UNITED NATIONS UNIVERSITY
UNU-EHS

Technical Report

Hurricane Ida

Authors: Oscar Higuera Roa, Jack O'Connor

2021/2022

Interconnected Disaster Risks

Technical Report | Hurricane Ida

Table of Contents

1. Introduction

Hurricane Ida started with a weak and slow tropical wave emerging from the coast of Africa on 14 August 2021, passing through the Caribbean Sea, where it quickly went from tropical storm to hurricane on 27 August (Figure 1) before making landfall in Louisiana, the United States, on 29 August. After wreaking havoc in the southern United States, Ida continued moving overland to the north-east, turning into a tropical depression and later into an extratropical low that hit New York on 1 September (Beven II and others, 2022). Weather stations in New York reported maximum wind gusts up to ~126 kmh-1 on 1 and 2 September (Beven II and others, 2022). However, as an extratropical low, Ida's major impacts on New York were related to heavy rains above 76 mm per hour, with a maximum storm total rainfall of up to 244.85 mm per day that ended up in flash floods (Beven II and others, 2022). For the first time, the city activated the flash flood emergency plan due to the extraordinarily high-intensity rainfall caused by the remnants of Hurricane Ida (Foerster, 2021).

The record downpours overwhelmed New York City (NYC), turning streets into rivers and flooding underground spaces, such as subway stations and parking places (Schumacher, 2021; Toper, 2022). Overall, the flood caused costly damage (Beven II and others, 2022) and the death of 13 people (Newman and others, 2021), of whom 11 were found trapped in basements (Zaveri and others, 2021). Most of those affected by the flood were people living in illegal basement apartments, which have been recognized as a refuge for thousands of the city's poor, especially for the immigrant community (Newman and others, 2021; Yam and others, 2021). This was not an incident isolated to North America. With heavy rain events catching authorities unprepared and wreaking havoc around the world in 2021/22, for example in Germany (Fekete and Sandholz, 2021), Brazil (Comin and others, 2021) and Australia (Reid and others, 2021), Hurricane Ida was a glimpse into a future of more unpredictable, wetter storms. More importantly, it is a stark reminder of the shortcomings of risk reduction strategies that overlook people living in informal settlements and the need to find strategies to better protect the most vulnerable.

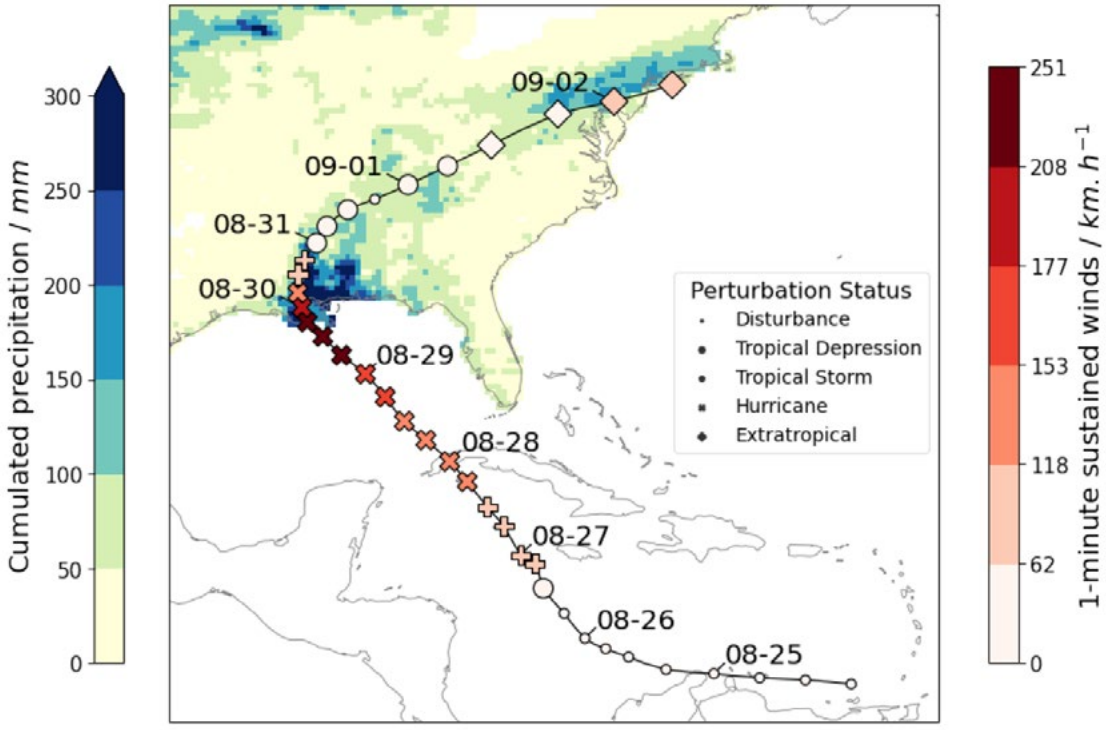

Figure 1: Precipitation and wind speed along Ida's track (Faranda and others, 2022)

2. Impacts

2.1 Infrastructure damage

Hurricane Ida caused damage estimated at $75 billion in total in the United States through winds, rains, storm surges and tornadoes, making it the costliest disaster in the world during 2021 (Kramer and Ware, 2021; Smith, 2022). The damages from Hurricane Ida alone accounted for over a quarter of the $280 billion in estimated asset losses and damages worldwide from disasters in 2021 (Münchener Rückversicherungs-Gesellschaft, and NatCatSERVICE, 2022). Infrastructure damage in NYC alone due to flooding was estimated at $7.5-9 billion (Beven II and others, 2022), with over 1,200 homes impacted (Welber, 2021). For example, transport infrastructure was extensively disrupted, with over $8 million in damage to buses, subway platforms and tracks, affecting about 9 million users highly reliant on public transportation (Plumer, 2021a; Morrison, 2022).

2.2 Loss of life

Ida caused 95 deaths across the United States (Kramer and Ware, 2021). In the north-eastern United States, the remnants of Hurricane Ida killed at least 43 people in New York, New Jersey, Connecticut and Pennsylvania (Plumer, 2021a). Thirteen people died during the downpours in NYC, ranging in age from 2 to 86 (Newman and others, 2021). Eleven of these thirteen drowned in their basement apartment residences (Beven II and others, 2022).

