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Resilience and Responses to El Niño Costero 2017: A Multidimensional Impact Analysis in Peru

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Abstract

This study examines the multifaceted impacts and responses to the El Niño Costero 2017 in Peru, emphasizing the event's socio-economic, environmental, and infrastructural repercussions. Utilizing a comprehensive analysis approach, the research delves into the effectiveness of disaster management strategies implemented and their outcomes on community resilience. Key findings highlight the critical areas of vulnerability and the adaptive measures adopted, offering insights for enhancing future disaster preparedness and response mechanisms.

Keywords: El Niño Costero, Disaster Management, Community Resilience, Peru, Climate Impact Analysis

1 Introduction

Peru is experiencing a pivotal transformation, with projections indicating that by 2025, urban populations will constitute 82% of the national total. In a context where cities are capital concentration hubs, we face significant challenges in economic, environmental, political, and cultural spheres. However, at the metropolitan level, there's a notable lack of medium and long-term planning strategies, resulting in millions of families living in highly vulnerable areas. This situation is worsened by the progressive privatization of public spaces and increasing ecological degradation. According to Cubas (2021), the reduction of green spaces in recent decades is a direct consequence of urban development, both planned and unplanned, leading to significant economic, social, and environmental impacts.

Geographically positioned in a strategic location, Peru is significantly impacted by coastal climatic phenomena due to the warming of the Eastern Equatorial Pacific waters. These events, unpredictable and periodic, signify the warm phase of the Equatorial Pacific climate cycle (Ropelewski & Halpert, 1987). Atmospheric pressure variations alter cloud distribution over the Americas, affecting marine ecosystems. The El Niño Southern Oscillation (ENSO) embodies these changes, with El Niño and La Niña phases influencing global and regional climates (Figure 1), notably in Peru (Wang et al., 2012; Bjerknes, 1966, 1969).

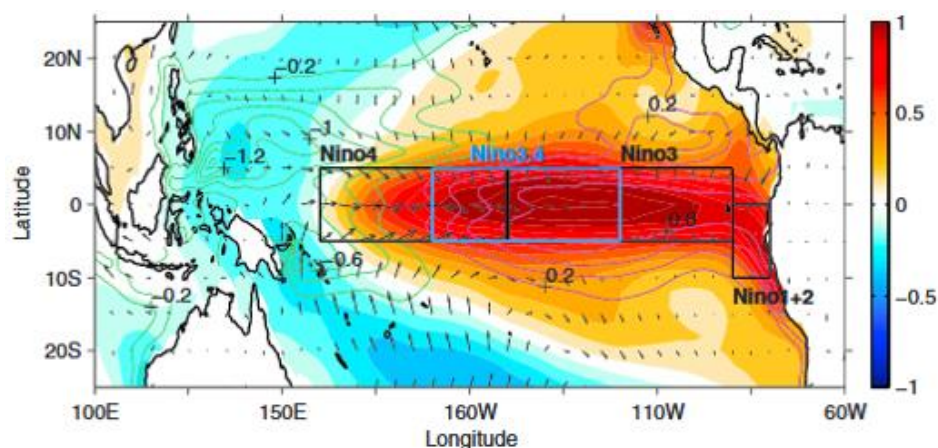


Fig. 1 Sea Surface Temperature Anomalies During ENSO Events. Source: Santoso et al., 2017.

In the past decades, the impact of ENSO phenomena on Peru's rainfall has been the focus of extensive research. Studies by Waylen and Caviedes (1986), Ropelewski and Halpert (1987), and Aceituno (1988) identified rainfall anomalies in southern/northern Peru, suggesting droughts/floods due to La Niña/El Niño events. These findings are confirmed by more

recent studies by Torres-Batló and Martí-Cardona (2020) and Canedo-Rosso et al. (2021), highlighting ENSO's key role in regional climate dynamics.

Piura, situated in northern Peru within the Piura River Basin, has an estimated population of 1.9 million as of 2017, per INEI. The area is prone to extreme weather events, influenced by oceanic and atmospheric anomalies in the Equatorial Pacific, known to trigger El Niño and La Niña phenomena (SENAMHI, 2004). The hydrological regime is marked by irregularity, with a significant rainy season and notable rainfall during El Niño events every five years, leading to unusual summer rains (L'Heureux et al., 2017).

El Niño events impacting Piura over the last century occurred in specific years, with 2017's Coastal El Niño showing unusual rainfall patterns. This year's precipitation, documented by Takahashi and Martínez (2017), contrasted with past events, highlighting the variability and intensity of these phenomena. The figure 3 representation of rainfall showcases the differences in precipitation levels, corroborating earlier studies by Waylen and Caviedes (1986) and Ropelewski and Halpert (1987) on the complex effects of El Niño on regional hydrology.

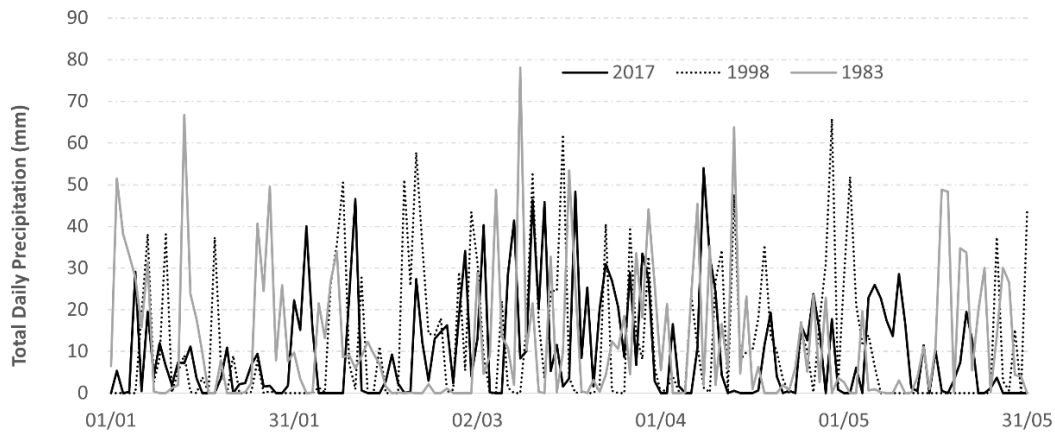


Fig. 2 Sea Surface Temperature Anomalies During ENSO Events. Source of data SENAMHI.

The Coastal El Niño event of 2017 was atypical due to its rapid onset and the severity of its impacts, which were highlighted by a marked peak in precipitation during March 2017 (see Figure 2). Unlike conventional El Niño phenomena, which are linked to atmospheric pressure changes across the entire equatorial Pacific, this particular occurrence of the Coastal El Niño was distinguished by the localized warming of sea surface temperatures along the Peruvian coast (refer to Figure 4). This condition precipitated localized and severe convection and precipitation events (illustrated in Figure 3), as detailed in the studies by Ramírez et al. (2017), Rodríguez-Morata (2017), and in the reports issued by ENFEN (2017).

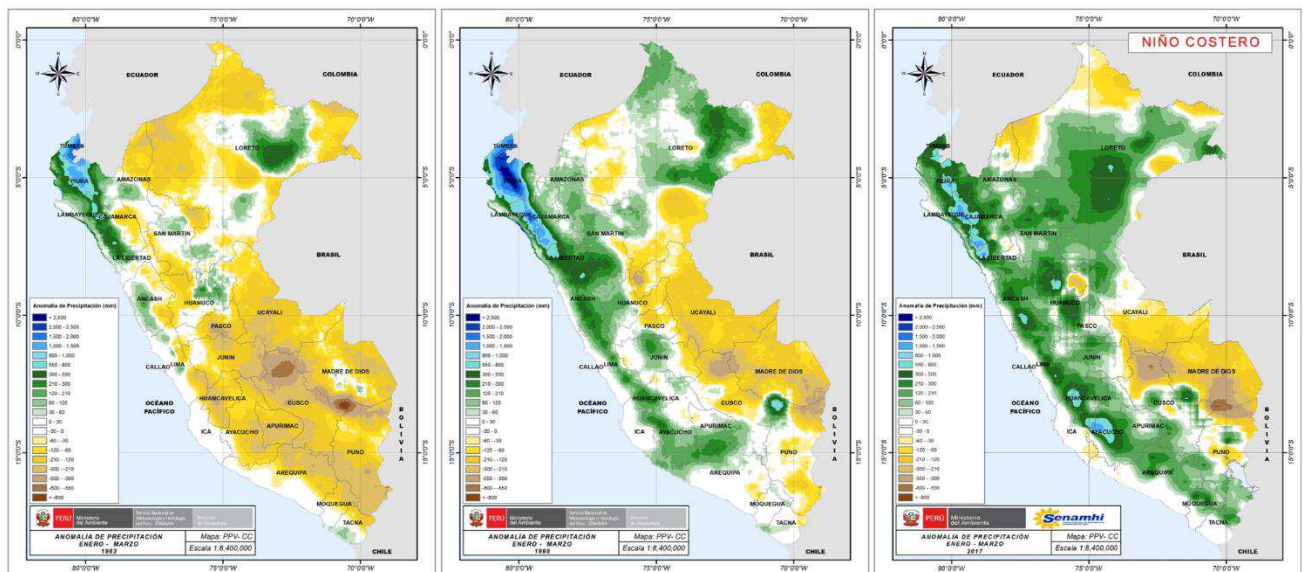


Fig. 3 Comparative Analysis of Precipitation Anomalies in Peru during January to March for El Niño Coastal Events: 1983, 1998, and 2017. Source SENAMHI.

