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Building Risk-Informed Communities: Case Studies on the Applications of Earth Observation Data

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ABSTRACT

Disaster risk is configured over time through complex climate interactions and development processes that generate conditions of hazard, vulnerability, and exposure. Unplanned urban expansion places communities at increased risk of human and economic loss from disasters. Limited examples exist of communities that have procedures for urban growth that incorporate disaster risk management into planning and development. Though global frameworks exist to provide guidance on how to mainstream disaster risk into urban settings, gaps remain in how to visualize and understand risk systemically and in transboundary and changing contexts. One method for addressing these gaps is through the use of Earth observation data products and tools, which can enhance knowledge of changing environments and the fundamental forces that drive vulnerability and exposure. This chapter considers two case studies on climate and disaster risk reduction in growing urban settings, where the applications of Earth observation data offer opportunities for building risk-informed systems. Integrating new methodologies such as these can improve the landscape of future urbanization toward more inclusive approaches for climate and disaster risk management.

7.1. INTRODUCTION

Building resilience through disaster risk reduction is often a key priority of governments, businesses, and the international community. This is attributable not only to the acceleration in the number and intensity of disasters, but also to the increasing exposure and vulnerability of communities, particularly those living in growing informal settlements and urban areas (Peel & Fisher, 2017). While public attention is often focused on the large or extreme events, many disasters remain less visible, including extreme temperatures and droughts, flash and coastal floods, and landslides and subsidence, but have extensive impacts on urban growth and development, and on lives and livelihoods. Notably, the European heat wave in the summer of 2003 led to

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Earth Observation Applications and Global Policy Frameworks, Geophysical Monograph 274, First Edition.
Edited by Argyro Kavvada, Douglas Cripe, and Lawrence Friedl.

DOI:10.1002/9781119536789.ch07

approximately 70,000 excess deaths across Europe (Robine et al., 2008).

Slightly more than half of the world's population is currently living in urban areas, a number that is expected to rise to 60% by 2030 (Brenner & Schmidt, 2014; UN DESA, 2014). Around 90% of growth in urban areas will occur in low-income countries (UN DESA, 2014). The primary factor contributing to these trends is neither fertility nor age structure, but migration (UN Habitat, 2016a). Unplanned urban expansion influenced by the quality of urban management practices places communities at increased risk of human and economic loss from disasters. Urban poor that live in peri-urban areas and in informal settlements are particularly vulnerable to disasters due to the development of insecure shelters in high-risk areas. (Peri-urban areas are transition spaces with some degree of intermingling of both urban and rural uses and are located on the fringe of heavily developed cities, often comprising a scattered pattern of low-density concentrations near transportation hubs (Wandl & Magoni, 2016). This is exacerbated by limited access to basic and emergency services, and an overall lack of resilience (Dickson et al., 2012).

Disaster risk is configured over time through complex climate interactions between development processes that generate conditions of hazard, vulnerability, and exposure. City governments are constrained by a lack of up-to-date, comprehensive information about hazard and exposure in urban areas, and there exist limited examples of cities that have standardized procedures for incorporating disaster risk management into city planning (Dickson et al., 2012). The 2030 Global Agenda for Sustainable Development and the Sendai Framework for Disaster Risk Reduction provide global guidelines for reducing the impact of disasters, while also addressing the underlying drivers of disaster risk and safeguarding current and future development gains (UN GA, 2015; UNISDR, 2015). These global frameworks also offer opportunities for governments and societies to implement concrete measures to avoid the creation of new risks and also reduce the level of existing risks in order to strengthen the economic, social, and environmental resilience of communities by addressing the exposure of people and other assets.

Earth observations (EO) gather information about the physical, chemical, and biological systems of the planet via remotely sensed technologies, supplemented by ground-based survey methods that can monitor and assess the status of, and changes in, the natural and built environment. This can include satellite technologies, in situ, and airborne operations that observe the Earth as a system. The high temporal and spatial resolution can complement local measurement and assessments, as well as the understanding of the uneven distribution of risk. Further, it can provide large-scale understanding of risk exposure in order to support further analysis of hazard distribution with regard to settlement areas, system services, and assets (UN SPIDER, 2014).

This chapter analyzes the approaches used for understanding rural, urban, and city contexts in regard to disaster risk management; the related challenges that occur within, across, and outside of these boundaries; and how EO can present opportunities for addressing these challenges. It considers two case studies on flash flood and urban heat island risk, highlighting the role that EO can play in building more risk-informed communities. It concludes with a brief analysis of the challenges and opportunities for addressing risk-informed disaster management in order to improve the landscape for future urbanizations.

7.2. DEFINING URBAN BOUNDARIES

The city, one of the world's biggest phenomena of the 21st century, has evolved greatly over the centuries, particularly in terms of its size, form, structure, and composition, while largely maintaining its importance in local and regional development. In just 65 years, the world has experienced a population shift from rural to urban, as witnessed by an increase in the global population living in urban areas from 29.6% in 1950 to 54% in 2015 (UN DESA, 2014). Today cities are a potent force for addressing sustainable economic growth, development, and prosperity. They can drive innovation, consumption, and investment in both developed and developing countries, but they can also introduce increased exposure to risk through changes in the built environment that ignore vulnerable populations (UN Habitat, 2016b).

Cities can certainly take the lead to address many of the global challenges of the 21st century, including poverty, inequality, unemployment, environmental degradation, and climate change. City density and economies of agglomeration link economy, energy, environment, science, technology, and social and economic outcomes. These interrelations are important to formulate integrated policies needed to reduce risk and achieve sustainable development. In working at an urban level, it is possible to include people, locations, and city conditions to ensure that no one, and no place, is left behind.