A flooded basement level apartment stands in a Queens neighborhood that saw massive flooding and numerous deaths following a night of heavy wind and rain from the remnants of Hurricane Ida on September 3, 2021 in New York City. (Image credit: Spencer Platt/Getty images via AFP)

2.3 Migration/displacement

Many New Yorkers, estimated to include over 200 families (Chung and others, 2021), were forced from their homes by the rising waters of the flooding caused by Hurricane Ida. People were transferred to temporary accommodation in makeshift facilities such as hotels; however, months later people were still without homes and waiting for federal aid to help rebuild their lives (Ramirez, 2021). As the people displaced were primarily working-class immigrants, often undocumented, the resources available for displaced people from organizations such as the Red Cross, who sought to arrange ~$500 support payments per household, pale in comparison to the ~$34,000 payments some flood victims managed to receive through the Federal Emergency Management Agency (FEMA) (Chung and others, 2021).

3. Drivers

3.1 Slower, wetter storms

During its formation, Hurricane Ida transformed rapidly from a weak hurricane to a Category 4 one in less than 24 hours as it reached unusually warm water in the Gulf of Mexico (Gibbens, 2021; Foerster, 2021; Shay, 2022), indicating the role of climate change in driving more intense storms through increasing ocean warming and the ability of warmer air to hold more moisture (Bhatia and others, 2019; Faranda and others, 2022). Since hurricanes feed on warm ocean water, they typically tend to weaken when they hit land (Foerster, 2021). However, the “brown ocean effect” caused by Louisiana’s wet inland areas fuelled Ida and allowed it to keep its strength as it moved further inland from the coast (Foerster, 2021; Faranda and others, 2022). The brown ocean effect occurs in areas with high humidity, and evaporation from wet soils releases large amounts of latent heat into an atmosphere with slight temperature variation in its lower levels (Hansen, 2013). As a result, tropical cyclones can maintain strength or even intensify over land, as was seen with Hurricane Ida (Hansen, 2013; Faranda and others, 2022).

Although Ida struck with powerful winds when it made landfall, the destructive force of its heavy rainfall was remarkable (Foerster, 2021). Since 1°C warmer air can hold 7 per cent more moisture, Ida’s downpours were more intense than expected (Schumacher, 2021; Gibbens, 2021). Moving from a tropical to an extratropical cyclone, Ida’s remnants brought warm, moist tropical air to the north-east, where it met with the cold fronts of the Atlantic coast, resulting in long-lasting heavy rainfalls (Schumacher, 2021; Livingston, 2021). Consequently, weather stations in NYC registered rains over 75 mm (3 inches) per hour (Schumacher, 2021), breaking the wettest day record with 244.85 mm (9.64 inches), which caused devastating urban flooding (Livingston, 2021; Beven II and others, 2022). Besides Ida’s wetter feature, its slow advance (10 mph) over land made it more destructive (Gibbens, 2021). The accelerated warming of the poles has weakened winds capable of moving hurricanes forward, and therefore, heavy rains were more devastating than wind gusts, as is typically the case with hurricanes (Gibbens, 2021; Intergovernmental Panel on Climate Change (IPCC), 2021).

3.2 Urbanization in hazard-prone areas

3.2.1 Increasing population in exposed areas

Eleven of the thirteen who died during Ida's floods in NYC were living in illegally converted basement apartments and belonged to the Asian and Pacific Islander (API) Immigrant Population (mainly represented by Indian, Korean, Filipino, Bangladeshi, Pakistani, Japanese, Vietnamese, Taiwanese and Nepalese people) (Newman and others, 2021; Yam and others, 2021). API residents (including immigrants and non-immigrants) have grown rapidly in number since 1990, from 490,000 to 1.2 million in 2019 (around 14.3 per cent of the NYC population) (NYC Mayor's Office of Immigrant Affairs, 2021). The latest city's report showed that a quarter of this population lives in poverty (NYC Mayor's Office of Immigrant Affairs, 2021), with 13 per cent of it being undocumented (Yam and others, 2021), which exacerbates vulnerability conditions, such as lack of health insurance, access to social programs or legal working conditions. With meagre income and no options to leave, hundreds of APIs in New York have no choice but to live in illegally converted basement apartments of their relatives and acquaintances (Yam and others, 2021). As APIs, informal housing has become the single option for the "coloured" working-class immigrants in the city (including Latin and black people, documented and undocumented) (Neuwirth and Sheth, 2008; Afridi and Morris, 2021). In the most recent inventory, nearly 30,000 unaccounted informal apartments (Afridi and Morris, 2021) were added to the almost 110,000 converted basement homes identified in 2008 (Neuwirth and Sheth, 2008). These numbers show the increasing creation of risk-prone areas within the city, hidden under the shadow of informality.

3.2.2 Lack of regulations / enforcement

New York City, like many major cities around the world, has for many years faced an "extreme affordable housing crisis" driven by landlords taking advantage of enforcement gaps, weakened regulations with low penalties and the fragmentation of housing-related duties among city and state agencies (Barker, 2018; Whitlow, 2019). Driven by an immensely profitable and increasingly deregulated local market, landlords have inflated rents to the point that it has become impossible for the poorest to afford a shelter in a city becoming more crowded and more expensive over time (Barker, 2018; Madden and Marcuse, 2016). As a result of the inaction and passivity of an outdated regulatory apparatus, an informal housing market has emerged from the underground, especially in ethnic enclaves of Asian, black, Hispanic and other immigrants (Barker, 2018; Usman and others, 2021). Knowing that little or nothing will happen, and even though it may be considered a crime, informal housing practices have emerged as an option for low-income immigrants in New York (Barker, 2018; Usman and others, 2021). For example, illegal room sharing, squatting, house subdivision and underground apartments (from converted basements and cellars) have become the housing option for those who arrived in the city with low-paid jobs, even if this housing does not comply with building, zoning or tenant protection codes (Usman and others, 2021).

A worker unblocks drains on a street affected by floodwater in Brooklyn, New York early on September 2, 2021, as flash flooding and record-breaking rainfall brought by the remnants of Storm Ida swept through the area. (Image credit: Ed Jones/AFP)

3.2.3 Insufficient land-use planning

Urbanization, and particularly the spread of artificial, impermeable surfaces, aggravates the impacts of rain and flooding caused by storms such as Hurricane Ida (Zhang and others, 2018). Natural systems such as streams, springs, wetlands and floodplains that were replaced by infrastructure and neighbourhood development decades ago tend to reassert their place in extreme events (McDonough, 2021; Ramirez and Kann, 2021). In the case of the Ida-related flood, the intense rainfall poured into the city's drainage systems and subway stations while turning streets into water channels after surpassing rivers' capacities (Schumacher, 2021). Furthermore, NYC was predominantly built on impervious surfaces without considering the functions of historical creeks and flood plains in regional water management, becoming more vulnerable to sudden extreme rainfall and increasing the likelihood of urban flooding (Plumer, 2021b; Ramirez and Kann, 2021). Consequently, neighbourhoods situated in flood-prone areas such as Brooklyn and Queens were critically affected by Ida (Ramirez and Kann, 2021).