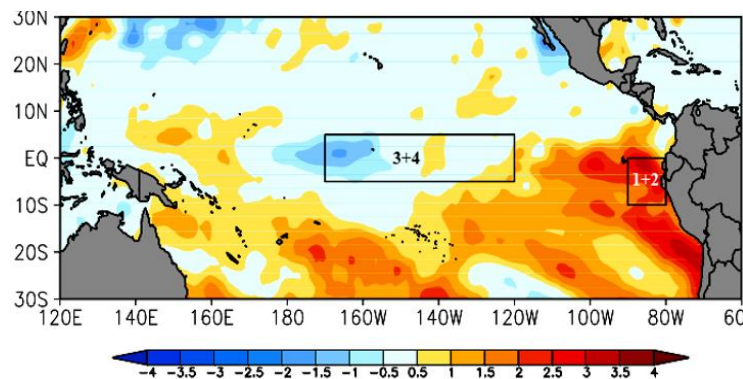


Fig. 4 El Niño-Induced Sea Surface Temperature Anomalies in the Equatorial Pacific Region, 2017. Source ENFEM

The 2017 Coastal El Niño phenomenon marked a significant departure from typical El Niño patterns, characterized by its localized nature and rapid escalation. Sea surface temperature (SST) anomaly maps for the event delineate a pronounced warming in the 1+2 region off the coasts of northern Peru and Ecuador. Notably, this warming correlates with severe climatic disturbances recorded in the Piura department, situated within this anomalous zone. The deep red hues on the map denote SSTs substantially exceeding historical norms, implicating these deviations in the extraordinary weather episodes during the period.

The uniqueness of the Coastal El Niño lies in its confined geographical influence and swift onset, distinguishing it from the broader, global El Niño events. The 2017 episode's impact was particularly acute, with the SST anomaly map (Figure 4) serving as a testament to the extreme climatic conditions that unfolded. The interplay between the anomalously warm waters and atmospheric dynamics over the region is posited as a critical driver of the extreme precipitation and subsequent flooding that besieged Piura and its environs in early 2017.

This event underscores the need for a nuanced understanding of ENSO variations, as localized manifestations like the Coastal El Niño can precipitate significant environmental and socio-economic consequences. The SST anomalies not only reflect a climatic irregularity but also serve as a precursor to the heightened vigilance required for future events that may follow a similar, atypical progression.

In 2017, the Coastal El Niño phenomenon was marked by an intense warming of sea surface temperatures in the 1+2 region off the northern coasts of Peru and Ecuador, as evidenced by the notable red hues in the anomaly maps (Figure 3). These elevated temperatures correlated with the severe weather impacts experienced in Piura, such as intense rainfall and flooding. The unique precipitation patterns of that year were not only above historical averages but also varied significantly across different months and regions, emphasizing the importance of local ENSO dynamics (Sulca et al., 2017; Gonzáles and Ingol, 2021; Jonaitis et al., 2021).

This variability and its impact on Peru are visually captured in the anomaly maps for January to March across the years 1983, 1998, and 2017 (Figure 3). The maps demonstrate the pronounced effects of El Niño events, with the northern regions, especially Piura, showing significant positive anomalies in contrast to the negative anomalies suggesting drought in the southern and central regions.

Historically, Northern Peru has been prone to flooding during extreme El Niño events, as seen in the years 1925-1926, 1972-1973, 1982-1983, 1997-1998, and 2015-2016 (L'Heurex et al., 2017; J. Sanabria et al., 2018). Post-event assessments have documented substantial riverbed expansion in the Piura River, leading to notable agricultural land erosion (GTZ-CTAR, 1999). Such events also exacerbate sediment transport (Morera et al., 2017), further emphasizing the need for comprehensive disaster management and preparation for future extreme climate events.

Following this trajectory, studies by Tapley and Waylen (1990), Vos et al. (1999), and Lagos et al. (2008), as well as more recent investigations by Lavado et al. (2012), Lavado and Espinoza (2014), Bourrel et al. (2015), Rau et al. (2017), and Sanabria et al. (2017), have all reported positive anomalies in rainfall (Figure 3) and river flows (Figure 5). These findings

indicate that the effects of ENSO events vary significantly across different regions of Peru, distinctly influencing precipitation patterns.

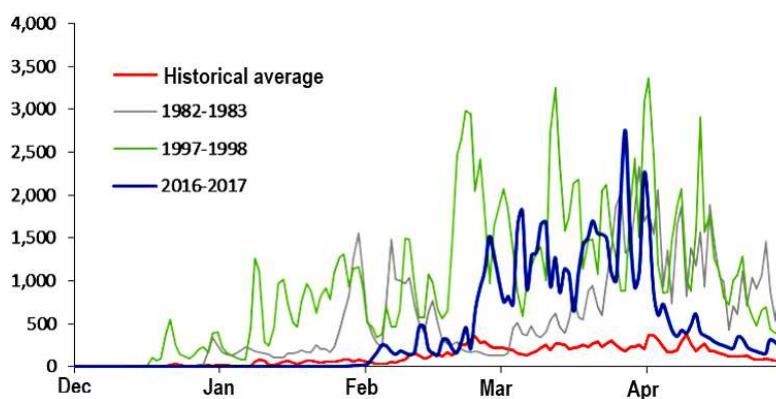


Fig. 5 River Runoff Levels During El Niño Events: A Comparison with Historical Averages. Source ANA - SENAMHI

The Coastal El Niño of 2017 was a localized event linked to the atypical warming of the Equatorial Pacific Sea in the El Niño 1+2 region, influenced by meteorological conditions such as rainfall, humidity, and winds along the coast of Peru, which led to the blocking of the trade winds (Takahashi and Martinez, 2017; Takahashi, 2017; CPC, 2018; ENFEN, 2017; ENFEN, 2020). This rapid warming of the sea did not exhibit the same physical mechanisms as typical El Niño events, which are related to Kelvin waves, making its prediction challenging and its development swift (Takahashi and Martinez, 2017; Takahashi, 2017). In this context, the study by Aguirre et al. (2019) emphasizes the effectiveness of preparedness and response actions based on forecasts and real-time monitoring. This approach allowed for a more rapid and efficient response to extreme weather conditions, minimizing impacts on vulnerable communities. The 2017 experience underscores the need for policies and practices that integrate up-to-date scientific and technological data to improve disaster risk management, a critical aspect for urban and regional planning in areas prone to extreme events like the Coastal El Niño.

This article explores the distinct challenges posed by the 2017 Coastal El Niño and aims to bolster the resilience of Peruvian communities in the face of future extreme climatic events. It underscores the significance of applying learned lessons, notably those recommended by Aguirre et al. (2019), for effective and inclusive disaster management planning. The research combines primary data from interviews with affected stakeholders and secondary data from academic and governmental sources to offer a comprehensive perspective on the event's diverse impacts.

The article advocates for a proactive stance, examining the effectiveness of strategies, policies, and practices that mitigated vulnerability to the Coastal El Niño. It assesses community resilience by looking at how local populations adapted to and adopted preventive measures in the wake of extreme weather occurrences.

In conclusion, the investigation presents targeted recommendations to enhance disaster preparedness and response, drawing from historical insights and local experiences. It calls for a forward-thinking approach in policy development, promoting proactive strategies that government entities and research institutions can adopt, thereby advancing disaster prevention and management strategies related to the El Niño Southern Oscillation (ENSO).

2 Methodological Approach: Bibliometric Analysis of the Literature on the 2017 El Niño Costero Phenomenon

This bibliometric analysis was extended to digital sources, including online journals and publications from organizations responsible for managing natural disasters. Notably, our search in Scopus revealed that the El Niño Costero phenomenon of 2017 was the subject of 28 academic publications throughout the year, reflecting considerable interest and significant concern generated by this extreme weather event. This multifaceted approach not only allowed us to understand the immediate responses and strategies implemented but also to identify gaps and opportunities for future mitigation and recovery actions. The aim of this research was to create a comprehensive overview of the impacts of El Niño Costero and the responses to it, providing a valuable guide for future policies and practices in disaster management.

129 3. Results

130 3.1 Vulnerability

131 3.1.1 Physical Landscape

132 The city of Piura, positioned on the northern coastal plains of Peru, is roughly 100 kilometers south of the Ecuadorian
133 border, 50 kilometers from the western coastline, and 60 kilometers from the Andean mountain range. It features a
134 predominantly flat topography with occasional dry riverbeds, shallow depressions, and mild elevations, where the Piura
135 River stands as a prominent geographical feature within the region. The river's lower section is marked by hydraulic
136 structures such as embankments along its edges and drainage channels, which regulate the water discharge into the
137 Ramón Grande Lagoon during the rainy season and control irrigation through gates during dry spells.

