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HEALTHCARE NETWORK'S RESPONSE AND RESILIENCE IN IQUIQUE AFTER THE 2014, PISAGUA EARTHQUAKE

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Abstract

On April 1st, 2014, the 8.2 M_w Pisagua earthquake affected the population in the north of Chile and generated disruption of services in the region. The largest effects of the earthquake were observed in the city of Iquique, capital of the Tarapaca Region, where more than 80% of the population of the region lives. This research describes the response of the public healthcare network of Iquique after the earthquake, and aims to identify the principal factors contributing to the network resilience during the early response and recovery phase after the earthquake. Despite the large magnitude of the earthquake, the observed structural damage was minor in the five healthcare centers considered (i.e., the regional hospital and 4 Primary Healthcare Attention Centers, PHACs). However, disruption of services in the healthcare network was large and due mainly to the collapse of non-structural components. Overall, the proper response of the healthcare network of Iquique was heavily supported by the PHACs, which largely provided first-aid, containment, and low-complexity attention to the population, allowing the hospital to focus on more complex procedures. The findings of this study suggest that the resilience of the healthcare network system, besides the robustness of the network's facilities and their critical units, is also highly dependent on the interrelations and interactions between them in early post-earthquake recovery phases.

Keywords: healthcare network resilience; healthcare network, seismic performance, loss of functionality

1. Introduction

On April 1st, 2014, at 20:46 local time, a M_w 8.2 megathrust earthquake struck offshore northern Chile, in the Tarapaca Region. The epicenter was located near the coast of the small fishing village of Pisagua, 94 km NW of Iquique, the main city of the Region [1]. The largest effects of the earthquake were observed in the city of Iquique, a coastal city and capital of the Tarapaca Region, which has a population of approximately 180,000, comprising more than 80% of the Region's population. Iquique hosts most of the main public services of the Tarapaca Region, the main healthcare public and private facilities, and the only high-complexity hospital of the Region, which annually serves about the 90% of total population of the city. Given these characteristics of the healthcare network in Iquique, the healthcare system becomes more critical in the context of an extreme event, considering the healthcare network plays a key role during the emergency providing psychological and medical attention to people affected and directly injured by the event, but also can help to avoid further problems such as an epidemiologic crisis [2].

Data describing the response of the healthcare network after extreme events such as earthquakes is an emergent topic that requires an interdisciplinary perspective [3]. The research on the performance of the healthcare network after earthquakes has increased since the 1994 Northridge earthquake and, more recently, research has used the available data not only for understanding the performance of isolated facilities, but also to calibrate functional models of these critical facilities when subjected to extreme conditions (e.g., [4]) and to characterize the hospital system's resilience [5]. Despite the existence of frameworks for assessing the resilience of the complete healthcare network, the literature has concentrated mainly on hospitals networks, and has given scarce attention to the primary healthcare attention. However, the experience after the latest earthquakes in Chile (e.g., 2010, 2014, 2015) and New Zealand (e.g., 2011) has pointed that primary healthcare attention and general practitioners heavily support the emergency period, focusing on population containment and low-complexity healthcare attention [3].

Considering the aforementioned context, this study describes the response of public healthcare network of Iquique after the Pisagua earthquake, and analyzes the network resilience in the early response and recovery phases. The data collected in this investigation is of archival nature and includes both qualitative and quantitative data. This research intends to understand the resilience of the network by integrating the response of the primary healthcare attention centers (PHACs), the hospitals, and their interrelations and interactions, thus comprehending the elements contributing to the overall resilience.

2. Description of the healthcare network of Iquique

The public healthcare network of Iquique is organized as primary, secondary, and tertiary healthcare attention. Primary healthcare attention consists on preventive medicine, basic ambulatory services and low-complexity urgencies, and is provided by four PHACs distributed throughout the city: Videla, Guzman, Aguirre, and Sur (Fig.1). On average, each PHAC provides attention to more than 40,000 people enrolled in the public healthcare system [6]. Secondary and tertiary healthcare attention refer to complex healthcare attention (e.g., hospitalization, surgeries, advanced treatments), and is provided only at the Iquique Hospital, which is also the only high-complexity hospital in the Tarapaca Region. Fig.1 shows the location of the public healthcare attention facilities within the city together with the population that each of them serves, and the tsunami inundation safety-line established at 30 m.a.s.l by the authorities.