This becomes even more critical when more than 2 million people, 40 per cent of water treatment plants, 60 per cent of power plants and other essential infrastructure (warehouses, railroads, highways, subways and airports) will be exposed to flood risks by 2050 (Humphries, 2019).Thus, previous experience demonstrates that when land-use planning does not consider the growing risks of extreme weather events, urban areas can by their design aggravate disasters caused by floods or other climate impacts (Zhang and others, 2018).

3.3 Ageing infrastructure

One of the major aspects of flooding events in NYC is its ageing sewage and storm water systems (American Society of Civil Engineers (ASCE), 2021). The latest National Climate Assessment warned about ageing and deteriorating infrastructure as incapable systems to manage water-related events like flooding, heavy rainfall, storm surge and rising tides (US Global Change Research Program (USGCRP), 2018). Currently, the city's infrastructure consists of an extensive network of about 12,000 km of sewage pipes, with more than 1,770 km over 100 years old and about 8,000 km installed before the 1940s (NYC Mayor's Office of Resiliency, 2021; Forman, 2014).

As a general trend in the United States, the performance of legacy storm water systems is declining due to climate change effects (ASCE, 2021). Unintentionally, storm water systems' current limited absorption capacity is due to the fact they were designed without considering storm frequency or intensity changes due to climate change, or massive urban sprawl (ASCE, 2021; Forman, 2014). Although NYC's sewer system is not designed to handle more than 1.75 inches of rain per hour, at one point Hurricane Ida dumped a record 3.15 inches on the city in a single hour (LeComte, 2022; NYC Mayor's Office of Resiliency, 2021). Despite this, the government faces a considerable task in upgrading large networks underneath densely urbanized areas due to high costs and engineering challenges (ASCE, 2021; Forman, 2014). In addition, about 60 per cent of the sewer system is combined, which means sanitary and storm flows are collected in the same pipes (NYC Mayor's Office of Resiliency, 2021). Then, during rainfall, a mixture of run-off and sewage fills the sewer system capacity (i.e. combined sewer overflow) and is discharged into local waterways, increasing its flow rate (NYC Mayor's Office of Resiliency, 2021; Forman, 2014) Since overflows occur about half the time it rains (Forman, 2014), the city was highly susceptible to flooding with Ida's heavy rains.

Typically designed for past environmental conditions, the century-old infrastructure systems not only show the city's unreadiness for current climate change effects but aggravate climate-related risks of tomorrow (Schumacher, 2021; Plumer, 2021b; USGCRP, 2018; Ramirez and Kann, 2021; Forman, 2014). It should be noted that there are extensive plans to address the issue being implemented by city authorities, including the incorporation of green infrastructure, retrofitting public urban spaces with gardens and parks, and restoring urban rivers and streams (City of New York, 2022). Such efforts must be stepped up, however, to account for the changing nature of the storms we could face in the future.

3.4 Insufficient early warning system

On the night of the emergency in NYC (1 September 2021), the urgent need to upgrade early-warning systems and how warnings can be communicated in the region was exposed. On the one hand, only around 900,000 New Yorkers out of more than 8 million residents were registered in the city's emergency alert system, Notify NYC. Likewise, the National Weather Service notifications reached citizens with newish phones in targeted geographic areas, leaving those with less advanced phones without alerts. On the other hand, the burst of 29 push notifications that Notify NYC users received in six minutes, with conflicting indications about tornadoes and flash floods, led to fatigue and confusion in users. For example, while tornado alerts recommended shelter in basements, flood alerts recommended not leaving the city but did not give information on the risks to basement dwellings. This lack of coordination of warnings also reflected the lack of communication and articulation among multiple risk management agencies. In addition, the use of technical and unfamiliar terms such as "flash flood" in the notifications demonstrated the mismatch between the message and the receiver (Walker, 2021).

Kayakers paddle down a portion of Interstate 676 after flooding from heavy rains from hurricane Ida in Philadelphia, Pennsylvania on September 2, 2021. (Image credit: Branden Eastwood / AFP)

4. Root causes

4.1 Human-induced greenhouse gas emissions

Given the excessive emission of greenhouse gases from human activities, the atmosphere has been increasing its average temperature in recent decades, leading to significant changes in climatic conditions (IPCC, 2021). Part of these changes have seen accelerated ocean warming, reflected in temperature trends at both the sea surface as well as deeper levels (Gibbens, 2021; Foerster, 2021; IPCC, 2021). These increased temperatures drive rapid transitional behaviour of hurricanes like Ida (Gibbens, 2021). Likewise, the intensification of extreme precipitation is linked to increased atmospheric humidity due to air warming (Gibbens, 2021; Faranda and others, 2022; Kirchmeier-Young and Zhang, 2020). Polar warming is also linked to the severity of Ida's long-lasting downpours. Since the polar region has been warming up faster in the past few decades, the north-east Atlantic cold fronts responsible for moving the tropical storms forward weakened, provoking prolonged heavy rains in New York (Gibbens, 2021; Faranda and others, 2022; Kossin, 2018).

4.2 Inequality of development and livelihood opportunities

Inequalities also come in the shape of urban infrastructure and planning. In NYC, climate adaptation plans reinforced underlying inequities by focusing on transforming urban infrastructure in wealthier areas like Manhattan's financial district. Conversely, vulnerable neighbourhoods located in flood-prone areas are relegated to future investments. These neighbourhoods, primarily inhabited by communities of colour, lack climate-resilient infrastructures such as urban green and blue spaces (Ramirez and Kann, 2021). However, the development of these centrally-located pockets of vulnerability and endemic poverty seems to be strategically beneficial to the broader economy of the city, which builds on cheap labour provided by the influx of low-wage migrants (Usman and others, 2021). Like many other cities, New York has ethnic enclaves (e.g. Bronx, Brooklyn, Queens) that serve as arrival centres for low-income immigrants (Usman and others, 2021). Emerging from discriminatory conditions and limited socioeconomic opportunities in mainstream society, these clustered communities are hotspots of an informal housing market (Usman and others, 2021).