But, what is exactly a city or an urban area? Which size is required to qualify it as a city? What type of particular administrative, legal, or historical status is needed? How do we distinguish an urban area from a town or a village? And what does this mean in the context of climate and disaster risk? A study of the city as a unit of analysis is critical for overcoming future urbanization challenges and for repositioning cities as engines of national growth and risk-informed development. However, these concepts and related monitoring approaches should not aim at changing existing administrative and statistical definitions in countries, but adopt a functional definition for cities for purposes of monitoring progress in a pragmatic, cost-effective, simple, and accurate manner at the global level. These global definitions should be applicable at a supranational level and used as guiding principles for collection of metrics that can provide data consistency and serve at the same time as a global and regional framework for comparability.

National statistics offices employ definitions for urban areas with very different criteria that are not compatible and make it difficult to aggregate values in a consistent manner. Such definitional difficulties are related not only to the use of various concepts, as it is the case with slightly more than half of countries applying two or more criteria, but also to the changes of definitions over time in the same given country. It is estimated that nearly two-thirds of countries utilize an administrative definition to classify urban areas, but almost all of them add additional elements such as population size, density, economic occupation, or urban functions to characterize urban settings. Forty-nine countries utilize only population size and density, but this number doubles when it is used in conjunction with other criteria (UN DESA, 2014). Things become further complicated when analyzing population thresholds used by countries to define urban/city areas. One third of countries use the concept of *urban agglomeration* to estimate their city data, and another 12% only for their capital cities. As much as 38% of countries use another concept, referred to as the *city proper*. It is estimated that one fifth of countries combine various definitions to estimate city and population data in their urban areas. Nearly 5% of additional countries use a different criterion to define their urban populations, which is the *metropolitan area* (UN DESA, 2014). Furthermore, many cities tend to expand on contiguous physical areas along their periphery, others mostly grow by the annexation of rural or urban settlements outside the urban extent, while others urbanize in areas that are not contiguous to the urban extent. These urban dynamics generate cities with different patterns and conditions that make it difficult to delimit an urban area. Cities can also be defined by their degree of urbanization, a classification that indicates the character of an area based on the share of local population living in local administrative units. Over the years, the concept has been updated to include other regions and countries, incorporate emerging settlement trends, as well as to incorporate new forms of data (e.g., spatial data) (JRC, 2016).

In order to provide relevant information at the intended level of management, there is need for spatial data, adequate technology, and management systems to complement high-quality official statistics in which spatial analysis becomes a central component. Earth observation data can provide relevant information for policy makers to decide on local-level allocation of resources and the monitoring of equitable outcomes across and within cities. It can also help policy makers identify development trends that contribute to exposure and vulnerability in order to decide on the risk management strategies needed.

The measurement of spatial indicators required to define city boundaries is not an easy task due to the uniqueness of the urban boundary, the fragmented and interstitial fabric of the cities, and the spatial and functional blur of urban-rural areas. However, geospatial and space-based information can detect, map, monitor, and visualize indicators related to risk, including infrastructure and land use, topography, urbanization, and transportation networks to detect changes over time caused by planned development and unforeseen crises. They can also be used to map uneven distribution of risk across borders to provide an improved understanding of settlement areas, system services, and assets. Finally, satellite data and related products aimed at improved climate and disaster risk decision support have improved immensely to become a key source of risk information and the sustainability of human interventions (UN SPIDER, 2014).

7.3. EARTH OBSERVATIONS FOR BUILDING RISK-INFORMED COMMUNITIES

7.3.1. Case Study 1: Flash Flood Risk in Lima

Building on the challenges with delimiting boundaries of changing urban settings, this section provides two case studies that explore challenges and opportunities for integrating Earth observations data in the context of climate and disaster risk. The ability to coordinate and better integrate EO data into long-term development is essential for building risk-informed communities.

Characteristics of Lima

Lima is located in a geographically complex region within the central Rímac river basin, situated along the Pacific Ocean, flanking the Andean Cordillera (Fig. 7.1) (Oliver-Smith, 1999). The majority of Lima lies within the coastal desert plain and receives low annual rainfall of 14 mm (Lagos et al., 2008). There is significant seasonality in rainfall, with the majority of rainfall occurring from January to March (IRIDL. 2018). While characterized as a desert due to low annual precipitation, Lima is sensitive to perturbations in coupled atmospheric-oceanic