On 2014, the public primary healthcare system provided medical attention to 160,514 people, almost 90% of total population in Iquique. While PHACs interact between each other, primary and complex healthcare attention systems also interact with each other by means of transfer of patients from the PHACs to the Hospital, and vice versa. In addition to the public healthcare network, two private clinics located near the coast provide medical attention in the city as well (Fig.1). It is important to notice that the distinction between public and private healthcare system is not only funding, but also the coordination during emergencies: while private facilities act individually and only use their installed capacities, public centers work as a network, and have established emergency protocols to successfully provide healthcare attention to the population while coping with the imminent disaster.

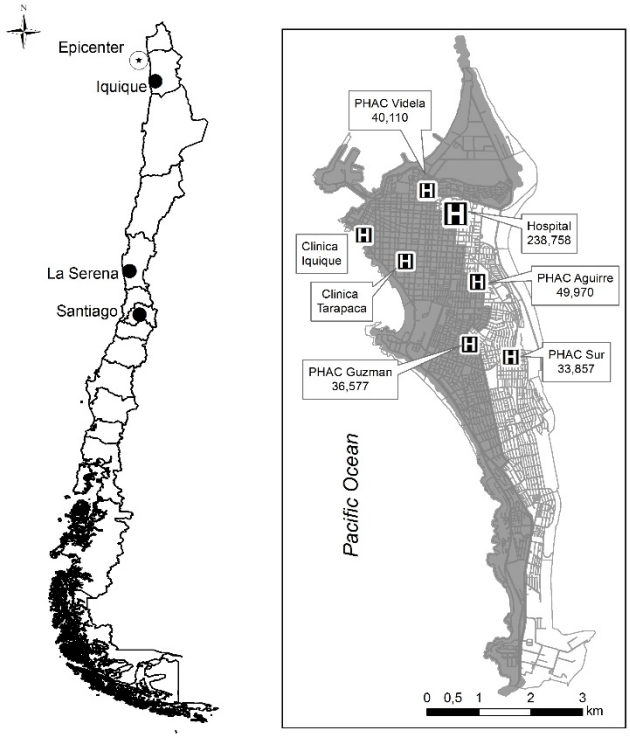

Fig. 1 – Four healthcare centers were located under inundation zone (two private clinics and two PHACs) at the moment of the 2014 Pisagua earthquake. The population served by each PHAC is shown in the figure. The cities whose healthcare networks received patients transferred from Iquique after the Pisagua earthquake are also shown: La Serena and Santiago.

The Ministry of Health (MOH) manages the Chilean healthcare system at national level. Additionally, the country is divided into 29 Healthcare Services that coordinate healthcare attention locally. In the Tarapaca Region, there is one service and is called Iquique Healthcare Service (IHS). IHS coordinates and provides funding for all the public healthcare attention facilities of the Region. In the city of Iquique, IHS funds directly Iquique Hospital, and indirectly funds the four PHACs through the Municipal Healthcare Corporation of the Municipality of Iquique (CORMUDESI), which locally manages the PHACs. Fig.2 shows an organizational chart of the healthcare system including national and local levels, identifying the autonomy of the facilities.