In New York, the limited access to housing insurance and loans of the coloured population, plus the unaffordable regulated rents and high living costs, led to various forms of informal housing (Ramirez and Kann, 2021; Newman and others, 2021; Yam and others, 2021; Usman and others, 2021; Baker, 2021). Limited by below-average income and severely affected by the COVID-19 pandemic crisis, immigrants have been the dominant dwellers of these informal settlements due to their proximity to employment opportunities (Yam and others, 2021; Usman and others, 2021). This is especially true for undocumented immigrants who face difficulties in regular employment and access to public assistance programs because of their status (Usman and others, 2021). Given this lack of formality, it is estimated that a high percentage of the around half a million undocumented immigrants residing in New York live in this situation, although precise numbers of the undocumented population and their occupancy of basement apartments are not known (Usman and others, 2021; Yam and others, 2021; Afridi and Morris, 2021; NYC Mayor's Office of Immigrant Affairs, 2021; Baker, 2021). Nevertheless, what is on record is that the main victims of Ida's remnants were immigrants (Yam and others, 2021; Usman and others, 2021; Newman and others, 2021).

4.3 Insufficient risk governance

The damage and fatalities caused by Ida showed that New York was not sufficiently prepared for such an extreme event and raised the question of whether the city is prepared for future climates (Ramirez and Kann, 2021). The city's poor risk governance was manifested in a number of ways.

In the first place was the institutional indifference to informal housing. By systematically disregarding complaints of landlord abuse and illegal apartment subdivision, city authorities allowed apartment development while ignoring the exposure of vulnerable populations to high flood risk (Yam and others, 2021; Barker, 2018). In addition, the areas where 11 people died in basement apartments were designated on federal flood risk maps as being of low inundation risk, highlighting the urgent need for these maps to be reassessed and updated (Frank, 2021). Second, the disarticulation and lack of communication among various agencies during the emergency led to confusion and disorientation of citizens, who were informed differently by different sources (Walker, 2021). Thirdly, outpaced urban

renovation could not respond to the advancing climate crisis. Locked by complex and dense urbanization, and limited by a low investment in public infrastructure, New York still has the enormous task of replacing or upgrading its old infrastructure (i.e. sewage and storm water systems) and redesigning its mobility to alleviate traffic problems in case of evacuation (Ramirez and Kann, 2021; NYC Mayor's Office of Resiliency, 2021; Forman, 2014).

Finally, the broken relationship between the local government and vulnerable sectors of the city only accentuated the impacts of Ida. The absence of appropriate housing and social service policies for vulnerable populations partially explained the mistrust of immigrants in public institutions (Usman and others, 2021). Moreover, many immigrants were reluctant to accept government support despite the destruction, driven by the fear of being criminalized for their immigration status or living conditions (Yam and others, 2021).

Hurricane Ida crossing the gulf of Mexico from the International Space Station
(Image credit: Thomas Pesquet / European Space Agency (ESA))

5. Big picture

Hurricane Ida is an example of the new era of hurricanes fuelled by hotter seawater emerging from a warming planet, bringing extreme rainfall and flooding (Foerster, 2021; IPCC, 2021). Influenced by climate change, hurricanes will be more frequent, more intense, slower and more capable of explosive growth, revealing new threats of tropical storms (Foerster, 2021; IPCC, 2021). With about 700 million people already experiencing devastating floods, urban communities will have to adapt to heavier rainfalls and growing flood risks as global temperatures rise (Foerster, 2021; Liao and Wishart, 2021; IPCC, 2021; McGlasson, 2021), even more so when projections suggest that around 70 per cent of the global population (6.2 billion people) will live in urban areas by 2050, mostly in developing countries (Liao and Wishart, 2021).

However, Ida's impacts brought an overlooked aspect of disaster prevention and management to light. Hidden under the shadow of clandestine and informal activities, more and more vulnerable people live in risky areas within the large cities of the Global North (Usman and others, 2021). Like New York, other cities in high-income countries experience informal housing markets created mainly by migrants, resulting from combined social, political and economic processes (Usman and others, 2021). These informal housing markets have created hotspots of vulnerability and exposure to flooding, where adverse impacts are amplified (Tate and others, 2021). Following a pattern, such hotspots are related to population characteristics such as nationality and ethnicity and social conditions such as unemployment, low income or migration status (Tate and others, 2021). Thus, examining these hidden urban phenomena and understanding who is more exposed is highly needed to develop better risk mitigation strategies.

6. Solutions

6.1 Innovate

Although cities are the habitat of modern humans, urban areas depend on green and blue spaces to be sustainable and safe places. The multifunctional nature of urban green areas can improve human health and well-being while playing an important role in mitigating climate impacts such as extreme floods (Haase and others, 2017; Wishart and others, 2021). Beyond that, urban greening can significantly reduce conditions of vulnerability in cities' poor areas. For example, strategic planning and design of natural and semi-natural areas such as urban forests, parks, gardens and green roofs can help control flooding (Haase and others, 2017) while providing environmental (e.g. habitat for biodiversity), social (e.g. inclusiveness) and economic (e.g. employment) benefits (Wishart and others, 2021). Thus, cities can mitigate future climate extremes and make progress on various societal challenges by integrating the restoration of ecosystem processes into urban spatial planning and territorial development policies (Haase and others, 2017).

One approach for improving the capacity for cities to deal with increasingly heavy rainfall events is the concept of "sponge cities," which incorporates a combination of open green spaces like parks and gardens, restored streams and wetlands, green roofs, porous construction materials and water recycling initiatives into city planning to reduce the amount of potentially dangerous and polluting urban run-off during storm events. In this way, sponge cities use green elements in planning, policies and designs to adapt urban infrastructure systems to collect, store and purify (excess)

rainwater to deal with with excess water but also preserve water in the event of drought conditions (Zevenbergen and others, 2018). This approach to redesigning our cities to incorporate a larger role for nature not only helps to reduce flood risk, but it can be up to 50 per cent cheaper than traditional grey infrastructure alternatives and has the potential to assist in mitigating urban heat islands that can magnify heatwave impacts (Khatri and others, 2022; He and others, 2019). In addition, there are potential benefits to enhancing urban biodiversity with green infrastrucutre; however, ecologists should be an integral part of the design process to ensure these benefits are maximized (Filazzola and others, 2019; Williams and others, 2014). Many cities, from Nairobi to Auckland, Shanghai to London, are trialling the "upscaling" of sponge city elements. In fact, in a recent study of the "sponginess" of cities, NYC ranked equal third with Mumbai and Singapore (ARUP, 2022), indicating how far there is to go in developing the integration of green infrastructure for flood risk management to keep pace with the effects of climate change.