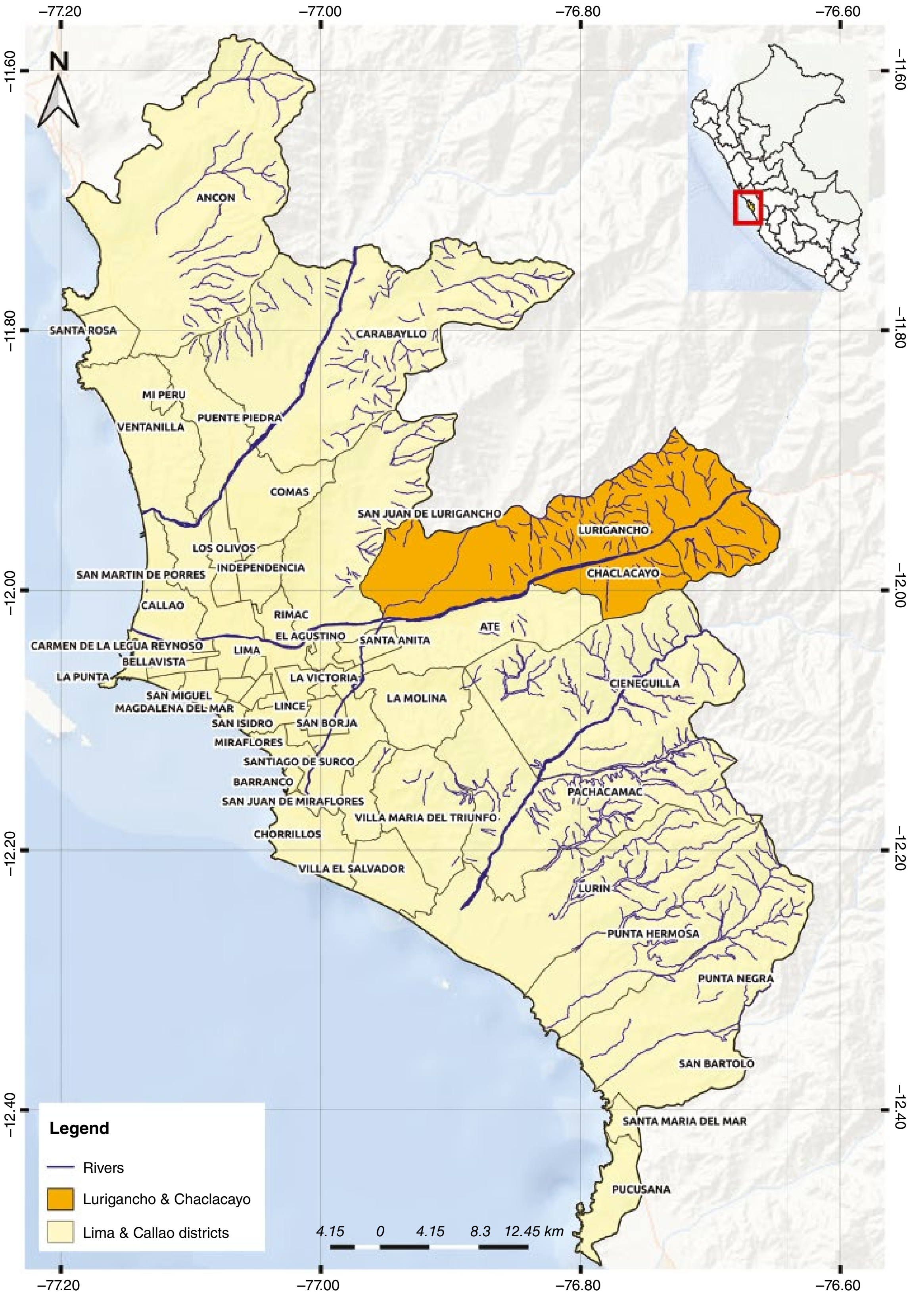

Figure 7.1 Map of Lima and the surrounding drainage basin (map produced by authors; data from National Institute for Civil Defense (INDECI)).

regimes, induced by local warming of the ocean off the coast. This includes both the larger scale warming and cooling of the equatorial Pacific ENSO (El Niño, Southern Oscillation), and the anomalous warming of Pacific Ocean waters adjacent to Lima's coast, El Niño Costero, the effects of which have historically led to increased heavy rainfall and flash floods in Lima and the broader region (Lavado-Casimiro, 2014; Francesconi et al., 2018).

Over the past 30 years, Peru, like many countries in South America, has experienced a rapid transition of populations from rural to urban areas (Villa & Rodriguez, 1996; Scott, 2005). This has resulted in an increase and persistence of informal settlements along the peripheries of Lima, the capital and largest city in Peru. These settlements, referred to colloquially as *Barriadas*, and other informal housing arrangements, account for approximately 40%–45% of the total population of Lima (Golda-Pongratz, 2004). Scott and Storper (2015) reflect on the concept of urban-rural divides in stating, "there can be no rigid and absolute boundary between any given city and the rest of geographic space" (p. 5). Lima exemplifies this difficulty in defining the reach and structure of an urban space, as the notational definition of the city often fails to capture the realities of city-related and urban-specific issues spanning across the metropolitan municipality of Lima's 43 districts.

Many of Lima's informal settlements date back to Fujimori's government land-titling campaign and continue to be the norm in Peruvian society, where approximately 80% of homes are self built (Cockburn et al., 2015). Barrios, such as José Carlos Mariátegui and Santa María de Huachipa, exemplify the differences in informal housing throughout the city, with the former existing along the steep hillsides that compose the city's peripheries and the latter existing at the heart of the city along the Rímac River (Fernandes, 2011). (Barrios, in the context of Lima, Peru, are defined as a peri-urban shanty towns. These are divisions of municipalities delineated by local authorities and often have a distinct character or particular specific socioeconomic status (Muhlare, 1996).) Varying degrees of infrastructure integration, government oversight, and socioeconomic status largely determine resident's exposure to natural hazards.

The integration of informal settlements into Lima's economy and governance structures has occurred in both the barrios and within the traditional city boundaries. Disjunction during community development has resulted in unintended consequences, where the construction of new housing or facilities potentially shifts exposure to natural hazards (Allen et al., 2017), an example of which is the integration of informal settlements into Lima's economy and governance structures. For example, introducing impervious surfaces to a natural, seasonal riverbed or drainage site, or discharging rainfall to a local or spatially distant area may inadvertently augment the magnitude of associated impact from flooding over areas that may expect, as well as introduce, the risk of impact from flooding to areas previously not exposed (Parkinson et al., 2007; Nichito, 2007). Because informal development often occurs over time, this process can lead to the production of risk traps, where cycles of climbing incremental risk and episodic hazard events compound to create highly vulnerable populations (Clima Sin Riesgo, 2015).

What Does Flood Mean to Lima?

For Lima, flood risk in general is commonly perceived as low, as are the risks of heavy rainfall and associated flash flooding in urban areas. However, flash floods and flash-flood-related debris flows (huaycos) are common in the Rímac River valley (Table 7.1). (Huayco, or huaico, deriving from the Quecha word *wayq'u*, is a Peruvian word that refers to the light and medium alluvium mobilized from the Andes and surrounding areas during rainy seasons (SINADECI, 2010).) In 1925 and 2017 (El Niño Costero years), huaycos and flash flooding occurred in Lima and Chaclacayo, impacting the hydroelectric plants in Yanacoto and Chosica, leaving Lima without electricity and clean water (Takahashi & Martinez, 2017). As seen in Table 7.1, huaycos in 2012, 2015, and 2017 have placed a larger population and region of the city at risk in recent years. To understand both the current risk and potential for future changes in risk of impact, there is a need for increased attention to the coupled risk of flash flood and huayco-related impacts, as well as potential risk mitigation pathways for Lima's most vulnerable populations.