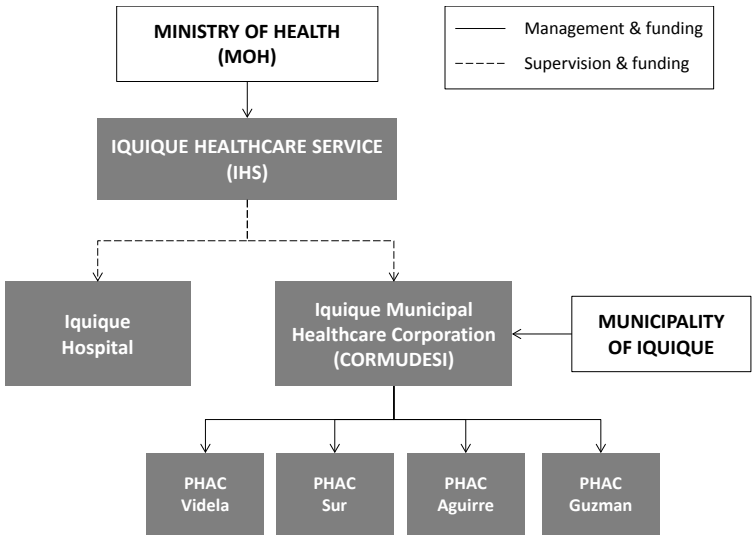

Fig. 2 – Iquique Healthcare Service (IHS) provides funding for the healthcare facilities of the Tarapaca Region. Funds are provided directly to the hospital, which is managed autonomously, and indirectly to the primary healthcare attention centers (PHACs) through the Municipal Healthcare Corporation (CORMUDESI), which manages them locally. Grey boxes show institutions were data collection was performed.

3. Data collection methodology

To collect data, a mixed methodology incorporating both primary and secondary information sources was used. Secondary information was collected at three different times: on two field trips (two weeks and six months after the earthquake), and on a follow-up survey by email one year after the earthquake. Data collected at different times consisted on baseline information and statistics on the functioning of the network, perishable information related to the contingency actions after the earthquake, and official earthquake damage reports provided by the authorities of the healthcare facilities.

No data on the performance of the system was directly surveyed or collected by the research team (i.e., no seismic or functional performance survey was conducted); instead, all the information generated by the different components of the network (e.g., baseline statistics, earthquake damages reports, presentations describing the emergency after the earthquake and the response of the network) was collected and further analyzed. In order to capture the emergency response from the healthcare facilities after the earthquake, a qualitative methodology was applied using focus groups. The participants of the focus group were the directors from each PHAC. The main purpose of the focus group was to capture the functioning of the network as a complex integrated system, the coordination efforts and emergent behavior beyond the official protocols, the weak links that support the system, and all the informal flows of communication that allow the system to function providing healthcare attention to the population in the emergency and recovery phases after the earthquake.

4. Impacts of the earthquake on the healthcare network in Iquique

Immediately after the earthquake, PHACs Guzman and Videla had to be closed and fully evacuated due to its location within the tsunami inundation zone (Fig.1). This caused an important instant decrease of the capacity of primary healthcare attention system, considering that Videla was one of the largest PHAC in the city. PHAC Guzman opened 12 hours after the earthquake, while PHAC Videla did not reopen until one week after the earthquake. On the other hand, PHAC Aguirre and Sur never closed.

The physical impacts of the Pisagua earthquake on each healthcare facility are reported on Table 1, while the functional damage of the different services of each healthcare facility are shown on Table 2. Overall, a total of 7 deaths were attributed to the earthquake. Based on the information provided by the reports and the focus group, PHACs Guzman and Videla had moderate overall damage, mainly attributed to non-structural damage, while PHACs Aguirre and Sur were severely damaged, presenting both structural and non-structural damage. For the Hospital, IHS reported that 30% of the building presented damage, mainly on non-structural elements, contents, and loss of stucco and coating in walls.

Table 1 – Physical damage of healthcare network facilities in Iquique

Healthcare center	Glazing	False ceilings	Partition walls	Plumbing	Elevators and stairs	Covering and coating	Building Contents
Hospital	Y-P	Y-P	Y-P	N	Y	Y-P	Y-P
Videla	ND	Y-P	Y-P	N	NA	ND	Y-P
Aguirre	N	Y-P	Y-P	N	NA	Y-P	Y-P
Guzman	ND	ND	Y-P	N	NA	ND	Y-P
Sur	ND	ND	ND	N	NA	ND	ND