138 The region's intense rainfall and the western slopes of the Andes see rapid runoff due to impermeable soil layers, leading
139 to abrupt flooding in elevated terrains and swift changes in water flow on flatter grounds. Stormwater also gathers in
140 depressions and riverbeds, particularly where natural drainage is impeded, causing rapid and substantial water accumu-
141 lation during heavy storms.

142 Piura faced devastating floods during the El Niño event of 1997-1998, exacerbated by intense rainfall and insufficient
143 urban drainage systems. The water levels in 1998 reached a peak discharge estimated at 4,424 cubic meters per second,
144 showcasing the city's susceptibility to extreme weather events. Additionally, the Piura River, which bisects the city from
145 east to west, spans several hundred meters across as it traverses the urban landscape. The embankments, initially erected
146 in 1984, were intended to restrain the river, which often rises above the ground floor level of the adjoining buildings. The
147 riverbed composition is sandy, and vegetation is prevalent along many sections of the riverbanks.

148 West of Piura, the river's flow diminishes and empties into La Niña Lagoon (ENFEN, 2017). During episodes of extraordi-
149 nary discharges, inadequate ocean drainage can cause rapid enlargement of the lagoon, modifying the river's elevation
150 as it flows through Piura and intensifying floods, particularly affecting the western communities of the city.

151 3.1.1 Past Floods

152 Peru, particularly the Piura region, is exposed to multiple natural hazards, with the threat of floods and earthquakes being
153 particularly prominent. Piura, located on the northern coastal plain, is prone to flooding during periods of intense or
154 prolonged rainfall, a situation often aggravated by El Niño events when increased sea surface temperatures near the
155 coast lead to heightened humidity. These events have been known to cause severe flooding, as witnessed in 1982/1983
156 and 1997/1998, resulting in devastating impacts ranging from loss of life and livestock to the spread of vector-borne
157 diseases and destruction of vital fishing ecosystems.

158 In addition to flooding, the Piura region is also at high seismic risk. The last major earthquake was recorded approximately
159 four decades ago, but the threat remains and must be fully integrated into disaster risk planning and management. In-
160 frastructure such as dykes and dams, if not designed to withstand seismic activity, may fail and exacerbate the conse-
161 quences of floods.

162 Aware of the country's vulnerability to El Niño events, the Peruvian government declared a 60-day state of emergency in
163 July 2015, in anticipation of an El Niño potentially as strong as or stronger than previous occurrences. Preparedness ac-
164 tivities were ramped up, though the 2015/2016 El Niño did not materialize with the anticipated intensity, leading to a
165 cessation of preparations.

166 El Niño events have also led to unexpected changes, such as the transformation of the Sechura coastal desert, which had
167 remained arid for fifteen years, into Peru's second-largest lake, providing temporary opportunities for fishing and agri-
168 culture. These episodes highlight the complex interplay between natural phenomena and human communities' adapta-
169 bility, underscoring the need for disaster risk planning to be holistic and adaptable to changing environmental and social
170 conditions.

171 3.1.1 Society

The Coastal El Niño event of 2017, which unexpectedly occurred at the beginning of that year, was deemed exceptionally large, though evidence suggests that the rainfall and flooding may not have been as significant as those recorded in the 1982/1983 and 1997/1998 events. This indicates that the 2017 floods were largely a disaster exacerbated by human actions, with infrastructure damage being greater in some sectors during the 2017 event, not due to the flood intensity but rather to rapid recent urbanization. Understanding the reasons behind this requires a detailed analysis of the social vulnerability of the areas affected by the floods and the general situation in Peru.

Peru, a middle-income country with high levels of inequality, experienced sustained economic growth between 2005 and 2014 (ANA, 1999). However, about 21% of the population still lives in poverty, and approximately 3% in extreme poverty, with regions like Piura, Cajamarca, La Libertad in the northeast, and Apurímac in the south-central area, where extreme poverty affects nearly 25% (Vargas, 2009). Women, in particular, make up the majority of the population living in extreme poverty, with up to 30% of them lacking access to personal income.

Following the fall of President Fujimori in 2000, the Peruvian government has been undergoing a transition to democracy. However, frequent changes in government have made it difficult to maintain consistent political agendas. Moreover, since 2020, Peru has been in a process of decentralization to reduce inequalities and improve quality of life and access to public services. Yet, decentralization has posed a challenge in a country with a history of centralism and authoritarianism.

Social and economic changes have also been limited by the history of mass migration from rural to urban areas. Between 1940 and 1970, the coastal population grew from 300,000 to 4 million, driven by economic opportunities in the western part of the country. This trend was intensified by the armed conflict that began in 1980. In recent years, Peru has experienced strong economic growth, especially between 2005 and 2011, with the economy growing at an average of 7% per year (Vargas, 2009). This growth was largely attributed to extractive practices, such as mining and logging, which in turn contribute to climate change.

Economic growth has helped reduce poverty and extreme poverty, allowing Peru to achieve "high development" status since 2013. However, most development investments have been concentrated in coastal urban centers, and poverty rates remain high. Intense migration has altered the risk landscape in Peru (INRENA, 2007). New migrants, often unfamiliar with coastal risks, struggle to adapt traditional building techniques and climate coping mechanisms to the new environment. Migration has increased the urban poor population, who settle in marginal areas, often invading land or forming informal settlements; 70% of the Peruvian population lives under these conditions (French and Mechler, 2007).

People have built homes in dry riverbeds or on steep slopes, areas prone to flash flooding. The government often provides essential urban services, such as water and sanitation, to these settlements, and before elections, local governments are known to grant land titles to families. Land trafficking, the illegal occupation and resale of land, has exacerbated the situation, with land often being occupied being marginal or disputed (MacClune et al., 2017).

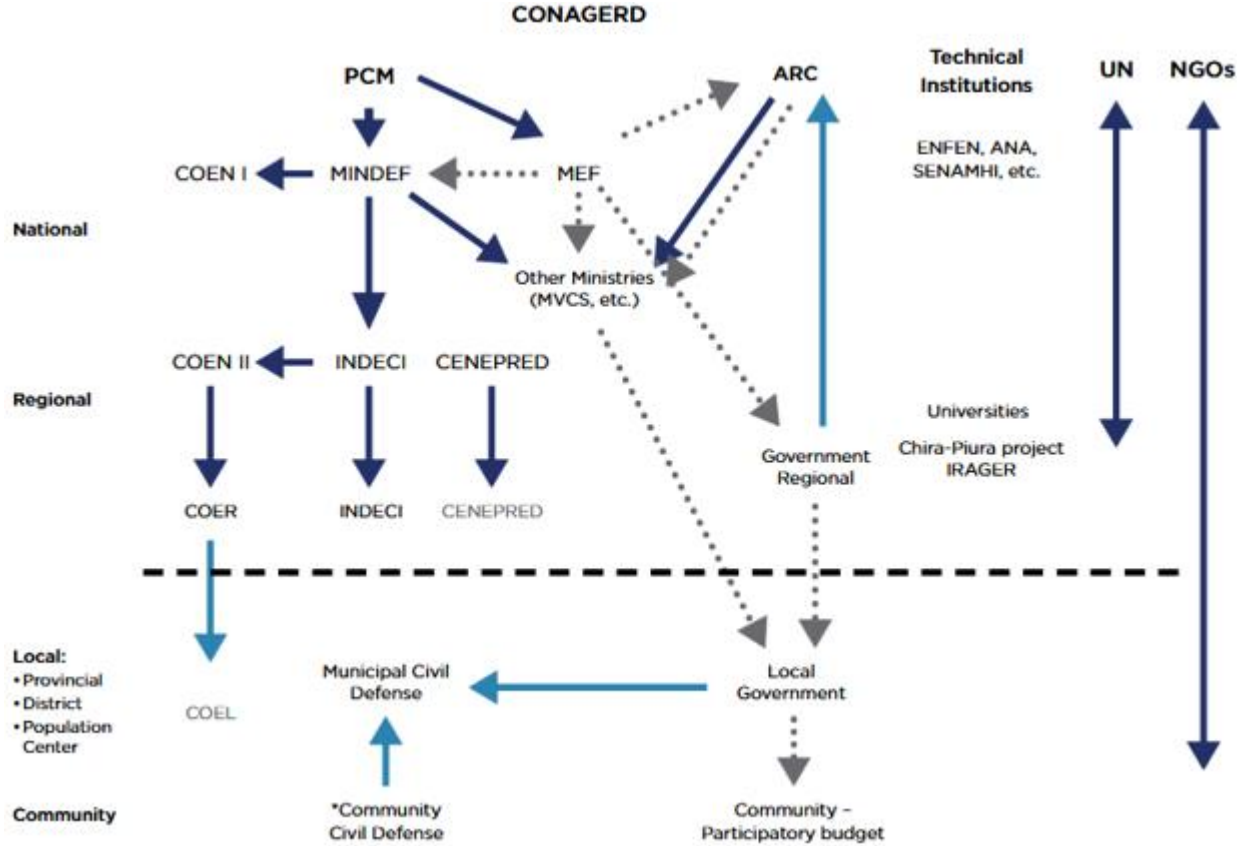
Construction in high-risk areas has been aggravated by the aridity of Peru's Pacific coast. With little rainfall most years, infrastructure is often built in flood zones and with materials ill-suited to handle significant rainfall and runoff. Thus, intense rainfall during El Niño events is particularly destructive (J. Sanabria et al., 2018).