6.2 Let nature work

Among various forms of restoration, rewilding strategically aims to restore self-sustaining and well-functioning ecosystems by minimizing human interventions and focusing on recovering ecological processes rather than biodiversity compositional states (Perino and others, 2019). Suitable urban areas for rewilding are watercourses. Given that rewilding seeks to enhance trophic complexity, stochastic disturbances and dispersal, restored floodplains and riversides can support biodiversity while helping cities to regulate water, reduce erosion, prevent sedimentation and protect infrastructure from overflows during storms (Perino and others, 2019; Rewilding Britain, 2020).

Given the limited number of suitable areas to undertake large scale restoration in cities (River Restoration Centre, 2017), a rewilding practice called "daylighting" seems an alternative strategy for multifunctional flood protection (Wild and others, 2011). Daylighting refers to the restoration technique that recreates natural settings and removes buried conditions of water courses that, at some point, were diverted below ground (Wild and others, 2011; Chiu and others, 2022). One example of this practice is the Tibbetts Brook Daylighting project in the Bronx, NYC. This multipurpose project aims to generate pleasant natural community areas while reducing flooding. By preventing 2 billion gallons of rainwater from entering the existing drainage system, this daylighting project envisages substantially alleviating discharges in the Harlem River and reducing floods due to combined sewer overflows (Figure 2) (Cruz, 2021).

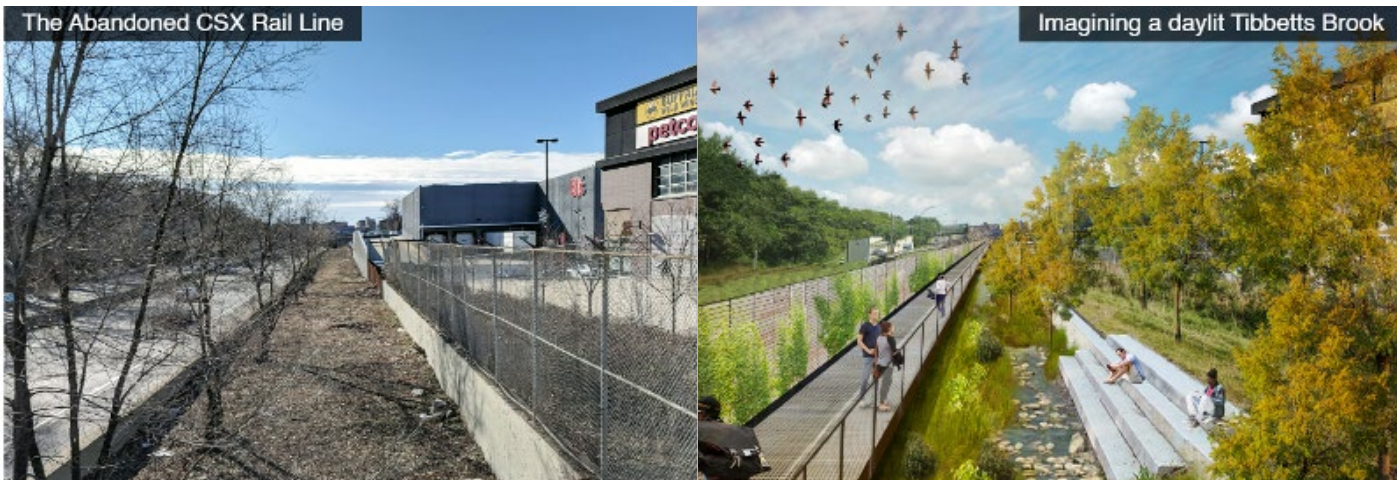

Figure 2: Before and after (render) of the Tibbetts Brook Daylighting project (Image credits: (Before - Aaron Asis) (After - Mary Miss, Julia Lindgren and Aaron Asis)).

Such an idea of rewilding urban areas challenges the paradigm of how society manages and interacts with nature and widens visions about what nature can bring to a city's needs. Therefore, urban policies that foster increasing wildness are both inspiring and useful for city managers and inhabitants. Another example of embracing natural processes to aid risk reduction is sustainable urban drainage systems (SUDS). SUDS are drainage structures that emulate the natural hydrological cycle in cities by slowing, storing and filtering rainwater and run-off to reduce flooding, improve water quality and beautify public spaces with greened areas (River Restoration Centre, 2017). In both cases, innovation unlocks the potential benefits of water stream restoration in urban areas. However, the potential to restore ecosystems in urban areas is limited by the space available, as well as by several interests, such as the need for flood protection, aesthetics or improving environmental quality (River Restoration Centre, 2017). These enabling conditions must be adequately addressed for projects like these, and the benefits they can provide for disaster risk reduction, to flourish.

6.3 Secure livelihoods

While solutions that build the resilience of infrastructure to disasters, like those described above, can help to reduce the severity of a hazard like a storm or a flood, it is also important to enhance the ability of people to withstand or cope with the impacts of hazards both before and after an extreme weather event. In the case of Hurricane Ida, the NYC government passed the Basement Apartment Conversion Pilot Program in 2019 to provide low, no-interest or forgivable loans to help low- and middle-income residents to convert their basements into safer dwellings that can be legally registered as apartments specifically to address those risks. Unfortunately, this program was stripped of funding during pandemic-related budget cuts (Abraham, 2021); however, the principle of making informal dwellings safer still has the potential to save lives. Government programs to assist landlords to upgrade dwellings to be safer as anticipatory actions to address the risks posed by extreme weather events are one way to decrease vulnerability in informal housing. However, this comes with the challenge of first being able to identify and engage with people who are essentially living outside of the law and may not want to be identified (Satterthwaite and others, 2020). This also applies to social transfer programs, whereby government buyouts can enable people to be moved out of high-risk areas. Such programs have seen different levels of success, and measures must be taken to ensure that the movement of people is hadled in a way that minimizes impacts on social cohesion and mental health (Binder and others, 2019). Relocations of entire communities can be successful when livelihoods are recreated and there is consensus among the affected people concerning the need to relocate in its form and timing, as shown in Fiji (McMichael and others, 2019).

6.4 Consume sustainably

As sewerage systems in cities around the world, including NYC, are pushed to breaking point by heavy rain events, our garbage is clogging vital waterways and contributing to the risk of flooding (Lamond and others, 2012). Unlike organic matter, human-made waste like plastics and other artificial materials often take longer to break down and can build up to clog drainage systems (Honingh and others, 2020). In the sewerage systems of big cities like New York and London, the rise in wet wipes being used as toilet tissue and flushed into the sewer system by residents has led to a phenomenon known as "fatbergs," whereby this waste combines with other garbage and fats to create large masses clogging up sewer systems (Alda□Vidal and others, 2020). Although marketed as "flushable wet wipes," they do not disintegrate well after disposal, and in the U.S. up to $1 billion a year is spent dealing with the problem (Harter and others, 2021; Bowden, 2019). Awareness campaigns like "Trash It. Don't Flush It," implemented by the NYC government, seek to educate and change the behaviour of residents to avoid actions that can increase flood risk by clogging up vital sewer systems.