NA: not applicable/service not provided, ND: no data availability, Y: total loss of the service, Y-P: partial loss of the service, N: No loss of the service

Table 2 – Functional damage throughout the healthcare network of Iquique

Healthcare center	Inpatient wards	Operating rooms	Laboratory	Radiology	Emergency Department	Outpatient clinics	Psychiatry	Blood bank	Sterilization	Vaccines Refrigeration	Kitchen	Laundry	Admin. Offices
Hospital	Y-P	Y	Y-P	Y-P	Y	Y-P	Y-P	Y	Y-P	N	ND	ND	Y-P
Videla	NA	NA	NA	NA	Y-P	Y-P	Y-P	NA	Y-P	Y	Y-P	Y-P	Y-P
Aguirre	NA	NA	NA	NA	Y-P	N	Y-P	NA	N	N	Y	Y-P	Y-P
Guzman	NA	NA	NA	NA	Y-P	Y-P	Y-P	NA	Y	Y-P	ND	ND	ND
Sur	NA	NA	NA	NA	Y-P	N	Y-P	NA	Y	N	ND	ND	ND

NA: not applicable/service not provided, ND: no data availability, Y: total loss of the service, Y-P: partial loss of the service, N: No loss of the service.

From Tables 1 and 2, it can be seen that overall the Hospital was the most affected facility of the healthcare network, added to the loss of functionality of two PHACs, which means more than a half of the entire healthcare network operating with a lower capacity. This situation was critical considering that the Hospital serves not only the population of Iquique, but also the entire Tarapaca Region. In general, slight and moderate structural damage was reported by the facilities (i.e., cracking on beams and columns and some concrete spalling), but severe non-structural damage affected the four PHACs and the Hospital, causing large disruptions of services and loss of functionality. Collapse of some medical contents (e.g., small laboratory equipment), damage in partition walls, and collapse of false ceilings were the most common non-structural damages reported by all the facilities. On the contrary, plumbing was the most robust system and did not present damage in any facility after the earthquake. Critical services such as sterilization, refrigeration, laboratory, and blood bank showed to be very fragile and were not able to withstand properly the earthquake.

The most significant type of non-structural damage was the cracking of partition walls in the all the seven operating rooms (ORs) of the Hospital, which caused the closure of the ORs for several days according to the sterilization protocols of the Chilean healthcare system. This left the entire Tarapaca Region without the capacity of conducting neither programmed or emergency surgeries. Both physical and functional damage disrupted the normal functioning of neonatology and Intensive Care Unit (ICU) for children and adults in the Hospital. Intermittent interruption of electric power supply also caused loss of diagnosis capacity due to problems at the laboratory and radiology services. The damage on some stairs and all the elevators in the Hospital hindered the vertical movements and relocation of critical patients throughout the Hospital.

The most damaged units among the PHACs were concentrated in sterilization and refrigeration units, both critical for the correct maintenance of vaccines and sterile material for minor procedures such as sutures. As a consequence, all the vaccines had to be stocked in quarantine, causing a decreased immunization of the population: before the earthquake, 479 people considered at risk (i.e., aged more than 65, less than 6 years old, or pregnant) were waiting for influenza flu vaccines preparing for Chilean winter; the number was triplicated to 1,224 patients after the earthquake.

Even though the entire healthcare network was affected by the Pisagua earthquake from a functional perspective, it was still able to support the emergency and continue serving the population that needed medical attention. For this reason, an assessment of the elements that determine resilience especially in early response and recovery phases is important to understand how the system was affected.

5. Resilience of the healthcare network

Considering the aforementioned impacts of Pisagua earthquake on the healthcare network of Iquique, this research intend to assess resilience of the healthcare system, understanding it as the capacity of the system to

cope with the disaster without losing functions [3], [5], [7], [8]. Due to the characteristics of natural disasters, resilience of healthcare facilities depends on a variety of elements such as connectivity, communication, emergency planning, vulnerability, and risk [8]. Specifically for healthcare facilities, their critical domains have been defined as safety, disaster preparedness, continuity of essential medical service, and recovery and adaptation [8]. These elements highlight the complexity of assessing resilience of a system after a natural disaster. To analyze the resilience of the healthcare network in the city of Iquique, the four dimensions of resilience as defined in [7] are assessed separately: robustness, redundancy, resourcefulness, and rapidity. Table 3 shows a description of these dimensions and the variable analyzed to describe it.