El Niño events cause destruction not only to homes and infrastructure but also devastate livelihoods. Infrastructure failures impact Peru's key economic sectors, affecting fishing, agriculture, and education and health services, as well as construction and transportation. Fisheries take time to recover from sea temperature changes, and floods and landslides devastate productive lands. Agriculture, climate-dependent and risk-prone, suffered long-term critical damage in the El Niño events of 1982/1983 and 1997/1998. Representing 7% of GDP but employing 23.3% of the workforce, agriculture is vital to Peru and ranges from subsistence to industrialized production (USAID, 2011).

3.2 Mitigation

Peru's disaster risk management system, though ostensibly robust with laws and national policies geared towards Disaster Risk Management (DRM) and Disaster Risk Reduction (DRR), grapples with challenges due to its relative institutional immaturity. Recent substantial reforms and the ongoing process of restructuring reflect the system's complexity and dynamism. The study by Bambaren et al. (2017) on the legal norms implemented in response to the 2017 Coastal El Niño sheds light on the country's institutional reaction to this devastating event. It identifies legal norms ranging from the declaration of emergencies to resource management and coordination of actions, highlighting the national response to a significant emergency and rehabilitation efforts. This context reveals the need for a system that not only addresses

220 prevention and immediate response but is also equipped for sustainable post-disaster recovery and reconstruction. The
 221 institutional landscape map shown in Figure 10 illustrates the DRM institutional framework in Peru. However, it should
 222 be noted that this is a simplified version of what is a highly complex and dynamic system.
 223



224
 225 **Fig. 6** Simplified Institutional Map of Peru's DRM as of Mid-2017. Source: French, A. and Mechler, 2017 [28]

226 **3.2.1 The National Disaster Risk Management System**

227 At the regional level, the government oversees and implements regional programs, acting as an intermediary between
 228 national and local governments and providing technical support to local governments to comply with national policies
 229 and Disaster Risk Reduction (DRR) requirements. The Regional Emergency Operations Centers (COERs) conduct short-
 230 term monitoring, analyze, and disseminate information on weather, climate, and natural hazards, using data from the
 231 National Meteorology and Hydrology Service (SENAMHI) and the National El Niño Phenomenon Study (ENFEN). Local
 232 governments, as the first line of response in disaster cases, are supposed to operate active Local Emergency Operations
 233 Centers (COELs) for oversight and direct response, though many remain inactive. They are also encouraged to pursue
 234 DRR and preparedness initiatives within their jurisdictions and can request funds from the national budget of the "Vul-
 235 nerability Reduction and Emergency Attention for Disasters" program (PREVAED), known as "budgetary allocation" (PP-
 236 0068), to finance DRM actions.

237 Since its establishment in 2011, the budget for PP-0068 has significantly increased, but many local governments have not
 238 benefited from these resources or from the available national and regional capacities. National and regional governments
 239 often criticize local governments for their lack of capacity and willingness to act; conversely, local governments argue
 240 that they do not receive necessary support from regional and national governments, nor are they adequately involved in
 241 broader decision-making processes. In practice, the challenges faced at the local level result from a combination of these
 242 factors, limiting DRR and preparedness efforts at the local level.

243 **Weak Incentives and Limited Budgets in Local Disaster Risk Management**

244 Local governments are mandated to allocate a portion of their annual budgets towards exercises, storage, awareness,
 245 and risk reduction measures related to Disaster Risk Management (DRM), such as improving drainage systems. However,

many fail to do so, perceiving their role primarily in emergency response rather than embracing the value of Disaster Risk Reduction (DRR) and preparedness. This reluctance is compounded by the tendency of local governments to prioritize investments based on potential electoral gains. Despite SINAGERD's requirements for local-level DRM, there are minimal incentives for local governments to apply for DRM funding and few penalties for inaction.

Additionally, local governments face challenges in developing their technical proposals to secure project funding due to limited budgets. Many are unable to bear the proposal development costs, a situation worsened by discrepancies in the timing of annual DRR funding allocations. Delays in funding allocations and strict deadlines for expenditure encourage short-term, project-specific initiatives over long-term integrated planning and capacity building, further limiting the effectiveness of local DRM efforts.

Technical Capacity Challenges and Inter-Governmental Coordination in Peru's Disaster Risk Management

Peru's technical expertise, particularly within its universities, is significantly underutilized in local government settings. The disconnect between local and higher levels of government hampers the local government's reach and collaboration with regional government expertise. This disconnect stems from local resentment over exclusion from higher-level decision-making processes and the perception that regional governments are implementing special projects at the local level, which should fall under local government jurisdiction.

Furthermore, competition between mayors and governors exacerbates the lack of coordination between local and regional governments. This is partly due to personal style differences among elected officials and political parties leading to conflicts, and partly due to competition within short-lived political movements and parties, resulting in elected officials lacking governance capabilities. These issues have led to poor implementation of national Disaster Risk Management (DRM) policies at the local level. For instance, SINAGERD mandates that all government entities across sectors and levels develop six disaster-related plans: Disaster Risk Prevention and Reduction, Preparedness, Emergency Operations, Community Education, Rehabilitation, and Contingency. The national government's attempt to incentivize local governments with the promise of additional funding for plan development has seen limited success, with most subnational governmental entities failing to develop these plans.

This scenario highlights the need for enhanced technical capacity building at the local level and improved coordination mechanisms between different levels of government to ensure effective implementation of DRM policies and practices in Peru.

3.2.2 Disaster Risk Reduction (DRR) and Preparedness in Anticipation of the 2015/2016 El Niño.

Forecasts of a significant global El Niño commenced in mid-2015, and by the end of August that year, ENFEN alerted that the El Niño could match the intensity of the 1982/1983 and 1997/1998 occurrences in Peru. Consequently, the national administration promulgated an "Urgency Decree" (DU No. 004-2015) in the early days of September to form the National El Niño Hazard Management Council (CONAGER-FEN) and expedite the reallocation of the national yearly budget to bolster efforts in Disaster Risk Mitigation (DRM) and readiness. The national administration apportioned funds, and CONAGER-FEN formulated sectoral and regional strategies for DRM. This anticipatory DRM strategy was not novel in Peru; akin allocations were effected before the 1997/1998 El Niño phenomenon. Nevertheless, the 2015/2016 El Niño precipitation was considerably below expectations, and the drive towards DRM and readiness diminished, with merely two-thirds of the 3.2 billion PEN dispensed by the national administration being utilized. From this sum, merely 25% of the assets were dispensed to regional and local administrations; a substantial portion of the DRM efforts were spearheaded by the national administration.

The bulk of the pre-El Niño readiness endeavors entailed hazard mitigation in crucial watersheds, orchestrated by the Ministry of Agriculture and regional administrations in rural and semi-urban zones, and by the Ministry of Housing in urban locales. Initiatives encompassed the clearing of riverbeds, irrigation channels, and debris drains, and enhancing water circulation. Initiatives were also undertaken to ready infrastructure within the health, education, water, and housing sectors, augment existing protective structures, and supply emergency provisions.

292 Inadequate maintenance of infrastructure persistently plagues all sectors in Peru. Maintenance pertinent to flooding,
293 such as augmenting water circulation in rivers and brooks and unclogging drains, is typically conducted solely in the lead-
294 up to an El Niño occurrence. Enhancements and enlargements of infrastructure, particularly protective structures like
295 dykes and drains, are usually executed only a year or two following significant flood events. For instance, the initial drain-
296 age system in Piura was established following the 1982/1983 El Niño, partly cleaned and broadened after the 1997/1998
297 El Niño, and again partially cleaned prior to the 2015/2016 El Niño, with scant attention during the intervals between
298 these events. Nevertheless, the city has witnessed rapid expansion, frequently infringing upon natural drainage areas.
299 Considerable efforts were also made to heighten the readiness of disaster response organizations. CENEPRED engaged
300 in refreshing risk evaluations and relayed this data to regional administrations. INDECI staged emergency provisions in its
301 regional depots and allocated supplies to local administrations. The majority of these projects were infrastructure-centric.
302 Despite the absence of a unified national early warning framework or protocols (Figure 7), the national administration
303 invested in enhancing early warning systems, with a significant portion of this investment directed towards Piura.