6.5 Conclusion

The solutions outlined above are only a selection of possible solutions for heavy rainfall-induced flooding in urban areas but exemplify a shift in our collective mindset to address the root causes, reduce the impact and increase resilience to storms in a holistic way. Therefore, they are intended to work together as a package, taking advantage of the different co-benefits and synergies of the collected solutions to address multiple challenges while minimizing trade-offs. The solution package approach also represents the idea that none of these solutions is sufficient if they are implemented in isolation; only through this integrated, multifaceted approach can the problem truly be addressed.

7. References

Abraham, Roshan (2021). NYC Funded a Pilot to Make Basement Apartments Safer, But Then It Went Off Track, 13 October. Available at https://nextcity.org/urbanist-news/nyc-funded-pilot-to-make-basement-apartments-safer-but-then-went-off-track

Afridi, Lena, and Rebekah Morris (2021). New York's Housing Underground: 13 years later. Available at https://prattcenter.net/uploads/1021/1634833975615756/Pratt_Center_New_Yorks_Housing_Undergound_13_Years_Later_102121.pdf

Alda□Vidal, Cecilia, Alison L. Browne and Claire Hoolohan (2020). "Unflushables": Establishing a global agenda for action on everyday practices associated with sewer blockages, water quality, and plastic pollution. *Wiley Interdisciplinary Reviews: Water,* vol. 7, No. 4, pp.1-15. DOI: 10.1002/wat2.1452

American Society of Civil Engineers (2021). 2021 Report Card for America's Infrastructure: A comprehensive assessment of America's infrastructure. Washington DC. Available at https://infrastructurereportcard.org/wp-content/uploads/2020/12/National_IRC_2021-report.pdf

ARUP (2022). *Global Sponge Cities Snapshot. London.* Available at https://www.arup.com/perspectives/publications/research/section/-/media/arup/files/publications/g/global-sponge-cities-snapshot.pdf

Baker, Bryan (2021). *Estimates of the Unauthorized Immigrant Population Residing in the United States: January 2015–January 2018.* Washington, D.C.: U.S. Department of Homeland Security. Available at https://www.dhs.gov/sites/default/files/publications/immigration-statistics/Pop_Estimate/UnauthImmigrant/unauthorized_immigrant_population_estimates_2015_-_2018.pdf

Barker, Kim (2018). Behind New York's Housing Crisis: Weakened Laws and Fragmented Regulation. *The New York Times,* 20 May. Available at https://www.nytimes.com/interactive/2018/05/20/nyregion/affordable-housing-nyc.html?mtrref=undefined&gwh=F74201571BD04A686A9A2F28AB6910C2&gwt=pay&assetType=PAYWALL

Beven II, John L., Andrew Hagen and Robbie Berg (2022). National Hurricane Centre Tropical Cyclone Report: Hurricane Ida. Available at https://www.nhc.noaa.gov/data/tcr/AL092021_Ida.pdf

Bhatia, Kieran T., and others (2019). Recent increases in tropical cyclone intensification rates. *Nature Communications,* vol. 10, No. 1, art. 635, pp. 1–9. DOI: 10.1038/s41467-019-08471-z

Binder, Sherri, and others (2019). Home buyouts and household recovery: neighborhood differences three years after Hurricane Sandy. Environmental Hazards, vol. 18, No. 2, pp. 127–45. DOI: 10.1080/17477891.2018.1511404

Bowden, Ebony (2019). Nightmarish 'fatbergs' are clogging New York's sewers. *New York Post,* 22 April. Available at https://nypost.com/2019/04/22/nightmarish-fatbergs-are-clogging-new-yorks-sewers/

Chiu, Yen-Yu, Nidhi Raina and Hung-En Chen (2022). Evolution of Flood Defense Strategies: Toward Nature-Based Solutions. *Environments,* vol. 9, No. 1, 2. DOI: 10.3390/environments9010002

Chung, Christine, Josefa Velasquez and Allison Dikanovic (2021). Undocumented Immigrant New Yorkers Shut Out of Federal Hurricane Ida Aid, 17 September. Available at https://www.thecity.nyc/housing/2021/9/16/22678701/undocumented-immigrant-new-yorkers-shut-out-of-federal-hurricane-ida-aid

City of New York (2022). NYC Green Infrastructure: 2021 Annual Report. New York. Available at https://www1.nyc.gov/assets/dep/downloads/pdf/water/stormwater/green-infrastructure/gi-annual-report-2021.pdf

Comin, Alcimoni Nelci, and others (2021). Extreme rainfall event in the Northeast coast of Brazil: a numerical sensitivity study. *Meteorology and Atmospheric Physics,* vol. 133, pp. 141–62. DOI: 10.1007/s00703-020-00747-0

Cruz, David (2021). How Extreme Flooding Of This Bronx Highway Could Have Been Avoided, 24 September. Available at https://gothamist.com/news/how-extreme-flooding-bronx-highway-could-have-been-avoided

Faranda, Davide, and others (2022). A climate-change attribution retrospective of some impactful weather extremes of 2021. *Weather and Climate Dynamics Discussions,* [preprint], pp. 1–37. DOI: 10.5194/wcd-2022-9

Fekete, Alexander, and Simone Sandholz (2021). Here Comes the Flood, but Not Failure? Lessons to Learn after the Heavy Rain and Pluvial Floods in Germany 2021. Water, vol. 13, No. 21, art. 3016, pp. 1-20. DOI: 10.3390/w13213016

Filazzola, Alessandro, Namrata Shrestha and J. Scott MacIvor (2019). The contribution of constructed green infrastructure to urban biodiversity: A synthesis and meta□analysis. *Journal of Applied Ecology,* vol. 56, No. 9, pp. 2131–43. DOI: 10.1111/1365-2664.13475

Foerster, Jim (2021). Climate Change Fuels Catastrophic Rainfall During Hurricane Ida, 8 September. Available at https://www.forbes.com/sites/jimfoerster/2021/09/08/climate-change-fuels-catastrophic-rainfall-during-hurricane-ida/?sh=699523494a61