Table 3 – Different variables were analyzed to characterize the four different dimensions of resilience as presented by [7]

Dimension of resilience	Description	Analyzed variable
Robustness	Ability to withstand the demand of the earthquake without suffering degradation or loss of functions	Damage to external (e.g., electricity, water, communications) and internal services (e.g., drugs and vaccines) affecting healthcare attention delivery
Redundancy	Ability to satisfy the functional requirements despite losing functionality of certain components	Presence of backup systems for service provided to the network and for internal services
Resourcefulness	Capacity to quickly adapt to the new conditions defined after the earthquake by applying resources (e.g., monetary, human) to accomplish certain goals	Recovery of functions after implementing emergent behavior using emergency resources
Rapidity	Capacity to contain losses and recover functionality in a timely manner after an extreme event	Availability of utilities (e.g., electric power and water supply) and internal services (e.g., human resources and vaccines) on time

5.1 Robustness

As reported on Section 4, the healthcare network suffered structural and non-structural damage after the Pisagua earthquake. The physical damage produced loss of functions of the different facilities, and had large impacts on the most critical units of the Hospital (i.e., ORs and ICU). This highlighted the weakness of the network, whose most important facility and only high-complexity center was disabled to perform emergency and high-complexity surgeries.

The healthcare network did not experience major interruption of electric power supply. This was fortunate, since the backup systems were not working properly when the earthquake stroke. As mentioned in Section 4, the PHACs and the Hospital reported sporadic electric supply interruption affecting some internal services, such as refrigeration and sterilization units. This situation caused strong dependency from the PHACs with the central service of refrigeration and sterilization at CORMUDESI building. The Hospital was able to fully solve the electricity supply interruption three days after the earthquake (see Table 4). Water supply systems were affected in all the PHACs but Aguirre, which is one of the largest facilities (Fig.1). The three centers also had problems with their backup systems, especially with damage to the pumps of the emergency water tanks (Table 4). The communication system was the least impacted external service. Emergency VHF radios were used as backup communication system together with *WhatsApp* in the primary healthcare attention system, which became available a few hours after earthquake [9].

Medical and administrative staff absence was also a problem. Despite the fact that all the facilities of the network were affected by staff absence, the most critical situation was for PHAC Videla, whose directive and part of its administrative and medical staff lived in Alto Hospicio [9], a city located next to Iquique and

connected by only one road that was heavily affected by the earthquake and disconnected both cities. To cope with staff absence after the earthquake, the PHACs and the Hospital adopted flexible extended workdays [9].

5.2 Redundancy

All the PHACs and the Hospital had backup systems for electricity and potable water supply. For electricity, the backup consisted of generators with different power capacities, which sometimes did not cover the complete electricity demand of the facility. For potable water, backup systems consisted on water tanks with capacities to provide autonomy for 2 to 3 days to the facility. No backup systems existed for sewage and wastewater. After the earthquake, several backup systems were damaged throughout Iquique after the earthquake, thus highlighting their fragility. Moreover, these backup systems were often outdated and lacked proper maintenance. Only the fact that main electric and water supply did not collapse due to the earthquake in the city allowed the continuity of operation in the healthcare facilities; there is no evidence that in the case that backup systems had been needed, they would have responded properly (see Table 4).

5.3 Resourcefulness

The Iquique healthcare network collaborated closely with other organizations for reinforcing healthcare attention. During the first days, the emergency attention of the Hospital was reserved only to people directly impacted by the earthquake. Overall, 56 surgeries were conducted, 268 births were assisted, and ambulatory attention was provided to 1,687 people in the 28 days following the event, while 22 additional patients were transferred by an Army's airplane to other high-complexity hospitals in La Serena and Santiago (Fig.1), activating the national healthcare network. Additionally, the healthcare network was reinforced by the Navy, which allowed the Hospital's staff to use the OR on board of Sargento Aldea Battleship, completing 27 surgical interventions in the three weeks following the earthquake.