304 **Fig. 7** Entry Points for Early Warning Systems in Peru. Source: Developed by the authors.

305 **3.2.3 The Role of Non-Governmental Actors**

306 Non-Profit Organizations (NPOs), especially, were instrumental in mitigating the shortcomings of government-driven Dis-
307 aster Risk Management (DRM) and readiness for the anticipated 2015/2016 El Niño. Given sufficient resources, numerous
308 NPOs embark on enduring initiatives and bolster community resilience. The initiatives that yielded the most significant
309 outcomes were those undertaken jointly with, or endorsed by, governmental entities and/or societal groups. These ini-
310 tiatives rendered considerable advantages to the communities throughout and subsequent to the 2017 deluges. Never-
311 theless, the capacity of NPOs to execute holistic and unified DRM is progressively constrained due to evolving financial
312 contexts. Acquiring sustained financial support proves arduous (in part owing to dwindling donor interest towards Latin
313 America and the unsuitable emphasis/scope of DIPECHO), prompting NPOs to procure funding on an individual project
314 basis. More frequently, NPOs infiltrate communities, execute initiatives, compile reports, and depart. This approach im-
315 pedes the establishment of enduring programs that substantially mitigate risk within communities.

316 DRM and readiness measures extended beyond NPOs and governmental efforts. For instance, the University of Piura
317 educated its personnel in emergency first aid and the management of floods and fires. They further instructed students
318 in assisting local administrations to request funds from the national government. Agro-industrial entities erected and/or
319 fortified barriers around their fields to shield their crops against an El Niño occurrence. Regrettably, while these barriers
320 were effective in preventing runoff from harming crops and irrigation systems during the 2017 episode, in certain areas,
321 these measures inadvertently redirected the floodwaters, channeling them towards populated regions.

322 **3.2.4 The 2017 Coastal El Niño Event**

323 The inundations in Peru were unforeseen; the United States National Oceanic and Atmospheric Administration (NOAA)
324 and other local and Peruvian weather authorities did not predict the occurrence. The coastal sea surface temperatures
325 commenced their ascent towards the end of December 2016. Accompanied by a surge in humidity and sea surface tem-
326 peratures, precipitation initiated in January 2017 across the central coastline, notably in Ica and Lima. It was not until the
327 sea surface temperatures sustained their upward trajectory throughout January, climaxing at 6.6°C above the norm on
328 January 31, that the authorities recognized they were confronting rainfall conditions reminiscent of El Niño. Following
329 the initial floods in January, the National Emergency Operations Center (COEN) was mobilized, enhancing engagement
330 and activities as the floodwaters spread. On February 23, an executive decree was proclaimed, enacting an emergency
331 state in Tumbes, Piura, and Lambayeque in the north of Peru.

332 On a national scale, daily assemblies were convened where all entities associated with Disaster Risk Management (DRM)
333 relayed information concerning the prevailing situation, encompassing risk assessments, climatic projections, meteoro-
334 logical data, the statuses of rivers and lagoons, sea surface temperatures, and the varieties of fish observed (to track
335 alterations in sea temperatures and the fisheries sector). Notifications were dispatched to the ministries, the prime min-
336 ister, and the regional authorities. Sanctioned alerts were broadcasted, ideally with a minimum lead time of 3 hours prior

to the flooding; nonetheless, certain alerts were not disseminated until it was too late to be of any utility. In Piura, the populace endured sporadic flooding due to the heavy downpours in February and March, with the most severe flooding transpiring between March 26 and 27, as the intense rainfall merged with the already elevated river currents. The Piura River surmounted the dykes within the city and surged through breaches in the concrete barricades, intensifying the flooding at Plaza Principal.

The municipal sewage systems, established post the 1982/1983 El Niño and revamped subsequent to the 1997/1998 El Niño, succumbed due to insufficient upkeep and the overwhelming influx of water. To the city's south, embankments ruptured, unleashing significant floods in Catacaos and Curamori, where the swift and profound waters claimed four lives. On March 29, the authorities announced a level 5 emergency for the Piura district - the apex on the national emergency grading - enabling the reception of domestic and global assistance and support for response measures. This decree, initially set for 60 days, was subsequently extended by an additional 45 days, and then by another 60 days. The entire metropolis, a pivotal economic hub, incurred residential damages and notable evacuations. The military deployed 3,600 troops and rendered aid to more than 5,000 individuals within the initial 48 hours. Approximately 10,000 individuals impacted in the Catacaos district were transferred to shelters in Piura. A total of thirty-one shelters and 1,041 tents were established to accommodate 11,652 individuals (UNDAC, 2017).

The magnitude of the destruction was, in part, a consequence of inadequate preparedness and communication. COEN bears the responsibility for issuing official hazard notices and alerts, drawing upon data received from ministries and agencies at the federal level. There exists a scarcity of formal protocols to integrate information originating at local or regional tiers up to the national echelon. Ideally, the Regional Emergency Operations Centers (COERs) are the recipients of official notifications.

3.2.5 Challenges and Responses to the Coastal Flooding in Peru during the 2017 El Niño Event

As the inundations along the Peruvian shoreline intensified, local leaders and regional heads were engulfed by the crisis and found themselves incapacitated to tackle the escalating emergency. The community-based defense units were devoid of contingency plans, and the local administrations were still awaiting the annual allocations from the central government (the fiscal year initiates in January, yet fund allocations frequently encounter delays), curtailing their operational capabilities. Hence, the plea for emergency provisions from local and regional administrations to INDECI commenced almost instantaneously. At the outset, INDECI exhibited reluctance, given that the local and regional bodies possess their distinct emergency response mechanisms - these administrations are beneficiaries of funds from PP 0068 designated for drills and emergency responses, coupled with the nationwide perception of mismanagement of these resources and the misuse of local emergency reserves for electoral gains. The clamor for assistance and backing from the lower-tier governments escalated, culminating in the proclamation of the situation as a national calamity. The head of state further directed the local bodies and other governmental units to repurpose their unutilized 2016 allocations towards the emergency. Campaigns for solidarity spearheaded by the media emerged, alongside propositions for international aid, albeit initially rebuffed by the central government.

The decree of national emergency also empowered the Peruvian Ministry of Defense (MINDEF) to helm the response coordination. The juncture was fraught with challenges; the national DRM framework was amidst a substantial overhaul during the flood incidents. MINDEF, recently entrusted with the leadership of national DRM, lacked the requisite experience in orchestrating a comprehensive disaster response. Concurrently, the stewardship of INDECI and CENEPRED was vested in new incumbents in 2017, who introduced their cadres. This transition led to ambiguity in command and a blurring of responsibilities. In response, MINDEF designated the military to steer the coordination and dissemination of the response initiatives. Historically, the Peruvian military's role was confined to maintaining order during crises; this marked their inaugural involvement in emergency response. General Jorge Chávez transformed the military command center into a COEN and swiftly rallied military assets for the response. This prompt, resolute, and efficacious maneuver garnered considerable acclaim for the General. The magnitude of the disaster warranted the intervention of MINDEF and the military, given their logistical prowess, capability for rapid resource mobilization, and execution of urgent reconstruction endeavors (e.g., bridge restoration).

Aid was initially directed predominantly towards Piura. INDECI's regional outpost in Piura had strategically stockpiled resources proximate to its urban bureau, and Piura was readily accessible. Other locales like Lambayeque, Rio La Leche, and Trujillo faced accessibility hurdles owing to bridge impairments along the Pan-American thoroughfare. Certain seg-

386 ments of La Libertad were accessible solely by aerial routes. The flood-induced damages also impeded access to settle-
387 ments along riverbanks and the upper catchment areas. INDECI undertook the transportation of provisions via air and
388 watercraft to isolated communities whenever feasible.

389 The deluges profoundly impacted dwellings in the low-lying urban zones of Piura, Catacaos, and Curamori. The regional
390 and local governments, alongside ministries, orchestrated the evacuation and relocation of over 11,000 individuals to
391 elevated terrains within the initial 48-hour window. COER and INDECI established makeshift refuges within public educa-
392 tional institutions. The displaced families were furnished with tents, cooking utensils, mosquito nets, and pails. The gov-
393 ernmental apparatus failed to dispense other essential emergency aids required by the flood-stricken populace, encom-
394 passing nourishment, hydration, sanitary facilities, healthcare services, and more enduring shelters. The adoption of
395 minimal protocols in Peru was not exhaustive. Health concerns, particularly the outbreaks of water and mosquito-trans-
396 mitted diseases (e.g., dengue, zika, chikungunya, and malaria), emerged as significant issues. The Health Ministry's inter-
397 vention post the March 26 inundation in Piura was delayed by 48 hours and lacked effective communication regarding
398 health hazards and preventive measures (e.g., the use of mosquito nets, insect repellants, and protective clothing). The
399 decline in disease transmission commenced in July, coinciding with the desiccation of the floodwaters.