Forman, Adam (2014). Caution Ahead: Overdue Investments for New York's Aging Infrastructure. New York: Center for an Urban Future. Available at https://nycfuture.org/pdf/Caution-Ahead.pdf

Frank, Thomas (2021). Deaths from Hurricane Ida Expose Flaws in FEMA Flood Maps, 6 October. Available at https://www.scientificamerican.com/article/deaths-from-hurricane-ida-expose-flaws-in-fema-flood-maps/#

Gibbens, Sarah (2021). How climate change is fueling hurricanes like Ida, 2 September. Available at https://www.nationalgeographic.co.uk/environment-and-conservation/2021/09/how-climate-change-is-fueling-hurricanes-like-ida

Haase, Dagmar, and others (2017). Greening cities – To be socially inclusive? About the alleged paradox of society and ecology in cities. *Habitat International,* vol. 64, pp. 41–48. DOI: 10.1016/j.habitatint.2017.04.005

Hansen, Kathryn (2013). 'Brown Ocean' Can Fuel Inland Tropical Cyclones, 13 July. Available at https://www.nasa.gov/content/goddard/brown-ocean-can-fuel-inland-tropical-cyclones/

Harter, Thomas, and others (2021). Reduced dispersibility of flushable wet wipes after wet storage. *Scientific Reports,* vol. 11, art. 7942, pp. 1-9. DOI: 10.1038/s41598-021-86971-z

He, Bao-Jie, and others (2019). Co-benefits approach: Opportunities for implementing sponge city and urban heat island mitigation. *Land Use Policy,* vol. 86, pp. 147–57. DOI: 10.1016/j.landusepol.2019.05.003

Honingh, Dorien, and others (2020). Urban River Water Level Increase Through Plastic Waste Accumulation at a Rack Structure. *Frontiers in Earth Science,* vol. 8, art, pp. 1-8. 28. DOI: 10.3389/feart.2020.00028

Humphries, Courtney (2019). The "mind-boggling" task of protecting New York City from rising seas, 24 April. Available at https://www.technologyreview.com/2019/04/24/135878/the-mind-boggling-task-of-protecting-new-york-city-from-rising-seas/

Intergovernmental Panel on Climate Change (2021). Summary for Policymakers. In *Climate Change 2021: The Physical Science Basis.* Masson-Delmotte, V., and others, eds. Cambridge and New York. Available at https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

Khatri, Akanksha, and others (2022). BiodiverCities by 2030: Transforming Cities' Relationship with Nature: Insight Report. Geneva: World Economic Forum. Available at: https://www3.weforum.org/docs/WEF_BiodiverCities_by_2030_2022.pdf

Kirchmeier-Young, Megan C., and Xuebin Zhang (2020). Human influence has intensified extreme precipitation in North America. *Proceedings of the National Academy of Sciences of the United States of America,* vol. 117, No. 24, pp. 13308–13. DOI: 10.1073/pnas.1921628117

Kossin, James P. (2018). A global slowdown of tropical-cyclone translation speed. *Nature,* vol. 558, No. 7708, pp. 104–07. DOI: 10.1038/s41586-018-0158-3

Kramer, Katherine, and Joe Ware (2021). Counting the cost 2021: A year of climate breakdown. Available at https://policycommons.net/artifacts/2429554/counting-the-cost-2021-a-year-of-climate-breakdown/3451146/

Lamond, J., N. Bhattacharya and R. Bloch (2012). The Role Of Solid Waste Management As A Response To Urban Flood Risk In Developing Countries, A Case Study Analysis. *WIT Transactions on Ecology and the Environment,* vol. 159, pp. 193–204. DOI: 10.2495/FRIAR120161

LeComte, Douglas (2022). U.S. Weather Highlights: 2021 Hurricane Ida, Historic Cold, Heat, Drought, and Severe Storms. *Weatherwise,* vol. 75, No. 3, pp. 14–23. DOI: 10.1080/00431672.2022.2042127

Liao, Xiawei, and Marcus J. Wishart (2021). Nature-based solutions in China: Financing "sponge cities" for integrated urban flood management, 2 August. Available at https://blogs.worldbank.org/eastasiapacific/nature-based-solutions-china-financing-sponge-cities-integrated-urban-flood

Livingston, Ian (2021). Ida's impact from the Gulf Coast to Northeast — by the numbers. *The Washington Post,* 3 September. Available at https://www.washingtonpost.com/weather/2021/09/03/hurricane-ida-numbers-surge-wind-pressure-damage/

Madden, David, and Peter Marcuse (2016). *In Defense of Housing.* London: Verso Books.

McDonough, Annie (2021). How New York can prepare for flooding, 2 September. Available at https://www.cityandstateny.com/policy/2021/09/how-new-york-can-prepare-flooding/183699/

McMichael, Celia, Manasa Katonivualiku and Teresia Powell (2019). Planned relocation and everyday agency in low-lying coastal villages in Fiji. *The Geographical Journal,* vol. 185, No. 3, pp. 325–37. DOI: 10.1111/geoj.12312

Morrison, Margaret (2022). Evaluating the Impact of Sea-Level Rise on Transportation in Red Hook, New York. Master Thesis. Duke University. Available at https://dukespace.lib.duke.edu/dspace/bitstream/handle/10161/24841/morrison_mp_final_20220422.pdf?sequence=1

Münchener Rückversicherungs-Gesellschaft, and NatCatSERVICE (2022). Factsheet natural catastrophes in 2021. Available at https://www.munichre.com/content/dam/munichre/mrwebsiteslaunches/natcat-2022/2021_Figures-of-the-year.pdf/_jcr_content/renditions/original./2021_Figures-of-the-year.pdf

Neuwirth, Robert, and Rachana Sheth (2008). New York's Housing Underground: A Refuge and Resource. New York: Pratt Center. Available at https://chhayacdc.org/wp-content/uploads/2019/11/New-Yorks-Housing-Underground.pdf

Newman, Andy, and others (2021). What we know about the people who died in the flooding, 14 September. Available at https://www.nytimes.com/2021/09/02/nyregion/ida-new-york-city-deaths.html

NYC Mayor's Office of Immigrant Affairs (2021). A Demographic Snapshot: NYC's Asian and Pacific Islander (API) Immigrant Population. New York. Available at https://www1.nyc.gov/assets/immigrants/downloads/pdf/Fact-Sheet-NYCs-API-Immigrant-Population.pdf

NYC Mayor's Office of Resiliency (2021). New York City Stormwater Resiliency Plan: Helping New York understand and manage vulnerabilities from extreme rain. New York. Available at https://www1.nyc.gov/assets/orr/pdf/publications/stormwater-resiliency-plan.pdf

Perino, Andrea, and others (2019). Rewilding complex ecosystems. *Science,* vol. 364, No. 6438. DOI: 10.1126/science.aav5570

Plumer, Brad (2021a). As Ida Deaths Rise, N.Y. Leaders Look Toward Future Storms. *The New York Times,* 3 September.