Due to complexities in capturing geophysical events, Lima Province lacks a long-term, site-specific compendium or map for identifying areas at risk for flash flood, riverine flood, and huayco events. Mapping and monitoring efforts are further complicated due to the limited spatial and temporal nature of these hydrometeorological events. While flooding impacts often occur within Lima Province, especially in the districts on the eastern edge of the Province on the western Andean Cordillera, the rainfall events causing flooding can be located deeper in the Cordillera or from other disparate sources. The lack of historical data makes it difficult not only to isolate the nature and characteristics of these events, but also to develop methods to forecast these events, and subsequently to develop improved preparedness and response actions (Kruczkiewicz et al., 2021a).

Table 7.1 Recent huayco events in Chaclacayo and Lurigancho districts

Date	Event description	District	Affected population
05/01/2012	Rainfall and huayco in the Quebrada Los Condores area	Chaclacayo	60
05/04/2012	Huayco impacts Lima Province	Chaclacayo	30
15/01/2017	Huayco	Chaclacayo	658
22/01/2017	Huayco due to overflow of the Cusipata River	Chaclacayo	0
25/01/2017	Huayco	Chaclacayo	59
26/01/2017	Huayco	Chaclacayo	3
27/02/2017	Huayco and surface runoff due to heavy rainfall	Chaclacayo	0
15/03/2017	Huayco and flooding due to runoff from Cerro El Mirador	Chaclacayo	0
15/03/2017	Huayco and flooding due to runoff from the Cusipata River	Chaclacayo	0
17/03/2017	Huayco and flooding from the Quebrada Los Condores area	Chaclacayo	0
05/04/2012	Huayco	Lurigancho	1,813
09/02/2015	Huayco of mud and stones following heavy rainfall	Lurigancho	80
23/03/2015	Huayco from various streams	Lurigancho	520
31/01/2017	Flooding and debris flow of detrital fragments	Lurigancho	355
27/02/2017	Flooding and overflow originating from persistent rainfall	Lurigancho	0
02/03/2017	Debris flow	Lurigancho	0
15/03/2017	Flooding of nine rivers due to persistent rainfall	Lurigancho	300
16/03/2017	Flooding of nine rivers and overflow of Rímac river	Lurigancho	100
17/03/2017	Debris flow	Lurigancho	500
18/03/2017	Collapse of Javier Perz Cuellar Huampani bridge	Lurigancho	0

Source: Data from INDECI (2017).

2017 Flash Floods and Huaycos in Lima

From January through April 2017, an El Niño Costero event promoted increased convection and subsequent heavy rainfall over land areas along the coast of Peru including Lima Province. While above average rainfall was experienced throughout this period (January to April), the peak impact from flash floods, huaycos, and mudslides was concentrated within Lima Province in February and March (Kluger et al., 2018). These events flooded houses, razed businesses, destroyed roadways, and caused 27 districts of Lima to shut down their potable water services (SEDAPAL, 2017).

The most pronounced flooding event began on 16 March, when the Rímac River continued to rise through the afternoon and into the night, until it flooded several sections of the Chosica and Lurigancho districts. Approximately 3,978 residents were affected, with 2 casualties (INDECI, 2017). In comparison, 9 casualties occurred in the same area during huaycos in 2015. A pedestrian bridge with socioeconomic and cultural importance, "La solidaridad," which connects San Juan de Lurigancho and El Agustino, collapsed, permanently cutting citizens off from vital access to schools, markets, and banking centers (El Comercio, 2018).

Due to the aforementioned complexity in forecasting when and where both El Niño Costero events and related extreme weather events may occur, many citizens felt unprepared for the individual flooding events. While official government El Niño multisector bulletins from 24 January noted the increased likelihood of an El Niño Costero event, only portions of Peru's northern coast were included in the disaster communication. Lima Province was not (ENFEN, 2017a, 2017b; French & Mechler, 2017).

Given the sensitivity of Peru and many other regions to El Niño and La Niña events, several organizations provide regular monitoring and forecasts. To estimate the probability of El Niño occurrence, Peru relies primarily on the National Oceanographic and Atmospheric Association (NOAA) ENSO alert system and forecast models, combined with regional expert judgment of both Niño 3.4 and Niño 1 + 2 regions (Ramírez & Briones, 2017). These monthly ENSO reports provide an important climate service, and are often paired with Peru's own coastal index, Indice Costero El Niño, to monitor changes in the Niño 1 + 2 region (Takahashi et al., 2014). While adequate basinwide and region-specific monitoring systems were in place prior to the start of the 2017 El Niño Costero event in January, NOAA and other international forecasting centers were still reporting ENSO-neutral conditions as late as March 2017 (NOAA, 2017; IRI, 2017). These conflicting ENSO forecasts likely exacerbated challenges with communication flows during this period (Ramírez & Briones, 2017).

Prior to the floods, it appears there was a disconnect in monitoring, where hydrological experts using river gauge systems focused their attention on water management rather than prioritizing communication of risk to relevant authorities or populations within Lima. When messages of increased risk of flooding were communicated, there was a perception among the general public and humanitarian organizations, such as the Red Cross, that they were not translated into useful information. Additionally, local institutions often lacked technical capacity, which meant that even when an information flow was established, and communication of an increased risk of flooding took place, the information was often disregarded or not fully utilized (Venkateswaran et al., 2017).