On the other hand, primary healthcare attention had to deal with the closure of two out of four PHACs because of their location within the tsunami inundation zone. Four mobile clinics were put in different parts of the city to provide primary healthcare attention to the population, thus compensating this loss.

5.4 Rapidity

Table 4 shows the evolution on time of the damaged services of each healthcare network facility (i.e., the Hospital and the four PHACs) after 1, 14, and 28 days after the earthquake. The condition of the different services at day 1 can be related to both robustness and redundancy of the system, showing their impact in the overall resilience during the early response phase. Data at 14 and 28 days can be related to resourcefulness and redundancy, highlighting the importance of these last two elements to understand the resilience during the recovery phase of the healthcare network from the earthquake. As shown for the case of the Iquique healthcare network, rapidity is highly correlated with the other three dimensions of resilience when considering the time variable.

Table 4 – Damaged services of healthcare network in Iquique from 1 to 28 days after Pisagua earthquake

	Iquique Hospital			**Videla**			**Guzman**			**Aguirre**			**Sur**		
Days after earthquake	*1*	*14*	*28*	*1*	*14*	*28*	*1*	*14*	*28*	*1*	*14*	*28*	*1*	*14*	*28*
External services															
Electricity	N	N	N	Y	Y	N	N	N	N	N	N	N	N	N	N
Backup electricity	Y	Y	N	Y	Y	N	N	N	N	N	N	N	N	N	N
Water	N	N	N	Y	Y	N	N	N	N	N	N	N	N	N	N
Backup water	Y	N	N	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y
Communication	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Fuel	N	N	N	N	N	N	Y	Y	N	N	N	N	N	N	N
Internal services															
Drugs and vaccines	N	N	N	Y	N	N	Y	N	N	N	N	N	N	N	N

Refrigerator	Y	N	N	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y
Sterilization	Y	N	N	Y	Y	Y	Y	Y	Y	N	N	N	Y	Y	Y
Worker's absence	Y	Y	N	Y	Y	Y	Y	Y	N	Y	Y	N	Y	Y	N
CPU	Y	Y	Y	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Blood	Y	Y	N	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Operating room	Y	Y	Y	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

NA: not applicable/service not provided, Y: total loss of the service, N: No loss of the service.

5.5 Overall resilience of the system

Overall, the Iquique healthcare network evidenced lack of robustness and redundancy. The system was not able to properly withstand the earthquake, and suffered generalized non-structural damage that forced not only stopping the operation of the facilities, but also induced sustained loss of functionality of the PHACs and the Hospital, leaving the city without the capacity to undergo emergency surgeries. The presence of two out of four PHACs of the city within the tsunami inundation zone evidences lack of planning of the critical infrastructure of the city (and region) regarding natural risks. The presence of emergency systems to secure external service supply shows redundancy; however, the backup systems were not robust enough to actually perform when needed. The system showed resourcefulness and adequate rapidity. The network was able to quickly adapt to the new conditions of operation to provide the healthcare attention to the population during the emergency, and to recover the functionality lost after the earthquake with external help of other institutions such as the Army and Navy. The network operation of the complete Chilean healthcare system under emergencies was also important, contributing to provide healthcare attention to high-complexity patients after transferring them to other regions of the country.

To quantitatively assess the recovery of functions of the healthcare network, Fig.3 presents the evolution of healthcare emergency attention delivery during the four weeks following the earthquake.