400 For the procurement of emergency aid and financial relief, the local administrations are mandated to compile and submit
401 a Damage Assessment and Needs Analysis (EDAN). The EDAN documentation registers the requests for aid within the
402 National Information System for Response and Rehabilitation (SINPAD). This procedure is intricate and laborious. Distinct
403 EDANs are requisitioned for each community, necessitating data at the household level. Moreover, the local authorities
404 grappled with uncertainties regarding the initiation of EDAN documentation, especially in locales grappling with recurrent
405 inundations. The EDAN submissions are directed to COER and INDECI for endorsement and financial allocation, a process
406 envisioned to span 24 hours but, in practice, could extend up to a week. Furthermore, once disbursed, the EDAN re-
407 sources are non-transferable amongst families or communities, even if the disaster scenarios have evolved or intensified.
408 Consequently, despite the solicitation of funds, their applicability and promptness were severely constrained.

409 3.2.6 The role of NGOs

410 In the absence of governmental provision of food and water, victims of the flooding depended on aid from Non-Govern-
411 mental Organizations (NGOs) and contributions from local inhabitants, eateries, faith groups, enterprises, and educa-
412 tional institutions. Households also welcomed kin; it is assessed that 20,000 households remained with kith and kin three
413 months post the flooding. Aid from NGOs predominantly targeted communities neglected or overlooked by governmen-
414 tal efforts. NGOs well-versed in specific locales proved particularly adept at aiding communities affected by the flooding.
415 For instance, Practical Action Peru engaged with Cuatro de Mayo, an impoverished informal community in Piura, focusing
416 on disaster risk reduction and readiness. Amid the flooding, Cuatro de Mayo faced inundation up to 1.5 meters, leading
417 to the destruction of abodes. Subsequent to the residents' return with their temporary shelters, Practical Action furnished
418 them with water reservoirs and constructed latrines, and is currently evaluating additional recuperation strategies for
419 the community.

420 Nevertheless, assistance from nascent NGOs encountered hurdles, particularly in grasping community needs and in liais-
421 ing with other community entities. Occasionally, due to this communication and coordination void, NGOs recognized
422 post-funding that their proposed aid was superfluous. An instance involved an NGO arriving in a community to focus on
423 hygiene and water projects, only to discover that preceding efforts by another group had largely addressed the intended
424 work, and given their funding was earmarked for water and hygiene, reallocating it to meet other community require-
425 ments was not feasible.

426 3.3 Protective Capacity and Recovery Efforts Post-2017 El Niño Coastal Event in Peru

427 In the aftermath of the 2017 Coastal El Niño phenomenon, securing access to vital utilities such as power, potable water,
428 and transportation emerged as essential for the sustenance of livelihoods and economic functions. Projects related to
429 infrastructure also created opportunities for income generation for individuals who had suffered the loss of homes and
430 means of living, aiming for recovery. Non-Governmental Organizations (NGOs) launched initiatives like 'monetary com-
431 pensation for labor' and 'food in exchange for work' in regions affected by the floods, an initiative not paralleled by
432 governmental efforts at that period. This emphasis on infrastructural development inadvertently sidelined social rehabil-
433 itation efforts. While construction endeavors do present chances for earning, they do not constitute a sustainable liveli-

hood strategy for the majority, nor is the practice of employing locals a stipulated or officially announced policy in reconstruction projects funded by the government, leaving numerous families in a struggle to rebuild their dwellings and ways of living.

The floods of 2017 adversely affected numerous settlements situated on lands susceptible to flooding. The relocation of these predominantly informal communities was contemplated as a feasible remedy in locales where the risk was significant and considered beyond mitigation. As per the Resettlement Law No. 29869, Article 4, relocation is advocated where "the execution of mitigation strategies is deemed more financially and logistically challenging than displacement." Despite the floods inciting widespread deliberation regarding the if and how of relocating communities severely affected by the floods, the concept of resettlement remains a multifaceted and contentious subject without a unified stance on an optimal strategy. The complexities surrounding resettlement can be dissected into categories of 'who', 'what', and 'where'.

The capability for protection was compromised as policies centered on reconstruction and recovery predominantly focused on physical infrastructure, thus marginalizing the aspect of social rehabilitation. Individuals were left grappling with the reconstruction of their residences and livelihoods, significantly hindered by losses in healthcare and educational sectors. The potential of utilizing infrastructural projects to employ individuals impacted by the floods, thereby facilitating local recovery, is not being consciously exploited. Absent directed support for recovery, the resurgence of families and communities has hit a standstill. In areas like Cuatro de Mayo, a community severely impacted, households are reliant on their social networks for day-to-day sustenance.

On a global scale, disasters of extensive magnitude frequently surpass the capabilities of governmental response and disrupt transportation systems, compelling communities and families to devise their own strategies for disaster response. Settlements such as Polvorines, which possess a robust grasp of risk factors, are better equipped and capable of a swifter response and recovery compared to those with limited information. In Polvorines, the civil defense group at the community level played a pivotal role in pinpointing local risks and facilitating the community's response. The local administration is presently collaborating with Polvorines to establish civil defense units in additional communities. This framework is one that could be endorsed and financially supported by national and regional governments, with NGOs providing auxiliary support. NGOs are positioned to experiment with methodologies and tactics for this purpose, with the government potentially institutionalizing successful models.

Reconstruction efforts are harnessed to aid in social recuperation. Following a disaster, there is invariably a surge in infrastructure repair and rebuilding activities. Policies mandating the employment of local residents and engagement of local construction firms offer the necessary employment opportunities for individuals who have endured the loss of livelihoods and assets, necessitating support for recovery. Similarly, while sectors like agriculture and fisheries typically bear the brunt of El Niño events, they also present opportunities, given the abundance of water, the feasibility of cultivating a variety of crops, and the utilization of lagoons for fishing. The establishment of public-private partnerships with the agribusiness and fisheries sectors prior to El Niño events, with the aim of leveraging these opportunities, can mitigate some of the adversities wrought by El Niño and contribute to the economic revival of certain segments, even as others remain disadvantaged.

3.4 Legal Norms in Response to the 2017 Coastal El Niño Event

The 2017 Coastal El Niño event posed significant challenges for Peru, necessitating a robust legal and institutional response. In reaction, the government implemented various legal norms aimed at mitigating the disaster's impacts. A key measure was the declaration of a state of emergency in several affected regions, enabling swift resource allocation and coordination of response and recovery efforts.

The legislation focused on prevention and preparedness for future events, highlighting the need for a proactive approach to disaster risk management. This included strengthening risk management structures at national, regional, and local levels and promoting greater collaboration between the government, NGOs, and local communities. The legislation also emphasized the importance of improving existing infrastructure, such as drainage systems and dykes, and implementing new technologies for climate monitoring and early warnings.

The study by Bambaren et al. (2017) focuses on identifying the legal norms established and implemented in response to the 2017 Coastal El Niño phenomenon in Peru. The document reviews the legal norms passed and published between

December 2016 and December 2017, highlighting the emergency, rehabilitation, and reconstruction measures adopted at national, regional, and local levels.

Among the key findings, 46 legal norms were identified, with 41% aimed at declaring emergencies and alerts, 22% at managing economic resources, and 13% at coordination actions. A significant percentage of these norms (62%) were established at the regional level, while 22% were at the national level. The study underscores the need for an integrated system that not only addresses prevention and immediate response but is also equipped for sustainable recovery and reconstruction post-disaster.

Furthermore, guidelines for the economic and social recovery of the affected areas were established. This included programs to support housing reconstruction, livelihood recovery, and the provision of essential services such as health and education. The government recognized the need to address social inequalities that were exacerbated by the disaster, focusing on assistance to vulnerable populations.

Finally, the 2017 Coastal El Niño experience highlighted the need for more comprehensive legislation adaptable to climate change. This implied revising existing policies and introducing new laws that consider the emerging challenges associated with extreme weather events. The legislation sought, therefore, not only to respond to the immediate disaster but also to prepare the country for future environmental challenges.

4 Discussion

Impact of the 2017 Coastal El Niño Event in Peru: A Multidimensional Analysis

The 2017 Coastal El Niño event in Peru represented an unprecedented challenge, revealing the complexity and multifaceted nature of natural disasters. This phenomenon highlighted the interconnection between environmental, social, and economic aspects of disasters. While Peru has experienced El Niño events in the past, the 2017 event was exceptional in its rapid onset and severity, testing the country's capacity to respond to large-scale emergencies.

The study by French et al. (2020) provides a crucial perspective on the political ecology of El Niño-related disasters in Peru. It identifies deep-seated issues of exposure and vulnerability, amplified by ineffective political institutions, that significantly contribute to disaster risk. The study highlights how political centralization, sectoral divisions, and corruption hinder the development of robust disaster risk management capabilities. This analysis reinforces the need to address not just the physical and technical risks but also the social, political, and economic aspects in disaster management, proposing an integrated and multidisciplinary strategy.