One of the primary information streams began in March, when the Peruvian government began cooperation with the EU's Copernicus program (Copernicus, 2017). Their Emergency Management Service utilized Earth observation data, drone imagery from the private sector, and government inputs to initially produce real-time damage assessment maps and maps of blockages in transportation infrastructure. For the damage assessment, Copernicus staff utilized SPOT 7 sensor data to provide pre-event optical imagery, and WorldView-2 data to provide postevent optical imagery. Two sources of synthetic aperture radar (SAR) data were respectively used for flood and landslide detection, Sentinel-1 and RADARSAT-2. Ancillary and population data were compiled from Open Street Map, administrative sources, NASA's Earth Explorer, and Google Earth/Maps (Copernicus, 2017).

Based on these inputs, Lima Province was found to have experienced significant river overflows, with 90% of flooding occurring along the Rímac Rriver. Landscape classification identified 1,322 ha of flood extent, with a total of 439 damaged structures and 60 km of roads, which were partially to fully flooded. It is unknown whether these information products were translated and distributed to local actors on the ground to aid in recovery efforts.

Because of the rapid onset of El Niño Costero conditions, it is unclear whether preparedness actions were taken in response to both the occurrence of El Niño Costero and the increased risk of El Niño Costero–related heavy rainfall, flash floods, and huaycos in Lima. Further, it is unclear if predictability of rainfall, flash floods, and huaycos in Lima exists when conditioned on Niño 1 + 2, further research on this relationship could be a next step in understanding the potential for early actions to be taken in Lima (Trenberth et al., 2019). (Niño 1 + 2 is the spatial area defined for El Niño Costero monitoring, which exists just off the coast of Peru.) If predictability of El Niño Costero–related heavy rainfall, flash floods, and huaycos is established, the understanding of appropriate formats of and communication pathways for products and services noting increased risk is central for improving preparedness actions (Vaughan & Dessai, 2014).

Addressing Risk With Earth Observations

The flash flood and huayco events in Lima Province reflect the complexities of defining urban boundaries and associated tasks in determining monitoring protocols that feed into the issuance of emergency alerts, which inform early warning and preparedness, rapid response, and ultimately long-term recovery activities. This challenge is not unique to flash floods, but provides a lens for further exploration of the relationship between extreme geophysical events and associated disaster management actions, and the need for established responsibilities and mandates to translate disaster warning products into useable preparedness communications (Kruczkiewicz et al., 2021c).

Addressing the risks associated with flash flood and huaycos in the context of this case study is complex. However, EO offers potential options for better understanding the occurrence of El Niño Costero events, the related risks of flash flood and huayco events, and their respective impacts. While EO to monitor and analyze El Niño events and their effects exists and is operational at the government level, the 2017 El Niño event was forecast with a relatively short lead time, and also evolved quickly into a significant El Niño Costero. Therefore, an increase in the lead time in forecasting the potential occurrence of an El Niño Costero could contribute to a significant improvement in forecasting shifts in rainfall conditions in adjacent inland areas. (The sample size of El Niño Costero events is currently small; therefore, limitations should be noted.) In order to improve the forecasting of these events, an increased understanding of the spatial and temporal elements of risk relative to huaycos and flash floods is needed. This includes enhancing the knowledge related to impact from flash floods and huaycos in a normal year and in an El Niño Costero year, which could potentially inform anticipatory actions with a seasonal lead time.

EO could be used to better understand risk of impact of flash floods, from both geophysical and socioeconomic perspectives. From a geophysical perspective, there is a gap in operational satellite data for monitoring. For example, methods relying on scatterometers and/or radiometers (such as Soil Moisture Active Passive (SMAP), Soil Moisture Ocean Salinity (SMOS), and Advanced Scatterometer (ASCAT)), do not provide observations at the frequency and timescale necessary. Opportunities exist for applying new methods, such as data from the Cyclone Global Navigation Satellite System (CYGNSS), which can provide information on floods that occur on small spatial scales and across short temporal scales (Ruf et al., 2012).

From a socioeconomic perspective, EO are available to better understand both where people are located and in what type of conditions they are living. For example, the Global Urban Footprint (GUF) leverages radar data from TanDEM-X and TerraSAR-X to produce representations of urbanized areas at 3 m spatial resolution (Esch et al., 2017). For determining levels of development and variability of socioeconomic conditions, such as power outages over time, data from the Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band (DNB) are driving the Black Marble product suite, allowing for insight into changes in these variables over time (Román et al., 2018). There are additional opportunities to iterate off these methods to explore vulnerability and exposure relative to impact from flash floods and huaycos in urban areas, within both a Lima context and larger Peruvian context.

Furthermore, the specific elements that require further analysis include identifying the differences in vulnerability and exposure between huaycos and flash floods, and a developing a better understanding of the distribution of both forms of risk at various city, urban, and regional levels. Smith et al. (2019) explore both riverine and flash flood exposure, and opportunities exist to improve their methods for defining the geophysical elements of flood risk impact, if a data set specific to flash flood impact were used. Doing so would have further influence on forecasting impacts on populations, which could improve the design of early warning early action systems such as Forecast-based Financing (Coughlan de Perez et al., 2015).

Last, the institutionalization of the use of EO for flash flood and huayco events can build capacity in a long-term, sustainable manner, and potentially lead to the development of supporting policy and mechanisms around changing zoning laws and the location of individuals in high-risk zones (UK Space Agency, 2018). While local hydrometeorological services and government institutions appear to have been able to identify the risk of impact from flood events in 2017, limitations existed in relation to the communication of different levels of risk and, specifically, the individual elements of risk (hazard, exposure, and vulnerability). These challenges occurred across multiple areas within Lima Province and impacted the coordination of activities across multilevel institutions, as well as the ability to respond to various impacts within and outside of Lima Province. By integrating the knowledge of improved lead times and risk-related impacts of flash floods and huaycos into formal institutions mandated for disaster warning, preparedness, and response, an enhanced understanding of not only the spatial (i.e., transboundary) elements of these events, but also the corollary collective actions to be taken can be better addressed.