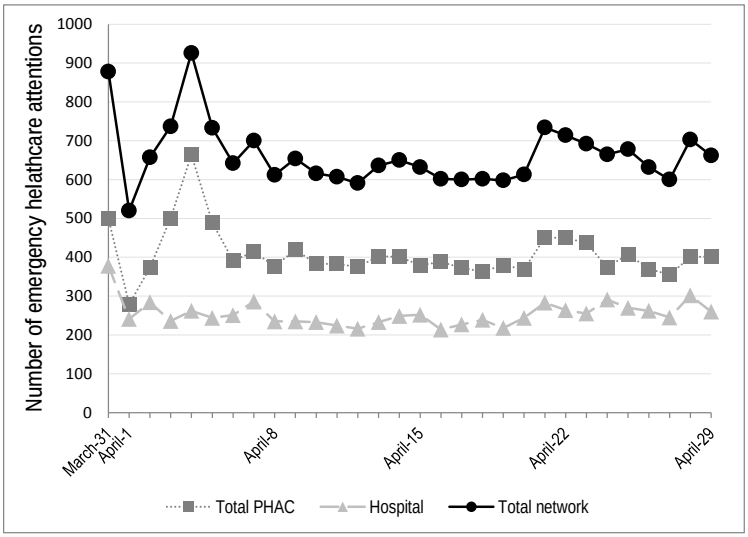

Fig. 3 – The total number of healthcare emergency attentions provided by the Iquique healthcare network was mainly supported by PHACs during the first month after the earthquake

Fig.3 shows that the normal operation of the network (i.e., number of emergency attentions on March 31st) was heavily affected by the earthquake on April 1st, causing a decrease of health attentions of 41% (from 878 to 520). The number of attentions starts increasing the day after the earthquake, reaching a peak on April 4th with 926 attentions. The shape of the curve of the total number of attentions provided by the healthcare network (*Total network* curve in Fig.3) is similar to the one of the total number of attentions provided by the four PHACs (*Total PHAC* curve in Fig.3), showing the peaks on demand for days 3, 13, 20, and 27 after the earthquake. On the contrary, the emergency attentions at the Hospital (*Hospital* curve on Fig.3) show an evolution rather different, with a number of attentions more constant throughout the first month after the earthquake. Primary healthcare

attention represented an average of 62% of the emergency healthcare attentions provided by the network during the first month after the earthquake, greatly absorbing the demand and over-demand of the population and reducing the stress that the Hospital normally suffers after large extreme events such as the Pisagua earthquake, when people not only go to the Hospital for medical attention, but also see it as a refuge that will not lack the basic supplies during the emergency [9]. This is highly relevant, showing the critical role that PHACs played on the emergency phase, allowing the network to continue providing healthcare attention to the population. This data shows that despite the generalized loss of capacity of the system, the contingency measures taken by the network allowed to continue providing the service the population needed, reinforcing the perception of resourcefulness and rapidity of the resilience of the system in both early response and recovery phases.

6. Conclusions

This article presents a summary of the reported effects that the 2014 Pisagua earthquake had on the public healthcare network in the city of Iquique in north Chile, comprising primary healthcare attention facilities and the only high-complexity center of the Tarapaca Region, Iquique Hospital. The impact of the Pisagua earthquake allowed us to assess the resilience of the healthcare network by comparing its normal functioning to the one showed in the emergency and recovery phases after the earthquake. Despite the fact that no significant structural damage was observed in the infrastructure of the healthcare network, large functional problems hampered the delivery of proper healthcare attention to the population after the earthquake. Nonetheless, a fast recovery of functions due to quick actions on the network enabled a better response of the system as a whole.

Statistics of healthcare emergency attentions during the four weeks following the earthquake show that PHACs played a critical role on the post-earthquake emergency and early response phase, allowing the network to maintain continuous healthcare attention delivery to the population. As it was observed, a key aspect toward improving resilience of the healthcare network has to do with mitigating the risk of PHACs, which are often the most fragile components of the system despite being responsible for taking care of the first needs of the population.

The healthcare network showed an evident lack of adequate preparedness of individual facilities, even though the support given by them in providing medical attention to patients. The system was able to properly respond exclusively because of the combining actions and interactions at the network level as part of the emergency plans of public facilities, thus enhancing the overall resilience of the system, but not due to their capacities individually.

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