Available at https://www.nytimes.com/live/2021/09/03/nyregion/nyc-flooding-ida

_____ (2021b). New York's Record Rain Carries Stark Warning About Climate Change. *The New York Times,* 2 September. Available at https://www.nytimes.com/2021/09/02/climate/new-york-rain-climate-change.html

Ramirez, Rachel (2021). Months after Ida flooded New York City, some residents still have no real homes for the holidays, 19 December. Available at https://edition.cnn.com/2021/12/19/us/ida-survivors-new-york-city-holidays-climate/index.html

Ramirez, Rachel, and Drew Kann (2021). Climate scientist warns NYC not prepared for future extreme rainfall, flooding, 5 September. Available at https://abc7ny.com/nyc-climate-expert-warning-storm-preparedness-hurricane-ida/11001057/

Reid, Kimberley J., and others (2021). Extreme Water Vapor Transport During the March 2021 Sydney Floods in the Context of Climate Projections. *Geophysical Research Letters,* vol. 48, No. 22, e2021GL095335. DOI: 10.1029/2021GL095335

Rewilding Britain (2020). Rewilding to Enable Natural Flood Management. Available at https://rewildingbritain.org.uk/blog/rewilding-to-enable-natural-flood-management

River Restoration Centre (2017). River restoration in Urban Areas. Factsheet, UK. Available at https://www.therrc.co.uk/sites/default/files/general/Training/esmee/river_restoration_in_urban_areas.pdf

Satterthwaite, David, and others (2020). Building Resilience to Climate Change in Informal Settlements. *One Earth,* vol. 2, No. 2, pp. 143–56. DOI: 10.1016/j.oneear.2020.02.002

Schumacher, Russ (2021). Hurricane Ida: 2 reasons for its record-shattering rainfall in NYC and the Northeast long after the winds weakened, 3 September. Available at https://theconversation.com/hurricane-ida-2-reasons-for-its-record-shattering-rainfall-in-nyc-and-the-northeast-long-after-the-winds-weakened-167252

Shay, Nick (2022). Hurricane Ida turned into a monster thanks to a giant warm patch in the Gulf of Mexico – here's what happened, 31 August. Available at https://theconversation.com/hurricane-ida-turned-into-a-monster-thanks-to-a-giant-warm-patch-in-the-gulf-of-mexico-heres-what-happened-167029

Smith, Adam B. (2020). *U.S. Billion-dollar Weather and Climate Disasters, 1980 - present (NCEI Accession 0209268).* Asheville, North Carolina: NOAA National Centers for Environmental Information. Dataset. DOI: 10.25921/STKW-7W73

Tate, Eric, and others (2021). Flood exposure and social vulnerability in the United States. *Natural Hazards,* vol. 106, pp. 435–57. DOI: 10.1007/s11069-020-04470-2

Toper, Ezgi (2022). The top ten most costly natural disasters in 2021, 12 January. Available at https://www.trtworld.com/magazine/the-top-ten-most-costly-natural-disasters-in-2021-53584

U.S. Global Change Research Program (2018). *Fourth National Climate Assessment. Volume II: Impacts, Risks, and Adaptation in the United States.* DOI: 10.7930/NCA4.2018

Usman, Mohammad, Sabina Maslova and Gemma Burgess (2021). Urban informality in the Global North: (il)legal status and housing strategies of Ghanaian migrants in New York City. *International Journal of Housing Policy,* vol. 21, No. 2, pp. 247–67. DOI: 10.1080/19491247.2020.1814189

Walker, Alissa (2021). What Went Wrong With NYC's Emergency Alerts, and How Can We Do Better?, 10 September. Available at https://www.curbed.com/2021/09/ida-emergency-alerts-flooding-new-york-city.html

Whitlow, John (2019). Gentrification and Countermovement: The Right to Counsel and New York City's Affordable Housing Crisis. *Fordham Urban Law Journal,* vol. 46, No. 5, pp. 1081-1136. Available at https://ir.lawnet.fordham.edu/ulj/vol46/iss5/2

Wild, T. C., and others (2011). Deculverting: reviewing the evidence on the 'daylighting' and restoration of culverted rivers. *Water and Environment Journal,* vol. 25, No. 3, pp. 412–21. DOI: 10.1111/j.1747-6593.2010.00236.x

Williams, Nicholas S.G., Jeremy Lundholm and J. Scott MacIvor (2014). Do green roofs help urban biodiversity conservation? *Journal of Applied Ecology,* vol. 51, No. 6, pp. 1643–49. DOI: 10.1111/1365-2664.12333

Wishart, Marcus, and others (2021). The Gray, Green, Blue Continuum: Valuing the Benefits of Nature-Based Solutions for Integrated Urban Flood Management in China. Washington, D.C.: World Bank. Available at https://openknowledge.worldbank.org/handle/10986/35687

Yam, Kimmy, and Sakshi Venkatraman (2021). Ida's forgotten victims: Nearly all storm's basement deaths were Asian residents, obscured by climate injustice, 18 October. Available at https://www.nbcnews.com/news/asian-america/ida-s-forgotten-victims-nearly-all-storm-s-basement-deaths-n1281670

Zaveri, Mihir, and others (2021). How the Storm Turned Basement Apartments Into Death Traps. *The New York Times,* 2 September. Available at https://www.nytimes.com/2021/09/02/nyregion/basement-apartment-floods-deaths.html

Zevenbergen, Chris, Dafang Fu, and Assela Pathirana (2018). Transitioning to Sponge Cities: Challenges and Opportunities to Address Urban Water Problems in China. Water, vol. 10, No. 9, art. 1230, pp. 1-13. DOI: 10.3390/w10091230

Zhang, Wei, and others (2018). Urbanization exacerbated the rainfall and flooding caused by hurricane Harvey in Houston. *Nature,* vol. 563, pp. 384–88. DOI: 10.1038/s41586-018-0676-z

Cover Image Credit: David Dee Delgado/Getty images via AFP
A person makes their way in rainfall from the remnants of Hurricane Ida on September 1, 2021, in the Bronx borough of New York City

https://doi.org/10.53324/NYKY2894

e-ISBN: 978-3-944535-75-3
e-ISSN: 2304-0467