7.3.2. Case Study 2: Urban Heat Island Risk in Chicago

Cities and Heat

Whether it be extreme heat, intense rainfall, coastal flooding, or a number of other hazards, cities face numerous climate-related challenges. Already vulnerable to present-day weather and climate risks, and with climate projections indicating more frequent extreme conditions in the future, cities are first responders in building climate resilience and require innovative approaches to managing these risks. Urbanization tends to be associated with elevated surface and air temperature, a condition referred to as the urban heat island (UHI) effect. As a result, urban centers and cities are often several degrees warmer than surrounding areas. The increased warming in urban areas is caused by the presence of heat-absorbing materials, reduced evaporative cooling caused by lack of vegetation, and the production of waste heat. Extreme temperatures and heat waves may cause blackouts, increased hospitalizations, and increased mortality. The elderly, the young, and those with pre-existing medical conditions, such as asthma or cardiovascular disease, are at greatest risk (Rosenzweig et al., 2018).

In recent years, there has been increasing awareness around the globe that extreme heat is dangerous. In the United States, extreme heat causes more deaths than any other weather-related hazard (US CCSP, 2008). During a severe heat wave that hit Chicago between 11 July and 27 July in 1995, 465 heat-related deaths were recorded on death certificates in Cook County (CDC, 1995) (Fig. 7.2). However, studies that compared the total number of deaths during this heat wave (regardless of the recorded cause of death) with the long-term average of daily deaths, found that the heat wave likely led to about 700 more deaths than would otherwise have been expected (NOAA; https://www.epa.gov/climate-indicators/climate-change-indicators-heat-related-deaths). As the population in urban areas continues to grow and with temperatures continuing to increase, the Urban Climate Change Research Network estimates that by 2050 more than 970 cities will experience average summertime temperature highs of 35°C (95°F) (UCCRN, 2018).

NASA's Perspective

One, and perhaps the first, step in preparing for climate change in cities is an assessment of the risks. Such an

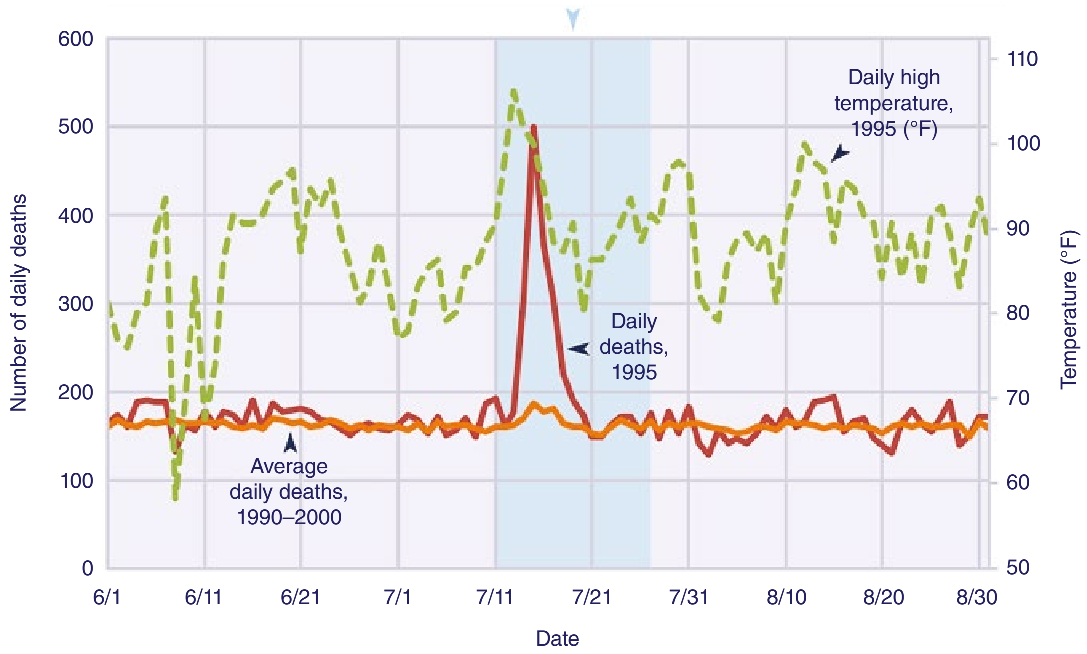

Figure 7.2 Examining heat-related deaths during the 1995 Chicago heat wave (NOAA, 2017). Cook County, 11–27 July 1995: Excess deaths compared with this time period during an average year: about 700. Deaths classified as "heat-related" on death certificates (not shown here): 465.

analysis requires data and, whenever possible, information at the finest spatial resolution possible. NASA has a number of data products that can be used by cities to understand their current and future climate risk.

Earth observations, including MODerate-resolution Imaging Spectroradiometer (MODIS) and Landsat, allow for examination of the spatial variability of heat intensity during extreme heat events and the related UHI effect. (There have been eight Landsat satellites; Landsat 7 and 8 are the two currently active.) As a result of Landsat's long data record, there exists the ability to monitor urban change and also forecast patterns of change in future urban landscapes (Rahman et al., 2017; Feng at al., 2018). The spatial resolution of Landsat data is at an ideal scale for observing human impacts on the land as its passive sensors are able to detect land surface changes (e.g., urban growth) consistently, objectively, and dependably over time. (Spatial resolutions range from 15 to 30 m over a 185 km swath. Passive remote sensors detect and record an external energy source, such as the energy that is reflected from the Earth.) While Landsat 7 and 8 have a 16 day temporal resolution (with an 8 day offset from each other), MODIS collects thermal imagery on a daily basis. MODIS offers a unique combination of features: it detects a wide spectral range of electromagnetic energy; it takes measurements at three spatial resolutions (levels of detail); it takes measurements all day, every day; and it has a wide field of view. (The instrument has a viewing swath width of 2,330 km. Its detectors measure 36 spectral bands between 0.405 and 14.385 μm, and it acquires data at three spatial resolutions: 250 m, 500 m, and 1,000 m.)

