the elderly, and ensures that the most vulnerable populations are not left behind in a rapidly changing environment.

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DECLARATION OF INTERESTS

Haijun Wang is an Editorial Board member of The Innovation Water and was blinded from reviewing or making final decisions on the manuscript. Peer review was handled independently of this member and their research group. The other authors declare no conflicts of interest.

DATA AND CODE AVAILABILITY

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