Impact of Climate Change on Migration Patterns in Peru

The study by Bergmann et al. (2021) reveals a significant relationship between climate change and migration patterns in Peru, particularly in response to extreme weather events like the Coastal El Niño. This phenomenon not only caused material and environmental damage but also triggered significant population movements. The most affected areas saw an increase in migration, with many seeking refuge and better living conditions in other regions or even urban areas.

These population displacements highlight the need for comprehensive policies that focus not only on climate change mitigation and adaptation but also on supporting vulnerable and displaced communities. Climate-induced migration is a complex phenomenon that requires a multidisciplinary response, integrating urban planning, sustainable development, and social protection.

Hence, the findings of Bergmann et al. (2019) reinforce the importance of an integrated disaster risk management strategy that includes measures to deal with the socioeconomic consequences of extreme weather events, like the Coastal El Niño, including the growing challenge of climate migration.

Impact of Urbanization on Disaster Risk Management: Lessons from the 2017 Coastal El Niño

The research by Aguirre et al. (2019) provides crucial insights into the influence of urbanization on vulnerability to natural disasters. This study reveals how uncontrolled urban expansion and the lack of adequate infrastructure development, especially in coastal areas, exacerbate the risks associated with extreme weather events like the Coastal El Niño.

During the 2017 Coastal El Niño event, it was observed that densely populated urban areas, particularly those developed without appropriate urban planning, faced significant challenges. These included flooding, erosion, and other environmental impacts, which were intensified by inadequate urban infrastructure.

This analysis reinforces the need to integrate disaster risk management into urban planning and the development of resilient infrastructures. Urbanization, when carried out without proper consideration of natural risks, can place communities at greater risk during extreme events. Therefore, urban planning and infrastructure development policies must be informed by a deep understanding of natural disaster risks and adapted to minimize these risks.

Legal and Institutional Response: Effectiveness and Challenges

The implementation of 46 legal norms in response to the Coastal El Niño illustrates a significant effort by the Peruvian government to manage the crisis. However, the effectiveness of these norms varied considerably, highlighting the importance of an integrated disaster risk management system that balances prevention, response, and post-disaster reconstruction. According to Yglesias-Gonzalez et al. (2023), this implementation reflects challenges in effectiveness and coordination at national and regional levels, suggesting the need for a more integrated management system to increase effectiveness in managing future extreme weather events. The research showed that, although there was a proactive response in terms of legislation, there were gaps in implementation and coordination, both nationally and regionally.

Importance of Multisectoral Collaboration

The study underscores the critical need for collaboration between the government, NGOs, and communities. The response to the Coastal El Niño demonstrated that effectiveness in disaster management depends on the active and coordinated participation of all these actors. NGOs played a key role in areas where the governmental response was limited, underlining the importance of strengthening these ties for future disaster responses.

Role of the Private Sector in Responding to the Coastal El Niño and Preparing for Future Events

The 2017 Coastal El Niño experience highlights the crucial role of the private sector in responding to natural disasters and preparing for future events. According to González (2023), the "Shoulder to Shoulder" initiative mobilized the Peruvian private sector to support the government in responding to the Coastal El Niño. This effort demonstrated the importance of collaboration between the public and private sectors, especially in terms of logistics, capacity building, and providing heavy machinery.

Moreover, preparation for the global El Niño phenomenon underscores the need for a proactive and integrated approach. Effective coordination and contribution of resources from the private sector are essential to mitigate the impacts of rising temperatures and extreme weather conditions. This case exemplifies how solidarity and partnership between different sectors can strengthen community resilience and improve disaster risk management.

The Role of Climate Change and Adaptation

The 2017 Coastal El Niño also highlighted the growing influence of climate change in intensifying extreme weather phenomena. This underlines the urgency of integrating climate change adaptation into disaster risk management, focusing not just on immediate response but also on long-term planning and the implementation of sustainable and resilient strategies.

5 Conclusion

Need for an Integrated Approach in Disaster Risk Management

This study concludes that an integrated and multidisciplinary approach is essential in disaster risk management. The Coastal El Niño event demonstrated that prevention, rapid and effective response, and sustainable post-disaster reconstruction are equally important components of this approach. Improvements in infrastructure and technology for monitoring and early warning, along with legislation adaptation to tackle climate challenges, are crucial. As highlighted in Bell et al. 2024, education plays a key role in disaster risk management. This focus complements the need for an integrated approach in risk management, as concluded in the study on the 2017 Coastal El Niño. The role of education, especially in terms of collaboration and community participation, reinforces the importance of active community involvement and

569 the recognition of the impact of climate change on natural disasters. Thus, integrating formal disaster education into the
570 risk management strategy contributes to a more resilient and sustainable future.

571 **Integration of Urbanization and Infrastructure Development in Disaster Risk Management**

572 This study emphasizes the need for an integrated and multidisciplinary approach in disaster risk management, as demon-
573 strated by the Coastal El Niño event. According to the analyses by Aguirre et al. (2019), urban expansion and infrastruc-
574 ture development, especially in coastal areas, are critical factors influencing vulnerability to natural disasters. Therefore,
575 disaster risk management must include urban planning and the development of resilient infrastructures as essential com-
576 ponents.

577 **Importance of Collaboration and Community Participation**

578 Effective collaboration between the government, NGOs, and communities is crucial for successful disaster management.
579 Communities, in particular, should be empowered and actively participate in risk management and decision-making. The
580 inclusion of local knowledge and experiences enriches the response and enhances resilience.

581 **Recognition of Climate Change in Disaster Risk Management**

582 It is imperative to acknowledge the role of climate change in amplifying natural disasters. Climate change adaptation and
583 mitigation must be integrated into all disaster risk management strategies, with a focus on long-term sustainability and
584 resilience.

585 **Towards a Resilient and Sustainable Future**

586 The lessons learned from the 2017 Coastal El Niño, along with the conclusions from Aguirre et al. (2019), point to the
587 need to develop policies and practices that integrate disaster risk management with urban planning and infrastructure
588 development. This integrated approach is vital to ensuring that communities are resilient and capable of adapting to the
589 emerging challenges of climate change and other disaster risks.

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599 The majority of the material preparation, data collection, and analysis were carried out by Eleazar Chuchón Angulo.
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604 ensuring the content's accuracy, relevance, and scholarly contribution.

605 Both authors have read and approved the final manuscript, affirming their agreement with the work presented and its
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References

- AACHCHP. (2005). Evaluación Local Integrada y Estrategia de Adaptación al Cambio Climático en la cuenca del río Piura.
- ACEITUNO, P. (1988). On the functioning of the Southern Oscillation in the South American sector. Part 1: surface climate. *Monthly Weather Review*, 116, 505-524. [https://doi.org/10.1175/1520-0493\(1988\)116<0505:OTFOTS>2.0.CO;2](https://doi.org/10.1175/1520-0493(1988)116<0505:OTFOTS>2.0.CO;2)
- AGUIRRE, ET AL. (2019). Early Action Mechanisms in Peru Regarding Preparedness for El Niño. In: *International Journal of Disaster Risk Science*, 508-509. <https://doi.org/10.1007/s13753-019-00234-6>.
- ANA. (1999). Estudio hidrológico - meteorológico en la vertiente del Pacífico del Perú con fines de evaluación y pronóstico del Fenómeno El Niño para prevención y mitigación de desastres.
- BAMBAREN, C., & ALATRISTA, M. S. (2019). Legal Rules for the Response and Recuperation Before the Phenomenon of El Niño Costero Peru 2017. *Disaster Medicine and Public Health Preparedness*. <https://doi.org/10.1017/dmp.2018.158>
- BELL, I., LAURIE, N., CALLE, O., CARMEN, M., VALDEZ, A. (2024). Education for disaster resilience: Lessons from El Niño. *Geoforum*, 148, 103919. <https://doi.org/10.1016/j.geoforum.2023.103919>
- BERGMANN, J., VINKE, K., FERNÁNDEZ PALOMINO, C. A., GORNOTT, C., GLEIXNER, S., LAUDIEN, R., LOBANOVA, A., LUDESCHER, J., & SCHELLNHUBER, H. J. (2021). Assessing the Evidence: Climate Change and Migration in Peru. Potsdam Institute for Climate Impact Research (PIK) e International Organization for Migration (IOM).
- BJERKNES, J. (1966). A possible response of the atmospheric Hadley circulation to equatorial anomalies of ocean temperature. *Tellus Series A-Dynamic Meteorology and Oceanography*, 18, 820-829. DOI: 10.3402/tellusa.v18i4.9712.
- BLAIKIE, P., CANNON, T., DAVIS, I., & WISNER, B. (1994). At risk: natural hazards, people's vulnerability, and disasters. Routledge. 284 p.
- CANEDO-ROSSO, C., HOCHRAINER-STIGLER, S., PFLUG, CONDORI, B., & BERNDTSSON, R. (2021). Drought impact in the Bolivian Altiplano agriculture associated with the El Niño-Southern Oscillation Using satellite imagery data. *Nat. Hazards Earth Syst. Sci.*, 21, 995-1010. <https://doi.org/10.5194/nhess-21-995-2021>
- COCKBURN, J. C., ROMERO, J. Q., LUCCHI, P., & LENHARDT, A. (2015). On the Path of Progress: Improving living conditions in Peru's slum settlements. *Development Progress*, Londres, Reino Unido.
- CPC. (2018b). Retrieved from http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php.
- CÓRDOVA, L. (2018). Hace 20 años La Niña llenó de vida el desierto norteño. *El Comercio*. Retrieved from <https://elcomercio.pe/archivo-elcomercio/grafico/20-anos-aguas-nina-llenaron-vida-desierto-noticia-505530-noticia/>.
- CUTTER, S. L. (1996). Vulnerability to environmental hazards. *Hazards Vulnerability and Environmental Justice*, 1-12.
- ENFEN. (2017a). Comunicados oficiales. Retrieved from https://www.dhn.mil.pe/comunicado_oficial_enfen.
- ENFEN. (2017b). Informe Técnico Extraordinario No 001-2017/ENFEN EL NIÑO COSTERO 2017. Resumen ejecutivo. Retrieved from http://www.imarpe.pe/imarpe/archivos/informes/imarpe_infco_informe_tecnico_extraordinario_001_2017.pdf.
- ENFEN. (2017g). Informe Técnico Extraordinario N° 001-2017/ENFEN. El Niño Costero 2017. Resumen ejecutivo.