Through thermal mapping, Landsat allows for estimates of relative land surface temperature that can be utilized to identify the hottest parts of the city during previous and current extreme heat events. (The use of satellite-derived LST can be limited because of cloud masking (Al-Hamdan et al., 2016).) The thermal images can also be utilized to assess the likelihood of extreme heat in the near future (Shandas et al., 2019). By coupling these data with socioeconomic information, stakeholders can identify the most vulnerable citizens and mobilize resources such as cooling centers and emergency response staff more efficiently. Since heat intensity will vary in space throughout a city, the spatial information that Landsat provides is invaluable for comprehensive heat mitigation planning efforts.

For observed/historical climate data, the Modern Era Retrospective Analysis for Research and Applications (MERRA) data set integrates observed climate variables with numerical models, incorporating over 4 million observations at one time. MERRA utilizes the NASA Global Data Assimilation System to produce a synthesis of climate observations from 1979 to the present; MERRA produces climate data in near real time. As a reanalysis data set, MERRA can provide gridded land-surface temperature data that complements available station-based data for a particular city. This can enable heat wave analyses for locations lacking sufficient station-based observations. There are also additional variables such as soil moisture within the data set that may be useful for drought monitoring and prediction. MERRA may be used to supplement historical data sets as planners assess previous extreme heat events.

The NASA Earth Exchange (NEX) Global Daily Downscaled Projections (GDDP) data set is intended for users who wish to apply the NEX- GDDP data set in studies of climate change impacts. NASA's NEX-GDDP data have over 20 climate models from which downscaled (city-specific) climate projections can be developed. The climate projections are downscaled at a spatial resolution of 0.25° x 0.25° (approximately 25 km x 25 km). Data from the NEX-GDDP data set can be used to assess how the intensity, frequency, and duration of heat waves in a given location may evolve over the 21st century. This information may be used to develop projections of future mortality and morbidity associated with heat waves. As the model outputs are daily, raw data may be used, or a bias-corrected data may be constructed with local historical data. The NEX-GDDP data set holds value for urban planners and health officials as the data set extends to the year 2100.

While all of these data products offer the scientific information for cities that serves as the foundation needed to build resilience, there are challenges that exist in making it useable. Large data files are often challenging to transfer and process; cities often lack the expertise to work with the valuable information, although it is freely available.

Chicago Heat

Over the last century, large heat waves (three or more days with high temperatures) have been generally more frequent in Illinois and the Great Lakes region since the 1980s (other than the highly unusual period of the 1930s) (US CCSP, 2008; Ebi & Meehl, 2007; Wuebbles et al., 2010). Compared with prior heat events, the 1995 heat wave featured more humid conditions, which exacerbated the impacts of the extreme temperatures. For people ages 65 years and up, hospital admissions and mortality rates were significantly higher during this heat wave (Whitman et al., 1997; Semenza et al., 1999). Age, race, and class were factors that contributed to vulnerability highlighting the disproportionate impacts that climate extremes can have on urban populations. Risk factors even included the fact that people in some neighborhoods were afraid to open their windows due to fear of crime (Hayhoe et al., 2010). Heat waves with similar characteristics to the 1995 event (to which several hundred deaths are attributed) are projected to occur twice a decade by midcentury (Wuebbles et al., 2010).

Chicago Partnership

Recognizing the ability of NASA to provide valuable data to cities and the need for this information to be accessible, a partnership was formed in 2016 between the agency and Microsoft. The goal of the partnership is to explore the potential of a dynamic urban environmental data dashboard that can aggregate and make available historic and real-time weather and climate data from ground observations, local sensor deployments, satellites, and climate models as well as other relevant data sets that might facilitate analytic tools and services to be applied to urban resilience and risk management challenges and solutions in cities around the world. The dashboard has the potential to assist those addressing urban challenges by supporting short-term operational decision making related to handling extreme weather events and informing local and regional planning efforts focused on developing long-term resilience of urban infrastructure and populations to shocks and stressors.

UI Labs, a multimillion dollar research institute that aims to bridge academia with the business sector to boost economic development throughout the entire Midwest, was instrumental in the early stages of the partnership. UI Labs was established to bring together top talent from universities + industry (UI) and civic organizations to pursue innovation and drive tech-based economic development in the Midwest.

City Tech Collaborative (City Tech; now Civic Infrastructure Collaborative and SWITCH; https://www.citytech.org/city-tech-launches-two-new-organizations-and-open-source-toolkit) was the urban transformation arm of UI Labs that develops cross-sector urban technology pilots to strengthen urban infrastructure and essential services. City Tech's collaborative pilots provided product, market, and business development opportunities for corporate partners while also providing civic design and engagement opportunities to make resulting innovations equitable, accessible, and sustainable. Their pilot work resulted in several scalable products and solutions (UI Labs, 2018). City Tech's partner consortium included innovative industry leaders such as Mastercard and Microsoft as well as major civic players such as the City of Chicago and the MacArthur Foundation.After a series of workshops organized by UI Labs and NASA, Chicago was selected as the pilot city for the data platform, extreme heat was selected as the initial climate risk, and the development of an urban heat response tool would be the focus for the pilot phase of the pilot. Leveraging advances in technologies such as cloud-based services, big data, and the Internet of Things, it is possible to optimize multiple sources of environmental data and envision solutions with the power and scale to profoundly improve the impact of environmental data on urban resiliency and risk management decisions and strategies globally. The Internet of Things refers to a giant network of objects that connect to each other to analyze and exchange data (Microsoft, 2019).

Use Cases for Risk of Extreme Heat

After settling on extreme heat as the focus of the pilot data tool, further individual conversations were held with the project stakeholders to understand their risks to extreme heat and introduce them to the NASA data that may help them address their needs. The goal of these discussions was to develop a set of use cases where the data from the urban environmental dashboard would provide information related to heat and vulnerable populations. In addition to the City of Chicago Department of Planning and Development (DPD) planning and promoting growth and sustainability throughout Chicago, other City of Chicago departments have policies, programs, and responsibilities associated with the objectives of this pilot, including providing health services, supporting vulnerable populations, integrating new technologies into the city's infrastructure, and preparing for and coordinating emergency responses. Additional Chicago-based stakeholders include Department of Family and Support Services (DFSS), Department of Innovation and Technology (DoIT), Department of Public Health (CDPH), and Office of Emergency Management and Communications (OEMC). The pilot will inform local and regional planning efforts focused on developing long-term resilience of urban infrastructure and populations to shocks and stressors associated with extreme heat events.

In June 2018, the Chicago pilot team met to review the developed use case scenarios and decide on whether to continue with the building and testing of a tool. Two scenarios were identified as potential opportunities to proceed: (1) leveraging NASA satellite data (e.g., Landsat, MODIS) to generate heat maps for cities, and (2) reviewing historical data to determine before and after heat effects of urban planning policies.

Currently, the City of Chicago has no way to track elevated surface temperatures. Learning what has been effective in the past will allow the city to plan future interventions. The Chicago partnership has identified how EO can be used to address extreme heat vulnerability through extensive scientist-stakeholder interactions. Future work by the pilot team will focus on the development of an environmental data dashboard that provides the city with the tools necessary to (1) obtain and analyze the historical heat maps to quantify the localized impacts of policies, plans, and projects in Chicago neighborhoods; (2) leverage information to report on program effectiveness, apply for grants, and track the effectiveness of city actions; and (3) reduce the need to hire consultant teams and use funds that would otherwise be spent on programming and operations, yielding a savings of up to $100,000 per occurrence.

While this pilot project is still in progress, participating scientists and stakeholders have high expectations as there are already early demonstrations (e.g., Baltimore Urban Heat Island Mapping project and the Rio image-comparison tool; https://earthobservatory.nasa.gov/images/90687/climate-proofing-rio-de-janeiro) that useful tools may be developed for urban planning and extreme heat risk assessment (McConnell et al., 2022). Research findings from the Washington, D.C. and Baltimore mapping project have been published in a peer-reviewed science journal (Shandas et al., 2019), and the data will be shared freely with city officials and interested members of the public.

7.4. CONCLUSIONS

In order to contribute to concrete reductions in the vulnerability and exposure of populations in changing urban contexts, a more comprehensive understanding of the integrated nature of risk is needed. The Sendai Framework for Disaster Risk Reduction and the Sustainable Development Goals Earth observations acknowledge that disaster risk reduction must be at the core of sustainable development, and these frameworks provide methods for identifying, measuring, and integrating the elements that contribute to disaster risk. Specifically, the Sendai Framework calls for the following: (1) integrates environmental and natural resources management approaches that incorporate disaster risk reduction, and transboundary cooperation on systems-based methods for building resilience (SDG 7); (2) supports public and private investment in disaster risk prevention and reduction through structural and nonstructural measures to enhance economic resilience and drive innovation and economic growth and job creation (SDG 8); (3) promotes the mainstreaming of disaster risk assessment, mapping, and management into rural development (SDG 15); and (4) calls for increased disaster risk governance and accountability, including through national disaster risk reduction platforms (SDG 16) (UNISDR, 2015). In this regard, Earth observations can provide methods for visualizing the interface and interactions of climate- and human-related elements that contribute directly to increased risk, specifically by substantially increasing the availability of and access to multihazard early warning systems and disaster risk information and assessments, and helping to monitor progress toward these targets consistently, with repetition, and with greater access (UN-Water, 2015; Kruczkiewicz et al., 2021b).

While the integration of EO into national and global targets can contribute to the building of risk-informed communities, challenges remain with the contexts in which risk is understood and managed. Improved delineation of urban, city, and rural extents particularly in regard to situations where risks are transboundary or accumulate as populations and communities grow in size and density are needed. As identified in the case studies, further challenges exist with the application of EO in vulnerable contexts, including situations where there is a lack of understanding, expertise, or confidence in using EO for particular risk-related decisions, where information for early warning of a transboundary disaster risk is only available to a portion of the affected region, and where large amounts of data are challenging to transfer and process.

In acknowledgement of these constraints, three options exist to address the challenges identified. First, the development of standardized protocols for managing climate and disaster risk could put urban areas on the path for developing the technical and institutional capacities necessary for addressing risk reduction. Second, partnerships between local communities and the providers and translators of EO can build the understanding and expertise needed to monitor and assess risks that are relevant to specific urban areas. Finally, the creation of city to city agreements (regardless of the city/urban delineation) can address and acknowledge the transboundary nature of climate and disaster risks. This would allow two or more neighboring areas to develop policy options and guidelines for how to address vulnerability and exposure. It could also include guidelines for data acquisition and data sharing and for integrating emergency warnings and communications.

Planning for risk reduction entails inclusion of a range of sectors, including spatial development and land management, environmental and economic management, and infrastructure development. It also includes a number of multilevel actors. It is the interplay between these sectors, levels of governance, and populations that creates an environment where disaster management can be developed. Strengthening the ability to gather, interpret, and use data for effective planning and development, for policy making, management, and evaluation provides urban areas with a comprehensive view of disaster and climate-related impacts and contributes to the development of more risk-informed communities.

ACKNOWLEDGMENTS

The authors would like to thank the NASA Earth Sciences Global Partnerships Initiative and Microsoft for their continued partnership and support. With special thanks to the EO4SDG Initiative, NASA's Applied Sciences Program, and the GEO Secretariat for supporting the production of this publication.

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