- FRENCH, A., MECHLER, R., ARESTEGUI, M., MAC CLUNE, K., & CISNEROS, A. (2020). Root causes of recurrent catastrophe: The political ecology of El Niño-related disasters in Peru. *International Journal of Disaster Risk Reduction*, 47, 101539. <http://doi.org/10.1016/j.ijdrr.2020.101539>.
- GOBIERNO REGIONAL DE PIURA – ANA – GTZ/PDRS. (2009). Proceso de elaboración de plan de gestión de la cuenca del río Piura – Aspectos metodológicos. Folleto, 32 pp.
- GONZALEZ, I. (2023, July 11). The historical impact of coastal El Niño in Peru and how local businesses are preparing for the global El Niño. CBI Secretariat. ReliefWeb. <https://reliefweb.int/report/peru/historical-impact-coastal-el-nino-peru-and-how-local-businesses-are-preparing-global-el-nino>.
- GTZ, CTAR – Piura. (1999).
- INEI. (2014). Compendio Estadístico Perú 2014. Retrieved from https://www.inei.gob.pe/media/MenuRecursivo/publicaciones_digitales/Est/Lib1157/libro.pdf.
- INRENA. (2007). Diagnóstico de la ocurrencia de sequías, inundaciones y cambio climático global en el Perú. Plan de defensas ribereñas y encauzamiento de ríos.
- JEGILLOS, S. (1999). Fundamentals of disaster risk management: How are southeast Asian countries addressing this? In A. Holloway (Ed.), *Risk, sustainable development and disasters: southern perspectives*. Periperi Publications.
- LACHIRA, P. (2017, February 7). Sechura: cientos de peces vararon en la bahía de Parachique. Walac. Retrieved from <https://walac.pe/sechura-cientos-de-peces-vararon-en-la-bahia-de-parachique/>.
- LAGOS, P., SILVA, Y., NICKL, E., & MOSQUERA, K. (2008). El Niño-related precipitation variability in Perú. *Advances in Geosciences*, 14, 231-237. <https://doi.org/10.5194/adgeo-14-231-2008>
- L'HEUREUX M ET AL. (2017). Observing and predicting the 2015/16 El Niño. *Bull Amer Meteor Soc.* <https://doi.org/10.1175/BAMS-D-16-0009.1>.
- MACCLUNE, K. K., & ENRÍQUEZ, M. F. (2017). El Niño Costero: The 2017 Floods in Peru. Zurich Flood Resilience Alliance.
- MORERA, S. B. ET AL. (2017). The impact of extreme El Niño events on modern sediment transport along the western Peruvian Andes (1968-2012). *Scientific Reports*. <https://doi.org/10.1038/s41598-017-12220-x>.
- OLIVER-SMITH, A. (1999). What is a disaster? Anthropological perspectives on a persistent question. *Disaster Prevention and Management: An International Journal*, 8(2), 121-122.
- PROGRAMA PRESUPUESTAL 068. (2014). Reducción de Vulnerabilidad y Atención de Emergencias por Desastres – Plan Nacional de Gestión del Riesgo de Desastres – PLANAGERD 2014-2021 (Objetivo Nacional y Objetivo Estratégico 1). El Fenómeno El Niño en el Perú, SENAMHI.
- RAMÍREZ I. J., & BRIONES, F. (2017). Understanding the El Niño Costero of 2017: The Definition Problem and Challenges of Climate Forecasting and Disaster Responses. *Int. J Disaster Risk Sci*. <https://doi.org/10.1007/s13753-017-0151-8>.
- RODRÍGUEZ-MORATA, C., BALLESTEROS-CANOVAS, J. A., ROHRER, M., & STOFFEL, M. (2018). The anomalous 2017 coastal El Niño event in Peru. *Climate Dynamics*. <https://doi.org/10.1007/s00382-018-4466-y>.
- ROMERO, C.C., BAIGORRIA, G.A., & STROOSNIJDER L. (2007). Changes of erosive rainfall for El Nino and La Nina years in the northern Andean highlands of Peru. *Climatic Change*, 85(3-4), 343-356.
- ROME-GASPAIDY, S., & RONCHAIL, J. (1998). La pluviométrie au Pérou pendant les phases ENSO et LNSO. *Bulletin de l'Institut Français d'Études Andines*, 27, 675–685.
- SANABRIA J ET AL. (2018). Rainfall along the coast of Peru during strong El Niño events. *J Int Climatol.* <https://doi.org/10.1002/joc.5292>.

- SANTOSO, A., MCPHADEN, M., J., & WENJU CAI. (2017). The Defining Characteristics of ENSO Extremes and the Strong 2015/2016. *Reviews of Geophysics*, 55, 1079-1129. <https://doi.org/10.1002/2017RG00560>.
- SENAMHI - PROCLIM. (2004). *Caracterización Climática de la Cuenca del Río Piura*.
- SHANEE, N., & SHANEE, S. (2016). Land Trafficking, Migration, and Conservation in the “No Man’s Land” of Northeastern Peru. *Tropical Conservation Science*, 9(4). <https://doi.org/10.1177/1940082916682957>.
- TAKAHASHI K, & MARTÍNEZ AG. (2017). The very strong El Niño in 1925 in the far-eastern Pacific. *Clim Dyn..* <https://doi.org/10.1007/s00382-017-3702-1>.
- TAKAHASHI, K. (2017). The El Niño phenomenon: Global vs coastal (Fenómeno El Niño: Global vs “Costero”). *Generacion de informacion y monitoreo del Fenómeno El Niño. Boletin Tecnico.*, 4(4), Instituto Geofísico del Perú. Ministerio del Ambiente, Perú.
- TAPLEY, T.D., & WAYLEN, P.R. (1990). Spatial variability of Annual Precipitation and ENSO events in Western Peru. *Hydrological Sciences Journal-Journal des Sciences Hydrologiques*, 35(4), 429-446.
- UNISDR. (2009). *UNISDR Terminology on Disaster Risk Reduction*. United Nations International Strategy for Disaster Reduction, Ginebra.
- USAID. (2011). *Peru Climate Change Vulnerability and Adaption Desktop Study*. USAID – Climate Change Resilient Development Task, International Resources Group, Washington, D.C.
- VARGAS P. (2009). *El Cambio Climatico y sus Efectos en el Peru*. Working Papers, Banco Mundial, Washington, DC.
- VON KOTZE, A. (1999). Who learns from disaster? The problem of 'lessons learned' revisited. *School of Environmental Sciences*, University of Natal, Pietermaritzburg.
- VUILLE, M., BRADLEY, R.S., & KEIMIG, F. (2000). Interannual Climate variability in the Central Andes and its relation to tropical Pacific and Atlantic forcing. *Journal of Geophysical Research Atmospheres*, 105(D10), 12447-12460.
- WISNER, B., BLAIKIE, P., CANNON, T., & DAVIS, I. (2004). *At Risk: Natural hazards, people’s vulnerability and disasters*. 2^a ed. Routledge, Londres.
- WPF. (2017). Peru Country Brief. ReliefWeb. Retrieved from <https://reliefweb.int/report/peru/wfp-peru-country-brief-may-2017>.
- YGLESIAS-GONZÁLEZ, M., VALDÉS-VELÁSQUEZ, A., HARTINGER, S. M., TAKAHASHI, K., SALVATIERRA, G., VELARDE, R., CONTRERAS, A., SANTA MARÍA, H., ROMANELLO, M., PAZ-SOLDÁN, V., BAZO, J., & LESCANO, A. G. (2023). Reflections on the impact and response to the Peruvian 2017 Coastal El Niño event: Looking to the past to prepare for the future. *PLoS ONE*, 18(9): e0290767. <https://doi.org/10.1371/journal.pone.0290767>.